“THE SPATIO-TEMPORAL CHANGES IN IMPERVIOUS SURFACE COVERAGE AND THEIR ENVIRONMENTAL IMPACTS DUE TO URBANIZATION IN KOCHI - A STUDY USING REMOTE SENSING AND GIS".

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By

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"The Spatio-Temporal Changes in Impervious Surface Coverage and Their Environmental Impacts Due to Urbanization in Kochi - A Study Using Remote Sensing and GIS"

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Certificate

This is to certify that the research work presented in the thesis entitled ***"The Spatio-Temporal Changes in Impervious Surface Coverage and Their Environmental Impacts due to Urbanization in Kochi - A Study Using Remote Sensing and GIS"*** *is an authentic record of research work carried out by Ms. Chithra S.V. under my guidance and supervision in the School of Environmental Studies, Cochin University of Science and Technology in partial fulfillment of the requirements for the degree of* ***Doctor of Philosophy*** *and that no part thereof has been included for the award of any other degree. All the relevant corrections and modifications suggested by the audience during the pre-synopsis Seminar and recommended by the Doctoral Committee of the candidate has been incorporated in the thesis.*

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Declaration

*I hereby declare that the thesis entitled "**The Spatio-Temporal Changes in Impervious Surface Coverage and Their Environmental Impacts due to Urbanization in Kochi - A Study Using Remote Sensing and GIS**" is based on the original work carried out by me under the guidance of Dr M.V. Harindranathan Nair, Associate Professor, School of Environmental Studies, Cochin University of Science and Technology, and no part thereof has been included in any other thesis submitted previously for the award of any degree.*

Kochi-22
July 2016 **Chithra S.V.**

To those dearer to me than myself:
My Husband Bivin J. B. and my daughter Jane,
My Appa, Amma and my parents at Kudayal House;
And my Kiddies Sreya, Saarang and Roshan.

Synopsis

Kochi (also called as Cochin) is a coastal settlement interspersed with a large backwater system and fringed on the eastern side by laterite-capped low hills from which a number of streams drain into the backwater system. The ridgeline of the eastern low hills provides a well-defined watershed delimiting the basin of Kochi, which help to confine the environmental parameters within a physical limit. This leads to an obvious conclusion that if physiography alone is considered, the western flatland is ideal for urban development. The western flatland of Kochi basin is a fast developing urban center and there is a proportionate increase in impervious cover, which makes a negative mark on the environmental footprint. Impervious cover serves as an indicator of environmental degradation. Growth of urban coverage can be taken as the indicator of impervious coverage growth, which prevents the infiltration of water to the ground. This result in increased runoff (flash floods) as well as decrease in ground water storage. Urban building materials such as concrete and asphalt increase the Land Surface Temperature thereby making the cities burning ovens compared to the surrounding villages.

At present, the city of Kochi is subjected to serious anthropogenic interventions due to development activities in the mainland like urbanization, industrialization (both in the Corporation and adjoining areas), activities in the port, shipyard etc. Due to unplanned land use, impervious cover of the city is increasing which creates ground water shortage, water pollution and drainage problems. Major issues faced by the city are uncontrolled vehicular traffic, solid waste management, lack of developable land and problems due to pollution. Kochi is ardently trying for a planned sustainable development by framing policies that can curb the problems faced by the city. Major objectives of the present investigation is to study the spatio-temporal variation in impervious surface growth and its impact on the environment, taking Kochi as the study area and to suggest appropriate Environmental Management Plans required for a sustainable development, comparing few other Tropical coastal Cities in the Asian Region geographically placed similar to Cochin.

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Abbreviation

ADB	Asian Development Bank
ANN	Artificial Neural Network
GCDA	Greater Cochin Development Authority
GIS	Geographical Information Systems
GLCF	Global Land Cover Facility
GPS	Global Positioning System
ICTT	International Container Transshipment Terminal
IPCC	International Panel on Climate Change
LNG	Liquefied Natural Gas
LULC	Land Use Land Cover
MLC	Maximum Likelihood Classifier
MRTS	Mass Rapid Transport System
NIR	Near Infra Red
NRSC	National Remote Sensing Centre
OBIA	Object Based Image Analysis
PCA	Principal Component Analysis
SWAT	Soil and Water Assessment Tool
TIA	Total Impervious Area
UHI	Urban Heat Island
USGS	United States Geographical Survey

Chapter

1

INTRODUCTION

Contents

1.1. General Introduction

Among all the existing species on the earth ecosystem, only the ***Homo sapiens,*** the so-called modern mankind can alter this living system, may be threatening his own very existence. As a Balanced System, all the species (from the micro- to macrocosm are influenced by and influence the environment; the Darwinian evolution or rather adaptation. In a functioning system there are self-controlling, self-regulating subsystems, in which all the species interact for the functioning of this self-sustaining ecosystem. In his voracious thrive to tame the nature, has he already forgotten that he is also one of the simple basic element of this huge and mysterious ecosystem? Have we already crossed the so-called tipping point of this system? Can we wishfully dream of a self-sustaining and peaceful earth for ourselves as well as the future generations?

"Within the last 10,000 years, man has invented an environment which is almost altogether artificial, with the consequence that he now lives in a world of his own devising (Lenihan and Fletcher, 1987)". Settlements begat villages, villages evolved into towns and cities, and cities now connect to form megalopolises - urban landscapes that stretch for hundreds of miles. Today, 54 % of the world's population lives in urban areas, and is expected to reach 66 % by 2050 (UN Population Report, July 2014). In India, the proportion of urban contribution to the national population went up from 19% in 1965 to 27 % in 1990 and 31.16% in 2011 (Census Reports). The average annual urban population growth rate was 3.7% in India (World Development report,'92) and 32% of the total urban population is concentrated in metropolitan cities. "In places where man's activities are most densely concentrated - his settlements - the environmental impact is greatest and the risks of environmental damage are most acute" (United Nations Report, 1974).

There are both environmental and social issues associated with urbanization. Major environmental issues are 1) Pollution 2) Land cover changes leading to reduction & fragmentation of wildlife habitat, changes in wind patterns, temperature, climate & hydrology, 3) Alteration of micro climate, 4) Hydro geological problems and 5) Inadequate and / or delayed disaster management. The impacts are not restricted to local areas, but can impact natural systems downstream, downwind, and across the globe. Social problems associated with urbanization are 1) Urban sprawl often leading to squatter settlements and slums, 2) Water supply and Transportation facilities, 3) Sewerage problems, 4) Waste disposal, 5) Urban crimes etc.

Landuse is man's activities on and in relation to the land, which are usually not directly visible from the satellite imagery. Land cover describes the vegetation and artificial constructions covering the land surface (Burley, 1961). Urbanization is the major driving force towards Land use / Land cover changes (Hasse and Lathrop, 2003). Land use/ Land cover (LULC) changes affect the cycling of water, carbon and energy, and are recognized as one of the most important element for global environmental change.

Certain aspects of man's artificial environment - the rooftops, sidewalks, asphalt, brick and concrete individually and cumulatively provoke changes to natural processes. This complex urban fabric is the product of human ingenuity and the environmental impacts of urbanization are contributed mostly by them (Lee and Lathrop, 2006). These tangible, quantifiable features of the built environment combined with other aspects of modern life (i.e. auto emissions, sewage effluent, nonpoint source pollution, etc.) result in reduced environmental quality. Instead of tree canopy and groundcover, rainfall strikes concrete, brick and asphalt. It has been proven that these man-made surfaces interfere with the hydrological cycle by altering the processes of interception, stream flow and overland flow and increasing the volume and speed of runoff, while reducing rates of infiltration and groundwater recharge. In addition to quantity related effects, growth in impervious surfaces has been correlated with decreases in water quality (Paul and Meyer 2001, Arnold and Gibbons 1996). A strong correlation between impervious surfaces and Land Surface Temperature (LST) is also being reported (Fei Yuan and Marvin E Bauer, 2008).

Impervious surfaces are defined as surfaces that prohibit the movement of water from the land surface into the underlying soil. Buildings and paved surfaces (e.g., asphalt, concrete), roof tops, roads, parking lots etc. are considered impervious covers. Natural conditions such as bedrock close to the surface, very dense soil layers such as hardpan that restrict water movement etc. are not considered "impervious cover." Major driving force towards the increase in impervious cover is the LULC changes occurred as a result of urbanization (Hasse & Lathrop, 2003). Increasing urbanization has resulted in increased amounts of impervious surfaces and a decrease in the amount of forested lands, wetlands, and other forms of open space that absorb and clean storm water in the natural system. This change in the impervious-pervious surface balance has caused significant changes to both the quality and quantity of the urban environment turning the cities to boiling pots, degrading streams and watershed systems. Impervious cover is used as an indicator of Environmental Quality. As reported by Arnold and Gibbons, 1996, four basic qualities of imperviousness that make it an important indicator of environmental quality are:

1. An impervious surface is a characteristic of urbanization,
2. Although the impervious surface does not directly generate pollution, a clear link is seen between impervious surfaces and the hydrologic changes that degrade water quality
3. Impervious surfaces prevent natural pollutant processing in the soil by preventing percolation; and
4. Impervious surfaces convey pollutants into the waterways, typically through the direct piping of storm water

Strong correlation between imperviousness of a drainage basin and the quality of its receiving streams has been reported. Stream quality starts to degrade, if more than 10% of the watershed is impervious. A good number of researchers attempted to find the watersheds' response to LULC changes over time (Shekhar and Rao, 2002, Santhilan et al, 2010). Impervious surfaces prevent infiltration, thereby reducing groundwater recharge and base flow (Harbor and Jonathan (1997), Pappas et al, 2008, Scheuler et al, 2009). Impervious surfaces can be used as an alternate measure for studying the impact of urbanization on water resources without having to consider specific factors. The other benefit is that it can be measured by a variety of procedures. Watersheds with large amounts of impervious cover may experience an overall decrease of groundwater recharge and base flow and an increase of storm flow and flood frequency. Furthermore, imperviousness is related to the water quality of a drainage basin and it's receiving streams, lakes, and ponds. Increase in impervious cover and runoff directly impact the transport of non-point source pollutants including pathogens, nutrients, toxic contaminants, and sediment. Increases in runoff volume and discharge rates coupled with non-point source pollution, can alter in-stream and riparian habitats, and the extinction of some critical aquatic habits.

The spatial extent and distribution of impervious surfaces impact urban climate by altering sensible and latent heat fluxes within the urban surface, canopy layer and boundary layers; Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other sources. The increasing imperviousness has five broad, interrelated impacts on the landscape: 1) alteration of local and regional hydrological cycles (changes in water quantity); 2) changes in water quality; 3) changes to local energy balances and microclimates; 4) habitat degradation, loss, and fragmentation; and 5) changes to stream and landscape aesthetics. Imperviousness directly affects storm water runoff and water quality (Arnold and Gibbons, 1996). Moreover, the temperature response and reflective properties of impervious surfaces are linked to the "urban heat island" effect, which affects human comfort and health because of changes in sensible heat fluxes and the concentration of atmospheric pollutants.

1.2. Imperviousness and Weather Change

Urban heat islands (UHI) refer to the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than the surrounding rural areas. The prime driving force behind UHI is impervious surfaces (Voogt and Oke, 2003). The land cover changes may affect the absorption, radiation and reflection of solar radiation and thereby alter the thermal properties of Earth. When buildings, roads and paved surfaces store the heat during the day and then release it slowly during the dark hours making urban areas hotter than their peripheries. The UHI occurs due to differences in thermal, and radiative properties of urban surface materials from the ones of natural surfaces, multiple reflection and absorption of sunlight by urban surfaces (due to specific geometry), anthropogenic heat sources and lack of evapotranspiration in urban areas. The thermal properties of various urban surface types are given in Table 1.1. The atmosphere in cities with sources of pollution and heat can also produce a heat island effect. "In densely built-up areas, it is possible to see the dome of warm air, which is the cause of urban heat islands (Emmanuel, 2005).

Table 1.1. The Thermal properties of various urban surface types (Minnie et al, 2013)

Sl.No.	Surface Type	Emissivity	Absorptivity
1	Highly reflective roof	0.85-0.9	0.3-0.4
2	Galvanized roof sheets	0.25-0.28	0.85-0.9
3	Grass	0.97-0.98	0.7-0.75
4	White tile	0.9-0.95	0.1-0.5
5	Tar and Gravel	0.28	0.82-0.97
6	Brick or Stone	0.87	0.6-0.8
7	Asphalt	0.92	0.8-0.95
8	Concrete	0.9	0.65-0.9
9	Dense Canopy trees	0.95-0.99	0.82-0.85
10	Water	0.99	0.95-0.98
11	Black loamy soil	0.66	0.82-0.87

The rural-urban temperature contrast in normal cases may vary between 1°C and 6°C (Stone and Rodgers, 2001). The intensity of UHI varies from one city to another but in extreme case; a rural-urban temperature contrast of 11°C has been reported (Sham Sani, 1991) in Malaysia. The situation in cities / urban areas is obviously more complex, following modification of the atmosphere due to urbanization, by which pollution dispersion-taking place differently from that observed in rural areas. Planting and growing trees will help to cover cities from incoming solar radiation. Large number of trees and urban parks tend to lower air temperature by 0.5–5ºC.

Several studies reports the prevalence of heat island effect in various cities throughout the world (Jusuf et al 2007, Elsayed 2011, Khalid 2014). Asimakopoulos in 2001 mentioned: "the temperature differences between urban and rural (suburban) areas belong to the heat from the streets, roads and the same constructions with dark surfaces during the day and the reflection of it after sunset". The following arguments of Oke (1981) and Landsberg (1981) are found relevant to the subject of this study. The size, effects and intensity of urban heat island may have variations in different time and spaces that have variety in their regional, meteorological and urban characteristics (Oke, 1982). Over the next century, human induced warming is projected to raise global temperatures by an additional 3 to 7°C (Chicago Climate Task Force, 2007) adding to the Global Warming Effect.

1.3. Hydrologic Effects of Impervious Surfaces

The water cycle is the most critical processes in supporting life on this planet, and fresh water is central to all aspects of our lives. Hydrology is the study of the movement, distribution and quality of water on earth and urban hydrology is the interdisciplinary science of water and its interrelationships with man in an urban watershed. In urban areas, due to the intense alteration of natural environmental processes by human activity, the watershed response to precipitation are also significantly altered (e.g. reduced infiltration, decreased travel time, higher runoff, urban flooding etc.). Although urban areas are quiet small relative to un-urbanized land, they significantly alter hydrology, biodiversity, biogeochemistry and climate at local, regional and global scales. K. Johnson in 2004 summarized the impacts of impervious surfaces on hydrology as follows; 1) Increase in storm water runoff and flood frequency 2) Reduction in stream base flow and ground water recharge 3) Increase in erosion and stream bank sloughing 4) Decrease in water quality conditions 5) Decrease in species diversity and riparian habitat 6) Alteration to stream geometry and 7) Increase in ambient stream temperature.

Land development causes pervious soft surfaces such as grass lands, water bodies and green vegetation being replaced by hard impervious surfaces. While forests capture much precipitation through interception and infiltration, even more is evapotranspired by the trees. Open land, such as a pasture or cultivated land, allows less infiltration than forest, and is often more prone to runoff. The larger volume of run-off and the increased efficiency of water conveyance result in increased severity of flooding, with storm flows that are greater in volume and peak more rapidly than that in the case of rural areas. Land use can have significant impacts on the amount and speed of infiltration in a basin. Impermeable surfaces, such as roofs, parking lots, and roads allow zero infiltration, forcing all water that falls onto them to runoff. The changing proportions of these land use types within a basin can have serious effects on discharge and response to storms, either increasing total yield of water, or decreasing and smoothing the hydrograph.

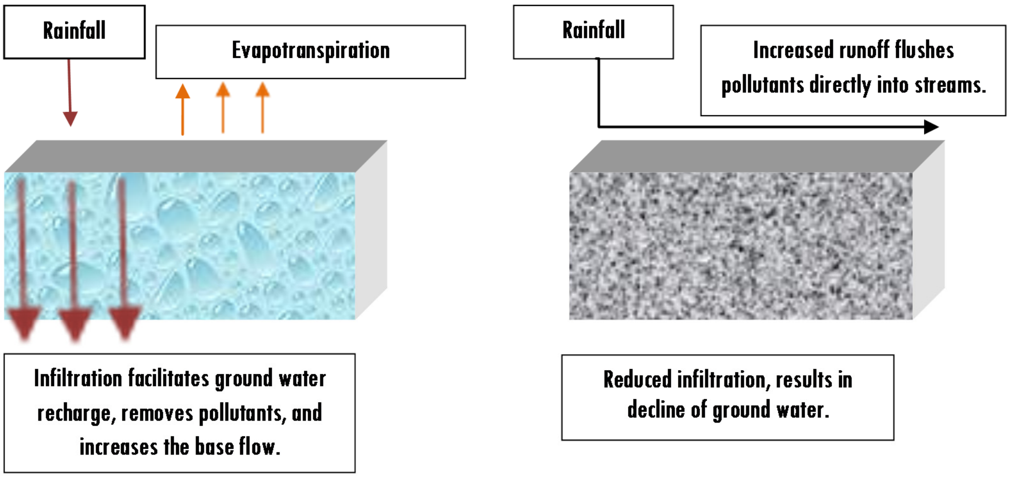

Figure 1.1 The Effects of Pervious Surfaces and Impervious Surfaces on Rainfall

1.4. Imperviousness and Water Quality

Impervious surfaces serve as a key indicator for health of aquatic ecosystems. Increased impervious cover is strongly related to increased deprivation of aquatic ecosystems. Such surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other line and point sources. Pollutants include sediment, pesticides, asphalt, fertilizers, bacteria and disease-causing organisms from failing septic systems; petroleum products such as oil and grease. Sometimes pollutants (e.g., used oil, paint thinners, etc.) are illegally dumped directly into storm drains and waterways. During rainfall events, accumulated pollutants are quickly washed off and rapidly delivered to aquatic systems. Urban pollutant loads are linked to watershed imperviousness and it serves as a key predictive variable in most simulations and empirical models used to estimate pollutant loads.

As the area under impervious cover increases, more water reaches the ocean as surface water run-off. Impervious surface affects the hydrology of a watershed, the geomorphology of stream beds, temperature, fish populations, macro invertebrates, microbes, algae, and macrophytes. Nutrients, toxins and sediment disrupt aquatic ecosystems and contribute to degraded water quality. The abundance and diversity of fresh water as well as marine organisms are harmed as the concentration of impervious surfaces increase. Galli in 1990 studied the thermal impacts associated with urbanization on streams by taking Impervious Surface Area as an indicator. They noticed an abrupt decrease in stream insect community structure as impervious surfaces increase above 6% of the total catchment area.

The expansion of urban areas is creating more impervious surfaces, which collect pathogens, heavy metals, sediment, and chemical pollutants and quickly transmit them to streams, rivers, estuaries or sea downstream during rain. This non-point source pollution is one of the major threats to water quality and is linked to chronic and acute ailments from exposure through drinking water, seafood, and contact recreation. Impervious surfaces also lead to pooling of storm water, thus increasing the potential breeding areas for mosquitoes, the disease vectors for a number of infectious diseases such as malaria, dengue hemorrhagic fever and Chikungunya. Reducing storm water runoff and associated non-point source pollution is a potentially valuable component of an integrated strategy to protect public health at the least cost. Runoff from urban environment may contain significant concentrations of copper, zinc and lead, which can have toxic effects in humans. Bioaccumulation of insecticides at levels considered harmful to organisms, raises concern about carcinogenic effects and disruption of hormonal systems in humans.

Community drinking water supplies are commonly disinfected with chlorine and, if the source is surface water, it is filtered to remove sediment and associated pollutants. Several common disease carrying microorganisms are resistant to treatment with chlorine and filtration, although the effectiveness of the filters varies with their pore size. Suspended sediment in source waters further reduces the effectiveness of chlorine. Nitrogen also poses direct health threats. Exposure to nitrate in drinking water increases the risk of methemoglobinemia, causing shortness of breath and blueness of the skin, especially for infants. Consumption of water with elevated nitrate is also suspected to increase miscarriage risk. Major sources of nitrogen from urban and suburban areas include fertilizers carried by storm water, vehicle exhaust, and septic systems. Fecal coliform bacteria in surface waters commonly exceed standards for recreation, and exposure to bacteria and parasites from swimming and other forms of recreation in water contaminated with urban runoff has caused numerous cases of illness, including ear and eye discharges, skin rashes, and gastrointestinal problems. Increasing impervious surface without storm water controls leads to increased runoff. Elevated fecal coliform levels also have been detected in suburban streams.

Some authors have questioned the accuracy of impervious surface measures with regard to their impact on water quality and quantity. For example, Total Impervious Area (TIA) includes all the impervious surfaces in a watershed, regardless of what kind of connection exists between the impervious surfaces and the basin's water bodies. Most of the satellite based estimates calculates the TIA only. Effective Impervious Area (EIA) includes only the portion of a watershed that allows water to cross only an impervious pathway to reach the water. Years of scientific inquiry has firmly established impervious surface coverage as a "reliable and integrative indicator of the impact of development on water resources". This combined with the fact that impervious surface is a measurable parameter, makes it an ideal substitute for measuring water quality in an urban environment. Developments in the field of Remote Sensing and GIS has made the previous studies cost effective and time bound.

1.5. Applications of Remote Sensing and GIS in Environmental Studies

Remote sensing is the art and science of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation. It can be described as the non-contact recording of information from the ultraviolet, visible, infrared and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners lasers, linear arrays, and / or area arrays located on platforms such as aircrafts or spacecrafts, and the analysis of acquired information by means of visual and digital image processing. Remote sensing functions in harmony with other geographic information sciences (often referred to as GI Science), including cartography, surveying and geographic information systems (GIS) (Curran 1987; Clarke , 2001; Jensen, 2005).

Owing to its unique ability of providing a synoptic view of a large area on the earth's surface, it is one of the outstanding tools for analysis of environment and invention of its resources. Each satellite image is a document as it objectively reflects the state of a locality at the moment of acquiring. It has multispectral capacity and provides appropriate contrast between various natural features. Its repetitive coverage provides information about the dynamic changes that are taking place on the earth's surface and in the natural environment. The synoptic view of large area obtained at one time by satellite remote sensing is very useful in analyzing impervious surfaces.

1.5.1. Geographic Information Systems

Geographic information systems are supporting tools for the studies as well as management of various geographical features. Rhind (1989) defined

GIS as a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems. GIS is a tool that manages, analyzes, and models data from our environment so that we can make decisions based on that information to better conserve its resources and protect its biodiversity. The strength of the GIS lies in the quality of the database, and how it can be used to address the application of interest. Each variable or 'layer' in the GIS will hopefully be useful in the application by supplying information on physical, chemical and biological processes or characteristics of the features. An important capability of GIS is the simulation of physical, chemical and biological processes using models. GIS can potentially be used with deterministic or complex models based on algorithms simulating processes or they can be applied with statistical models. The requirement is that the model to be applied has the capability to take spatial data and multiple file or layer data as input to computations. GIS Technology integrates common database operations such as statistical analysis with unique visualization and geographic analysis facilitated by maps. These abilities distinguish geographic Information Systems from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes and planning strategies. GIS databases and products are also amenable to evaluation of quality. A number of methods are there in GIS for accuracy assessment.

1.6. Application of Remote Sensing and GIS in Urban Hydrology.

Remote sensing provides several major benefits for urban studies. First, perhaps the largest benefit of remote sensing is its capability of acquiring images covering a large area. Also, it is capable of providing a synoptic view that allows identifying objects, patterns and human-land interactions. It reduces the effort of field surveying. Field measurements can become prohibitively expensive over a large area. Moreover, remote sensors can measure energy at wavelengths which are beyond the range of human vision. Remote sensor data collected from the ultraviolet, infrared, microwave portion of the electromagnetic spectrum can help obtain knowledge beyond our human visual perception. Thermal remote sensing can measure spatially continuous surface temperature that is useful to examine the urban heat island effect (Lo, Quottrochi and Luvall, 1997). Remote sensing finds a wide range of application in hydrology to assist basin wide studies, watershed modeling, drainage basin delineation, flood monitoring, urban flood prediction etc.

1.7. Statement of the Problem

Cochin is a coastal settlement interspersed with a large backwater system and fringed on the eastern side by laterite-capped low hills from which a number of streams drain into the backwater system. The ridgeline of the eastern low hills provides a well-defined watershed delimiting Cochin basin, thus confining the environmental parameters within a physical limit. This leads to an obvious conclusion that if physiography alone is considered, the western flatland is ideal for urban development.

The city of Kochi is fast developing as an urban center and there is a tremendous increase in Built-up areas. It shows a positive impact on development whereas it leaves several negative marks on the environmental footprint. However, it resulted in serious environmental deterioration, particularly its predominant extent of wetlands. For the ever-increasing land requirements, there has to be large scale filling up of these wetlands which includes shallow mangrove-fringed water sheets, paddy fields, Pokkali fields, estuary etc.

As cities develop, paved areas, surfaces and buildings substitute the natural landscape. Hard impervious surfaces like parking lots, roofs and roads attract the greatest amount of heat which results in heat island effect - a localized increase in temperature in urban areas caused by the multiple reflection of solar radiation by the highly reflecting building materials. Large masses of the reinforced concrete and steel structure buildings absorb and produce huge amount of heat, which in turn are radiated to the surroundings. Accordingly, in urban areas temperatures can be more above suburban areas" (EPA, 2005). Also the impervious surfaces prevent the infiltration of water into the soil, preventing percolation. This can cause serious damage to the water table and results in increased runoff and water shortage. Scheuler (1987) reports that increased impervious cover results in stream degradation. A lot more problems are associated with this. Many of the environmental problems of Cochin are hydrologic in origin; like water-logging / floods, sedimentation and pollution in the water bodies as well as shoreline erosion. Rapid population growth exerts and aggravates pressure on living space with a consequent deterioration in environmental quality. The population of Kochi increased from 1536400 in 2001 to 2117990 in 2011. The population density in the city also increased because of the increasing number of migrants searching for better working opportunities, services, and facilities. The city of Kochi today is under the stress of urbanization and population.

1.8. Objectives of the Work

The present work attempts to study the impacts of increasing impervious surfaces on the environment taking Kochi as the study area. The impacts on Land Surface Temperature and Hydrology are covered under this study. Major objectives of the present investigation is to study the spatio-temporal variation in impervious surface growth and its impact on the environment, taking Kochi as the study area and to suggest appropriate Environmental Management Plans required for a sustainable development, comparing few other Tropical coastal cities in the Asian Region geographically placed similar to Cochin. The objectives can be summarized as,

- To estimate the impervious cover of the city by way of remote sensing techniques.
    - To find a suitable classification method for the estimation of impervious surfaces.
    - To study the spatial changes of impervious cover during a few decades till 2014.
- To study the impacts of impervious cover on Land surface Temperature.
    - Temporal changes using Landsat and IRS Images.
    - Diurnal variation using MODIS imagery.
    - Seasonal changes using Landsat-8 images.
    - To study the Heat Island Phenomenon of a few cities.
- Impacts of impervious surface on Hydrology.
    - To study the temporal variation of run-off using ArcGIS.

1.9 General structure and layout of the thesis

The thesis is divided into six chapters.

Chapter I: General Introduction and Review of Literature.

Chapter 2: Profile of Study Area

Chapter 3: Mapping and change detection of Built-up Impervious Surfaces

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Chapter

2

STUDY AREA

• Contents •

2.1. Introduction

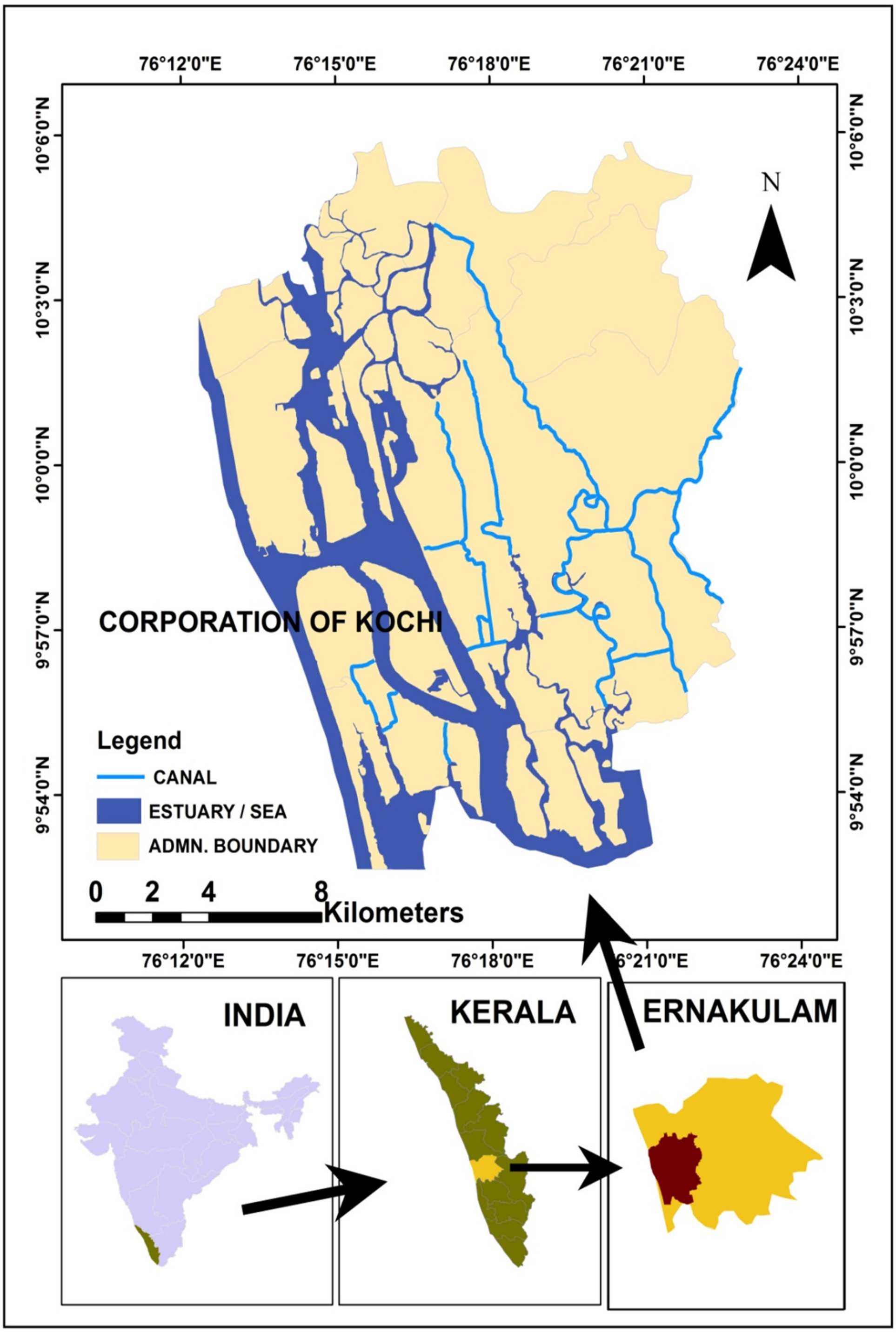
The Kochi city lies near the western coast of Kerala, the south-western state of India. It is the commercial capital of the state and is one among the five major ports of the country. Kochi port was formed in 1341, as a result of deposition of silt on the mouth of the harbor due to heavy floods (Benjamin, 1998). It is situated on the bank of Cochin estuary, (known as Kochi Kayal in local parlance), a part of Vembanad - Kol wetland system - the longest wetlands of South-India. Kochi is linked to the entire coastal stretch of Kerala through inland waterways. From 16th century, Kochi was colonized by various European powers. Portuguese was the first to arrive, followed by the Dutch and British. The population of the city is increasing at a fast rate due to local immigration stimulated by the commercial and industrial growth. Major developmental activities, in recent times include International Container

Trans-shipment Terminal (ICTT) at Vallarpadam, Liquified Natural Gas (LNG) terminal at Puthuvype and Metrorail having a stretch of 25.612 km. in length. The city is interspersed with backwater system and has dense mangrove vegetation on its fringes.

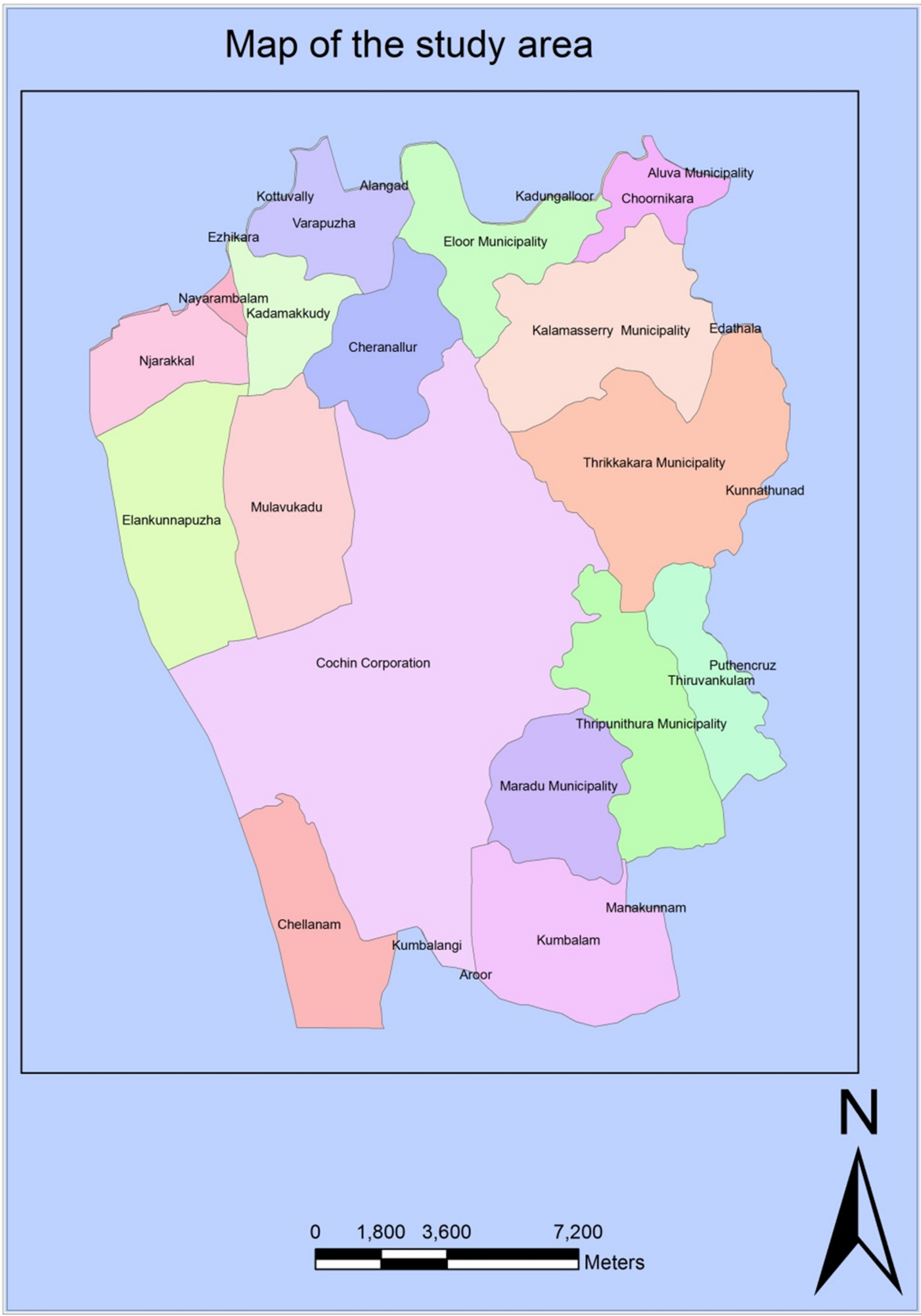
This profile traces the city's metamorphosis as a European colony to a highly urbanized regional center and discusses its major environmental problems and concerns and a viable strategy to attain sustainable development.

2.2. Geographical Location

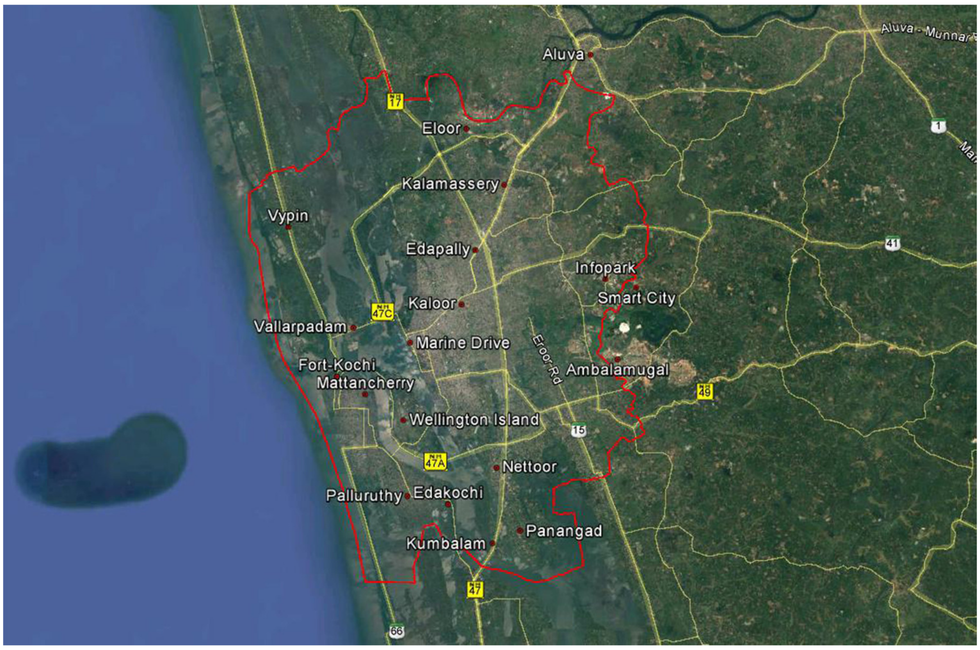
The Kochi City and the surrounding urbanizing area comprises about 330 Sq. km extending from 9º 49' to 10º14'N latitudes and 76º 10' E to 76º 31'E longitudes. Tourism has always been a major contributor to the prosperity of Cochin. Year by year, the number of tourists to this 'Queen of the Arabian Sea' keeps increasing. Kochi is geographically linked with the wetlands of Vembanad estuary. The Vembanad Lake and the surrounding geological formation are the fruit of all the major rivers of central Kerala, namely Chalakkudypuzha, Periyar, Muvattupuzha River, Meenachilar, Manimalayar, Pampa River and Achancoil River and lesser rivers like Keecheri, Karuvannur and Puzhackal. The silt and sand washed down by these rivers from the Eastern highlands originally sculptured the landscape of the coastal belt on either side of Cochin. The wetland system with its drainage basins cover an area of about 16,200 sq, kms, which is about 40% of the area of Kerala (James et al, 1996).



Map.2.1. Location map of Kochi



Map.2.2. Map showing the local governing bodies in the study area



Map 2.3. A Google Earth picture showing the places in Kochi

2.3. Early History

Kochi Port was formed in 1341, when the heavy floods of that year silted up the mouths of the Musiris harbor and the surging waters forced a channel past the present inlet into the sea. The old merchants of Musiris shifted to Kochi as soon as the new outlet became more or less stable. As the harbour gained prominence, the then ruler of the region shifted his capital also to Kochi, giving further impetus to the growth of the town. The early settlement of Kochi was at Mattanchery, facing the protected lagoons in the east, which provided safe anchorage to country crafts in all seasons. Mattanchery was linked to the entire coastal stretch of Kerala through these inland waters. Thus gradually it grew into a busy settlement. Nicolo Conti recorded that, by 1440, Kochi was a city 5 miles in circumference and that Chinese and Arabs carried on brisk trade with the natives of this town.

Kochi finds its way into modern history with the arrival of Vasco da Gama in 1498 and the advent of European colonialism. In early 16th century, Mattanchery and Kochi regions had grown as important trading posts where merchants and sailors of various nationalities jostled. In 1663, the Dutch overthrew the Portuguese. The Dutch East India Company tried to persuade the local rulers into giving them monopoly in pepper trade. In this attempt, they came across varied interests of other forces viz. English and the French. For about hundred years Kochi thus became the center of political and commercial battle. In 1795, The British took over Kochi from the Dutch. Fort Kochi thus became British Kochi and it became a Municipality in 1866.

Kochi emerged as a major port city on the west coast in 1939 through the zeal and vision of Sir Robert Bristow. Under the direction of Sir Robert Bristo, the sand bar at sea mouth was cut open and a deep shipping channel was dredged to the backwaters. The spoil of the dredging was used to reclaim Wellington Island from the backwaters. Road connection to the main land on the west and road-rail connection to the east from the island was completed in 1940 when the Government of India declared Kochi as a major port. Wellington Island developed with its wharfs, quays and other infrastructure as terminal complex of transportation. Centered around the port facility grew several business and commercial establishments providing the economic base to the city. In order to streamline the municipal administration, the Kochi Corporation was formed in 1967, incorporating the three Municipalities (Fort Kochi, Mattanchery and Ernakulam), Wellington Island and few surrounding areas in the suburbs.

2.4. Demography

A unique demographical feature of Kerala State is that it is more or less a uniformly continuous, scattered city or town from north to south unlike other dwelling concentrations interspersed with vast agricultural or barren lands found elsewhere in India. Various cities in the Kerala State accommodate only 2.90% of the urban population of India. A remarkable feature of urbanization in Kerala is that though the urban content of the state's population is only 25.97%, Ernakulam is the most urbanized district in the state in terms of absolute number of urban population (14.77 lakhs) and the percentage of urban to total district population (47.56%) as per 2001 census (City Development Plan, Kochi, 2007). The population of Kochi goes on increasing at a fast rate due to immigration stimulated by the developmental activities. The population of Ernakulum town at the end of 19th century was below 20,000. From the beginning of 20th century, an explosive growth in population was observed. By the end of 20th century the population in the corporation area was 5, 95, 000 with a density of 5950/ sq.km. Human resource indicators such as education levels and literacy are unusually high throughout Kerala; the literacy rate is reported to be virtually 100%.

2.5. Physiographical Significance and Climate

Being a coastal district, majority of the Kochi region is within the low land regions of the state. The average altitude of the land is less than 1 meter above MSL. The whole of the land slopes gradually from east to west. The soil of the planning region can be broadly classified into two categories viz. alluvial and lateritic. The flat terrain of the central city with the low altitude interspersed with a network of canals provide link to the backwaters. The secondary canals in the city used to serve as natural drainage for flood waters, but today they are in an advanced stage of deterioration through silting and waste dumping and fail to serve their purpose. The wetlands are formed by the gradual leaching of dry land into the flood basins of the watercourse, canals and estuaries. They remain covered by water during rainy seasons, but in summer they partially dry up and become suitable for paddy cultivation and aquaculture.

Tidal canals play a vital role in the surface water hydrology of Kochi. The vegetation is found to reveal remarkable zonation even within few tens of meters from the backwater system (Benjamin, 1998). In the waterward and landward edges of intertidal areas, vegetation is found to be exclusively mangrove species, whereas in the areas above the high tide level, remnants of mangrove species along with mesophytic vegetation are found to co-exist. Vegetation of the backwater shores (Mangrove and associated vegetation) exists in patches in the shorelines of the backwater system, particularly, in the intertidal areas. These plants, that once relentlessly protected the shores, are now being destroyed to residual remnant stands. The city hosts a bird sanctuary at its center. Mangalavanam Bird Sanctuary is a small mangrove area comprising of a shallow tidal lake in the centre with its edges covered with thick mangrove vegetation. It is considered as the ‘green lung’ of Ernakulam City, which is now polluted by many industries and motor vehicles (Jayson, 2001).

Kochi has a tropical climate with intense solar radiation and abundant precipitation. Like the rest of coastal Kerala, Kochi experiences warm climate with gentle prevailing winds and daily temperatures varying in the range 23 - 34º C. Annual temperature ranges between 20°C and 35°C (68–95°F). Coastal location along with its proximity to the equator results in a very low seasonal temperature variation with moderate to high levels of humidity. Humidity ranges from 65% and 95% with diurnal and seasonal variations and the average annual rainfall is 3,359.2 mm (Groundwater Board, Government of India, 2007). There are two distinct periods of higher than average rainfall from June to August and October to November.

2.6. Economic Growth and Landuse

The economy of the region emphasizes trade, including major exports of fish, prawns, coconut-derived fibers, tea, cashew kernels, and rubber. In addition, although the state of Kerala is not one of the heavily industrialized regions of India, the Cochin area is the site of the state's largest concentration of industrial activity. The special economic zone of Kochi zone includes 55 facilities producing food and agricultural products, chemicals, textiles, ceramics, latex products, wood processing, electronic hardware and software, biotechnology, and engineering. Eloor, situated 17 km north of the city, is the largest industrial belt in Kerala, with more than 250 industries manufacturing a range of products including chemicals and petrochemical products, pesticides, rare earth elements, rubber processing chemicals, fertilisers, zinc and chromium compounds, and leather products. *Ambalamukal industrial area is also within the city premises.* The per capita income of Cochin is about 25000 rupees/year (roughly $500 per year), which is above the state average. Land use in Kochi is diversified. According to the estimates of Greater Cochin Development Authority (GCDA), 78% of the land area of the Cochin Corporation is residential, followed by 9% for transport and communication, 3% for commercial establishments, 3% for industry, 6% for public and semi - public institutions, and 1% for open space (Development Plan For Kochi City Region, 2031). The percentage of residential land to the net dry land is 69.39 % in the Kochi City Region. Considering the existing population (11, 64,225 as per 2001 census) the gross residential density is 32 persons per hectare in the Kochi City Region. The gross residential density of Kochi City is 63 persons per hectare.

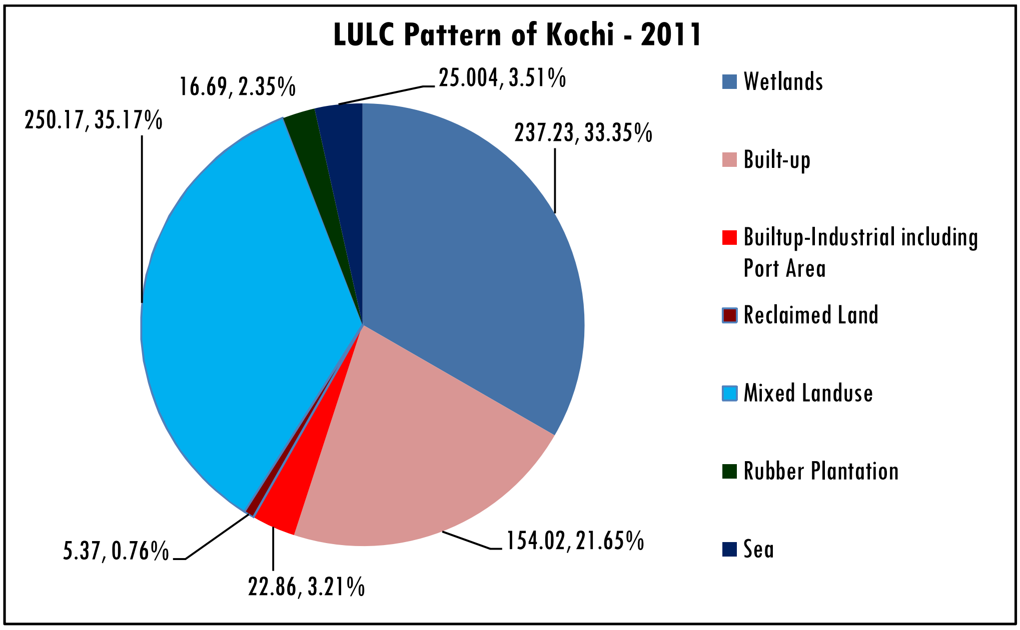


Figure 2.1. Land Use Land Cover pattern of Kochi (P.T.Dipson, 2011)

2.7. Major Developmental Activities

Major developmental activities of Kochi are ICTT, Metro Rail, Liquefied Natural Gas (LNG) Terminal, Kochi International Airport, Smart City, Info Park etc. ICTT is the first container trans-shipment hub in India. For close to two decades, the proposed development of a world class container transshipment terminal was under consideration of government of India. Several studies have clearly demonstrated the geographic advantage that Kochi enjoyed being strategically positioned in close proximity to the major global east-west trade routes. Creating a trans-shipment hub at Kochi is beneficial to both importers and exporters as an alternative solution to move their cargo at lower costs. The LNG terminal has been constructed and commissioned in August, 2013 and is currently operating at 8 percent capacity. Present transport facilities and infrastructure of Kochi are grossly inadequate for a developing city, resulting in wastage of time resources, fuel and increased pollution level as per the traffic survey conducted by the corporation in 2011; peak cover peak direction traffic (PCPDT) in Kochi is 13,861. Annual growth in vehicles is around 12-13%. As a solution for the problem due to increased vehicular traffic, a Mass Rapid Transport System (MRTS), Metro rail started its construction in 2012. It is expected to be complete by 2016.

Smart city is a planned industry township for information technology and enabled services, media and bio-technology. It is a joint venture between the government of Kerala and Dubai, Technology Electronic Commerce & Media Free Zone Authority (TECOM). Info Park is an IT park promoted by the Government of Kerala, located at Kakkanad, Kochi. Kochi International Airport, situated at Nedumbassery on the outskirts of the city, has recorded the highest number of flights and passengers (international and domestic) in Kerala. Cochin port, one of India's twelve major ports, is located in Wellington Island. It is an ISO 9001-2000 certified port administered by a Board of Trustees under the Major Port Trust Act 1963. As per Asian Development Bank (ADB) projection for G.D.P growth, traffic through Cochin Port could be over two million Twenty Foot Equivalent Units (TEUs) by 2012 and by 2022, it is projected to go up to 3.3 million TEUs.

2.8. Major Problems and Concerns

The most decisive problem faced by the city is the poor state of transport due to increased vehicular traffic and the lack of wide roads to accommodate the increased number of vehicles. In order to curb this problem a Mass Rapid Transport System (MRTS) - Metro Rail - will be commissioned in 2016. Solid Waste Management (SWM), which is an obligatory function of the Urban Local Body (ULB), is in a pathetic state resulting in problems of flood, water logging, mosquito menace, sanitation and environmental and health related problems. Management of solid wastes and Sewerage system are critical environmental issues associated with high rise buildings and apartments. A solid waste management plant was commissioned at Brahmapuram, but was only a partial success. Air and water of the city are polluted significantly. Percolation of septic tank effluents and dispersion trenches pollute the ground water. Commercial wastes are mostly directed to open surface drains. Coastal aquifers in this area experience severe degradation of water quality due to various anthropogenic activities. The main driving forces of coastal pollution are pollution owing to population followed by discharge of industrial effluents, oil pollution, indiscriminate use of agricultural chemicals which damages the quality of river water and ending up as marine pollution.

Some of the problems faced by the city are geographic in origin. Kochi is crisscrossed by a network of canals that were earlier used for navigation. Today, these canals have been turned into wastewater drains. The canals show high levels of pollution, clogging due to weeds, disposal of plastics and other wastes, encroachment and filling of many portions of these networks, finally resulting in floods during the monsoon season. Development of the slums around narrow streets and sides of canals combined with the lack of awareness on hygiene create large scale environmental problems for the Corporation to deal with. Most of the low lands in the Corporation area were earlier used for paddy cultivation. These low lands have undergone large-scale reclamation, both legal as well as illegal encroachments and land filling.

2.8.1. Impacts of Global Warming and Climate Change

It is reported that there is already an increase of 2.2 mm annual rise in sea level in the coast of Kochi which will amount to 22 cms in the next 100 years. If it happens, millions of people would be forced to relocate; human stress, anxiety and discomfort would be the result. International Panel for Climatic change (IPCC) in 1990, has predicted a 31 cm rise (lower scenario) in sea level induced by greenhouse warming, by the year 2100. Such a rise in ocean levels would cause the sea to move several meters farther inland thus permanently inundating a large area of the highly urbanised western flatland region of the study area (Benjamin, 1998).

2.9. Rationale for Selecting Kochi as the Study Area

Greater Cochin area, for one, falls in the grey area between land and ocean and the thick of the city is chronically plagued by water logging. Cochin is endowed with a fairly large estuary and an elaborate network of tidal canals. Such a complex and highly productive ecosystem is, at present, not effectively managed but subjected to severe exploitation. Increasing population and urbanization have far reaching impacts on the environment. At the same time ground water resources are heavily taxed to cope up with the burgeoning demand for fresh water. The municipal water supply fails miserably to meet the ever increasing demand of this fast growing city. Canals have already become a dumpsite of urban waste as well as drainage and untreated sewage. At present, the city of Kochi is subjected to serious anthropogenic interventions due to development activities in the mainland like urbanization, industrialization (both in the Corporation and adjoining areas), activities in the port, shipyard etc. Due to unplanned land use, impervious cover of the city is increasing which creates ground water shortage, water pollution and drainage problems. Major issues faced by the city are uncontrolled vehicular traffic, solid waste management, lack of developable land and problems due to pollution. Kochi is ardently trying for a planned sustainable development by framing policies that can curb the problems faced by the city. During the past decades, large areas of land have been reclaimed from backwaters and other wetlands to supplement the developed land (P.T. Dipson et al, 2013). Deliberate steps and policies were taken to retain a part of agricultural land within the city to cater to the open space requirement of future population. Most of the problems faced by Kochi are due to unplanned development. Planned development of water fronts and canal system will make the city beautiful and good to dwell.

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Chapter

3

MAPPING AND CHANGE DETECTION OF BUILT-UP IMPERVIOUS SURFACES IN AND AROUND KOCHI USING GIS

Contents

3.1. Introduction

Development of the scientific basis for the relationship between landuse and impervious surface began in the field of urban hydrology during the 1970's (Barbec et al, 2002). In the early studies, Imperviousness was evaluated in four ways: 1) identifying impervious areas on aerial photography and then measuring them using a planimeter, 2) overlaying a grid on an aerial photograph and counting the number of intersections that overlaid a variety of land uses or impervious features, 3) digital image classification and 4) equating the percentage of urbanization with the percentage of imperviousness.

Many factors must be taken into account in selecting an image processing method for use. A review of the literature on remote sensing of impervious surfaces over the past decade shows that spatial resolution of remotely sensed data is an important consideration in the selection of image processing methods to be used. Researchers may have to consider the user's need, research objectives, availability of remotely sensed data, compatibility with previous work, and availability of image processing algorithms and computer software, and time constraints (Lu & Weng, 2007). Among these factors, the selection of suitable remote sensing data is the first important step for a successful application (Phinn, 1998; Phinn et al., 2000). The data selection closely relates to research purposes and requirement, the scale and characteristics of a study area, the analyst's understanding of image data and their characteristics, cost and time constraints. Since remotely sensed data vary in spatial, geometric, radiometric, spectral, and temporal resolutions, complete understanding of the strength and weakness of various types of data is key to a proper data selection.

Numerous research efforts have been devoted to quantify urban impervious surfaces using ground-measured and remotely sensed data (Deguchi and Sugio, 1994; Phinn et al., 2000). The methodologies range from multiple regression (Foster, 1980; Ridd, 1995; Xiao et al, 2007), spectral mixture analysis (Lu et al, 2011), artificial neural network (Civico and Hurd, 1997), classification trees (Yang et al, 2003), integration of remote sensing data with geographic information systems (Prisloe et al., 2001) and digital image classification. Various methods of estimation and mapping of impervious surfaces are discussed below.

3.2. Methods of Estimation of Impervious Surfaces

3.2.1. Optical Surveying and Global Positioning Systems

The first method involves the physical measurement and quantification of area for all impervious surfaces by either a traditional optical ground-based survey technique or through the use of a global positioning system (GPS).

3.2.2. Aerial Photography

Similar to optical surveying and GPS, interpretation of aerial photographs can be time consuming and very expensive. Application of aerial photography is only suitable for small area impervious surface mapping.

3.2.3. Population Density

A more indirect approach of estimating impervious surfaces is in using population densities. Stankowski (1972) developed a quantitative index of urban land use characteristics that could then be applied to water resource analyses. From his results, Stankowski suggested population density was the only independent variable needed to empirically estimate proportions of impervious surfaces associated with different degrees of urban development.

3.2.4. Digital Image classification

Image classification is one of the widely used methods in extraction of impervious surfaces (Hodgson et al., 2003; Dougherty et al., 2004; Jennings et al., 2004), but results are often not satisfactory because of the limitation of spatial resolution in medium resolution imagery, spectral similarity of various features in an image and the heterogeneity of urban landscapes. The ultimate aim of image classification process is to categorize all pixels in a digital image into one of several land use/land cover classes or “themes” (Lillesand and Kiefer, 2000).

Digital classification techniques are of two types: supervised classification and unsupervised classification. In a supervised classification, the analyst identifies in the imagery homogeneous representative samples of the different surface cover types (information classes) of interest. These samples are referred to as training areas. The selection of appropriate training areas is based on the analyst's familiarity with the geographical area and their knowledge of the actual surface cover types present in the image. Thus, the analyst is "supervising" the categorization of a set of specific classes. The numerical information in all spectral bands for the pixels comprising these areas is used to "train" the computer to recognize spectrally similar areas for each class. The computer uses a special program or algorithm (of which there are several variations), to determine the numerical "signatures" for each training class. Once the computer has determined the signatures for each class, each pixel in the image is compared to these signatures and labelled as the class it most closely "resembles" digitally. Thus, in a supervised classification we are first identifying the information classes which are then used to determine the spectral classes which represent them. There are mainly three classification algorithms: Mean distance to minimum, Parallelopiped and Maximum likelihood classifier (MLC). MLC is the most accurate among these three (Lillesand et al, 2004, P.T.Dipson, 2012). Unsupervised classification image do not utilize training data as the basis of classification. This family of classifiers involves algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural grouping or clusters present in the image values. A widely used method for unsupervised classification is an algorithm Called Iterative Self Organizing Data Analysis (ISODATA).

3.2.5. Application of NDVI, Tasseled cap greenness and PCA

Because of the near inverse correlation between impervious surface and vegetation cover in urban areas, one potential approach for impervious surface extraction is through information on vegetation distribution (; Carlson & Arthur, 2000; Gillies et al., 2003, Bauer et al., 2007). Normalised Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near infrared region of the electromagnetic spectrum and is used to assess whether the target being observed contains live green vegetation or not. The NDVI subtracts the red reflectance values from the near infrared (NIR) and divides by the sum of NIR and red bands. The NDVI or tasseled cap greenness or principal component analysis (PCA) can be utilized to represent vegetation distribution. Impervious surfaces are then estimated based on: (1) complement of vegetation fraction; or (2) regression models with vegetation indices.

3.2.6. Sub-Pixel Analysis

The area represented by a single pixel in an image may contain more than one thematic class. Such a problem arises due to many reasons and makes it difficult to process the data using conventional classification techniques. In such cases with mixed pixel problem, sub-pixel classification can be implemented. The idealized, pure signatures for a spectral class is called an end member. Because of sensor noise and within class signature variability, end members only exist in concept and as idealizations in real images. There are many different methods of implementing sub-pixel classification. Regression analysis, Spectral mixture analysis, artificial neural networks, soft maximum likelihood classifier, support vector machines etc. can be employed to do sub-pixel classification. However, these methods share a common problem, that is, impervious surface tends to be overestimated in the areas with small amounts of impervious surface, but is underestimated in the areas with large amounts of impervious surface.

3.2.7. Regression Models

Another method is regression, either statistical regression which relates percent ISA to; Tasseled cap' greenness (Bauer et al, 2004) or regression tree(Yang et al, 2003). Yang et al. (2003) extended the regression method by developing a classification and regression tree (CART) algorithm, which used the classification result of high resolution imagery as the training dataset to generate a rule-based modeling for prediction of sub-pixel percent imperviousness for a large area.

3.2.8. Artificial Neural Networks

Artificial Neural Network (ANN) has been widely used in remote sensing image analysis. Natural networks can be employed to perform traditional image classification tasks (Civco, 1993; Foody et al., 1995) as well as subpixel classification (Flanagan & Civco, 2001; Lee & Lathrop, 2006). A neural network consists of a set of three or more layers, each made up of multiple nodes. These nodes are somewhat analogous to the neurons in biological network's layers and include an input layer, an output layer, and one or more hidden layers. The nodes in the input layer represent spectral bands from a remotely sensed image, used as input to the neural network. The nodes in the output layer represent the range of possible output categories to be produced by the network. If the network is being used for image classification, there will be one output node for each classification system.

3.2.9. Object Based Image Analysis (OBIA)

Object based image analysis (OBIA) has been increasingly used in remote sensing applications after the introduction of high resolution satellite imagery, hyper spectral imagery and the emergence of commercial software (Wang et al., 2004). Traditional pixel based approaches have difficulties processing high-resolution imagery resulting in a 'salt-and-pepper' effect where pixels cannot be aggregated properly which later results in poor readability. Classical pixel based techniques assume individual pixels on each image as independent and they are treated in the classification algorithm without considering any spatial association with neighbouring pixels. 'Object based' classifier first segments an image into clusters of similar 'neighbouring pixels (objects), and then classifies the clusters according to average spatial properties.

3.2.10. Conceptual Models

Ridd (1995) proposed a conceptual model, i.e., vegetation-impervious surface soil (VIS) for urban ecosystem analysis. This framework presents a systematic standard for characterizing urban ecosystem from morphological, biophysical, and anthropogenic perspectives. In this conceptual model, combinations of green vegetation, impervious surface material, and exposed soil were considered the most fundamental components of the urban ecosystem. Using this model detailed land cover land use and biophysical parameters were obtained for urban ecosystems using remote sensing. Wu et al, 2005 applied V-I-S model to Shanghai City, China.As described above numerous methods are there for the estimation of impervious surfaces.

3.3. Data used for the Study

IRS LISS (Linear Imaging Self Scanning Sensor)images for the years 2007, 2009 and 2011 were procured with minimum cloud cover with the help of National Remote Sensing Center (NRSC) image browsing facility. The images for 1990, 1998 and 2014 were downloaded from Global Land Cover Facility (GLCF) and 1973 image was downloaded from U.S. Geological Survey (USGS). The details of the data used are given in the table 3.1.

Table.3.1. List of Satellite Images used in this study

Space-craft	Acquisition Dates	Sensor	Bands	Spatial Resolution (Meter)	Radiometric Resolution (Bits)	Source	Image Details	Level of Processing
Landsat-8	11-02-2014	ALI	2,3,4	30	16	GLCF	Path-143, row-53	Geo rectified, radiometric corrected.
IRS-P6	08-02-2012	LISS-IV	2,3,4	5.6	16	NRSC	Path 99, Row-66, Sub scene-B)	Geo-rectified, radiometric corrected.
IRS-P6	01-02-2011	LISS-III	2,3,4	24	7	NRSC	Path-99,Row-66 (70% Shifted to Row 67)	Radiometric corrected
IRS-P6	20-12-2009	LISS-III	2,3,4	24	7	NRSC	Path-99,Row-66 (70% Shifted to Row 67)	Geo-Rectified
IRS-P6	07-12-2007	LISS-III	2,3,4	24	7	NRSC	Path-99,Row-66 (70%Shifted to Row 67)	Radiometric corrected
IRS-IC	04-01-1998	LISS-III	2,3,4	24	7	GLCF	Path-99,Row-66 (70%Shifted to Row 67)	Radiometric corrected
Landsat 5	24-01-1990	TM	2,3,4	30	8	GLCF	Path-144,Row-53	Geo-Rectified
Landsat 1	10-02-1973	MSS	2,3,4	60	6	USGS	Path-155 Row-53	Radiometric corrected

3.4. Methodology

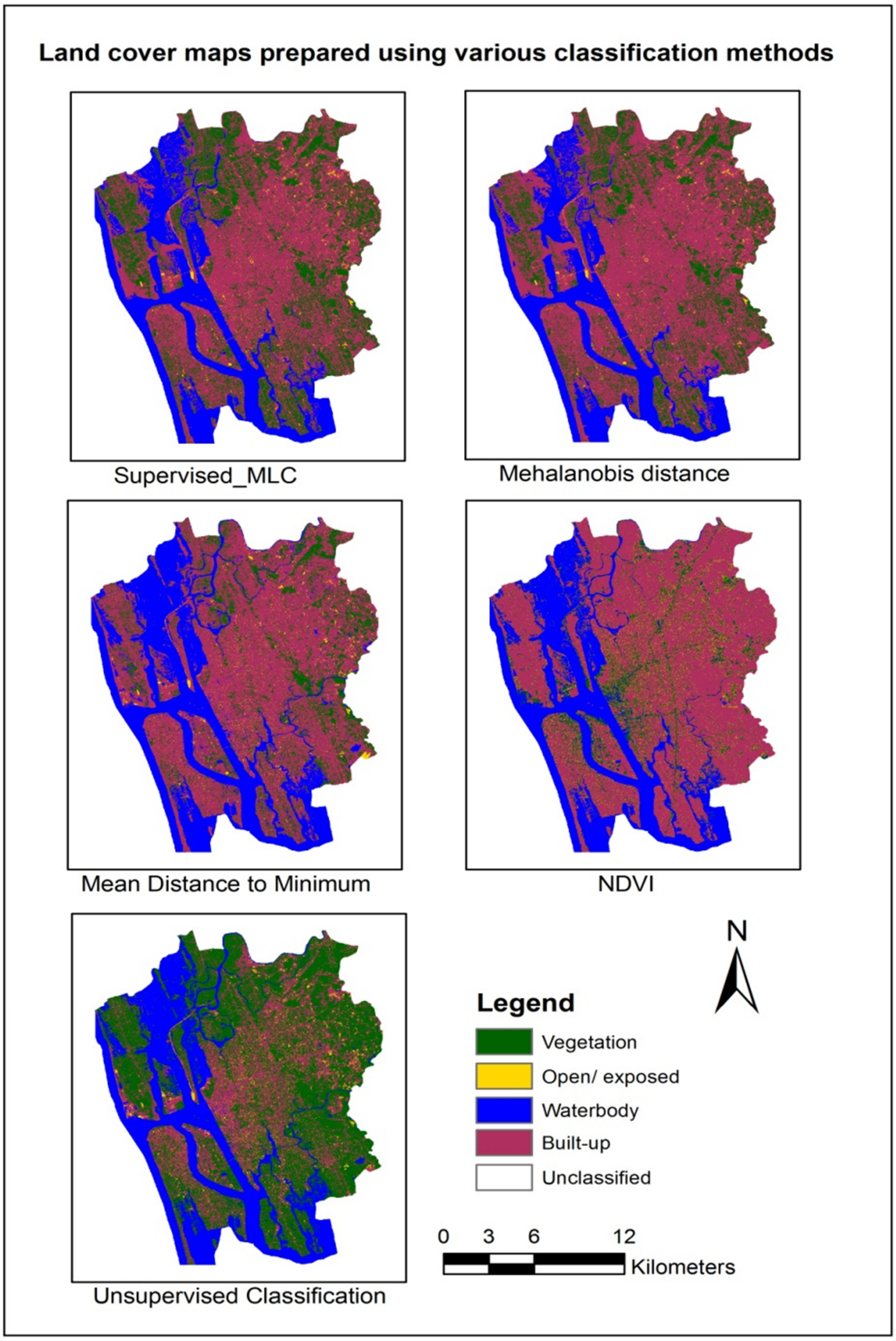
3.4.1. Pre-processing of Satellite Images

All the LISS III, LISS IV, Landsat MSS and Landsat TM images were co-registered or geometrically corrected using image to image registration with reference to geometrically corrected 2014 Landsat 8 image using first order polynomial equation with nearest neighbour resampling techniques. The Image was projected to UTM WGS 84, zone 43 N projection. All the images were co-registered to < 0.5 pixel accuracy. All the image processing were done in ArcGIS 9.3 and Erdas Imagine 9.1. Digital Number obtained from digital images were first converted to Top of Atmosphere reflectance as mentioned in Chandler and Markholm, 2003. Atmospheric correction was done using minimum pixel subtraction method (Crane, 1971; Chavez et al, 1977, Kok et al, 2009). All the images were georectified and subsetted using the subset tool in data preparation menu in the ERDAS imagine software.

3.4.2. Selection of a suitable method for the preparation of impervious surface map.

Land cover maps having four classes - Water bodies, Vegetation, Open/Exposed and Built-up areas are prepared using three different digital image classification techniques. IRS LISS IV image for the year 2012 having 5.6 m. spatial resolution was used for this analysis, which is having the highest spatial resolution available in public domain. The different classification techniques tried are supervised and unsupervised classifications, as well as Normalised Difference Vegetation Index (NDVI). There are mainly three classification algorithms for supervised classification. Mean distance to minimum, Mehalanobis distance and Maximum likelihood classifier (MLC) as mentioned in section 3.2.4. Unsupervised classification is done with Iterative Self-organizing Data (ISODATA) Algorithm. In this study, the image is subjected to unsupervised classification with a cluster size of 30 clusters. After classification, each of these 30 clusters is assigned with one of the four land use classes by correlating the classified image with ground reference. After the classification, accuracy assessment to each classified image is done using the accuracy assessment tool in Erdas Imagine. Sampling points (300) were selected at random and the accuracy assessment is done for all the classified images, supported by ground information collected using a Garmin-60 hand held GPS system. Google Earth is also used to obtain the current spatial scenario.

Among all these classification techniques and algorithms 'Supervised Maximum Likelihood Classification (MLC) yielded the highest classification accuracy and was selected for further estimates. The classification accuracy is in the following order; Supervised MLC > Unsupervised classification > NDVI > Mean distance to minimum > Mehalanobis Distance.



Map 3.1. Land Cover Maps prepared using various Classification Methods

3.4.3. Preparation of 'Total Impervious Surface (TIA)' maps

Land cover classified layers for the years 1973, 1990, 1998, 2007, 2009, 2012 and 2014 having the four classes were prepared using supervised MLC classification. Vegetation and Open / Exposed land is considered as pervious and Built-up areas alone is taken as impervious. Confined water bodies, which adds to the perviousness, are absent in the study area. There are only flowing water bodies, which do not add to the infiltration (perviousness) but only increase the run-off. Hence, they are considered neither as pervious nor impervious and hence are left alone as water bodies in Map 3.4. Total Impervious Area (TIA) maps for the city were composed from these layers.

3.4.4. Spatio - Temporal Analysis of Impervious Surfaces

Spatio temporal analysis of TIA is performed by considering the image differences of 1990 and 2014 TIA layers. Even though data for the year 1974 was available, a comparison between 1974 image with 72 m. resolution and 2014 image with 30 m. resolution can result in serious error. Hence only the 1990 image having 30 m. resolution is used for the comparison with 2014 data.

3.5. Results and Discussion

Before 1990, Built-up area in Kochi was quiet low as seen in 1973 image in Map 3.2. Built-up areas can be seen in Mattancherry, Fort-Kochi and Ernakulam area. Kumbalam, Panangad, Palluruthy, Edakochi, Nettoor and Vypin areas seems unoccupied and the island of Vallarpadam is in the formation stage (Locations are shown in Map 2.3). During 1990's, Cochin Port Trust introduced its container storage area near Wellington Island after reclaiming an estuarine area. A major portion of the Wellington Island became occupied (mainly by the Cochin port trust) and Thevara-Wellington Island Bridge was constructed during early 1990's.The industrial activity of

Kochi is concentrated in Eloor and Ambalamugal area. Not only industrial or commercial but also residential areas increased in these areas as can be seen in 1990 image. A tremendous increase in built-up area was seen in M.G road, Kaloor and Ernakulam region. Also the M.G. Road area witnessed the proliferation of several commercial activities, which was later followed by Marine Drive area. After 1998, residential areas spread to Edapally, Edakochi, Kalamassery and Aluva.

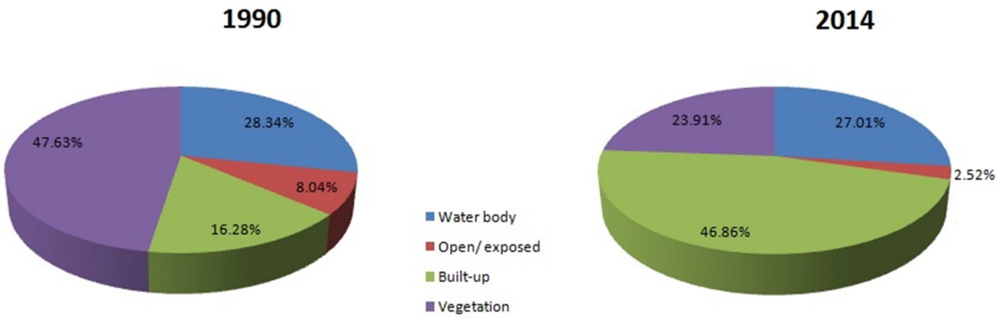
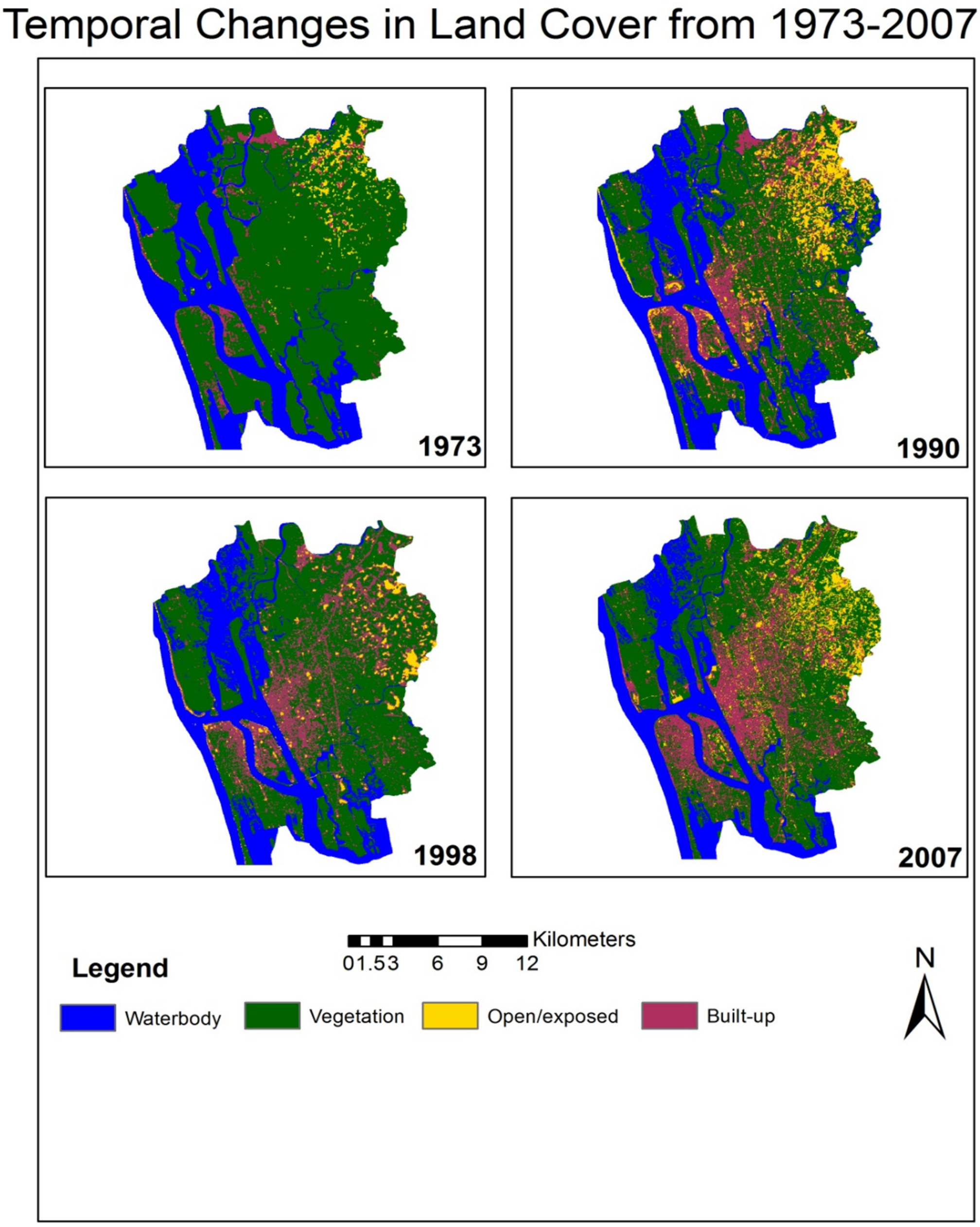
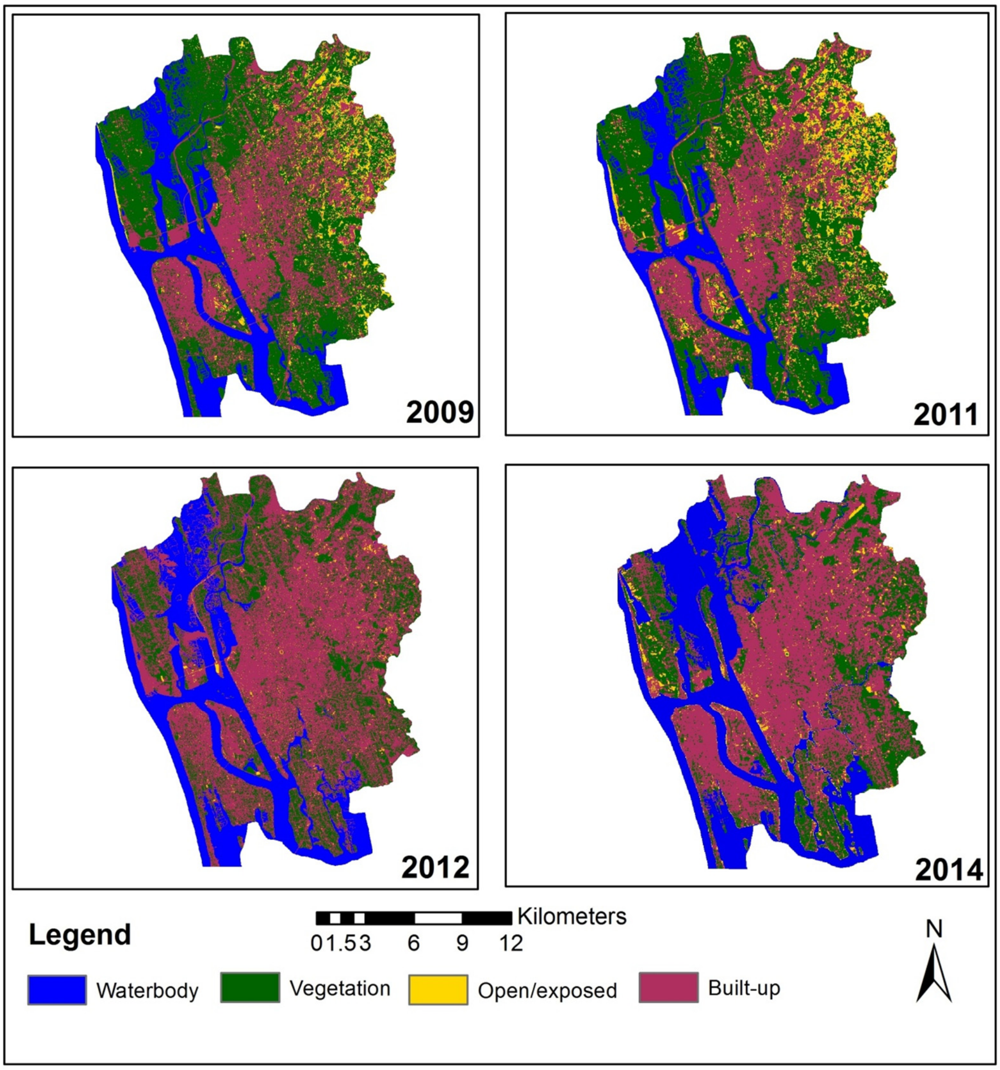


Figure.3.1. Landcover Pattern for 1990-2014

Built-up areas increased tremendously with the construction of NH-47 bypass. The impervious surface expansion mainly takes place along the periphery of new roads as can be seen in Map 3.4. In addition, impervious cover of the city increased considerably with the onset of major developmental activities such as International Container Transshipment Terminal (ICTT), Metro Rail, Liquefied Natural Gas (LNG) Terminal, Kochi International Airport, Smart City, Info Park etc. Construction of ICTT was started in 2005 and it became fully operational in 2011. Metro rail project started in 2013 also added its own share of impervious surface increase for its allied infrastructure developments. Change detection studies shows that impervious cover over the city is increasing at a very rapid pace. Land cover maps for the years 1974, 1990, 1998 and 2007 are given in map 3.2. and that for the years 2009, 2011, 2012 and 2014 are given in the map 3.3. Spatio temporal changes of impervious surface from 1990 to 2014 are given in map 3.4.



Map 3.2. Map showing Temporal Changes in Land Cover from 1973-2007

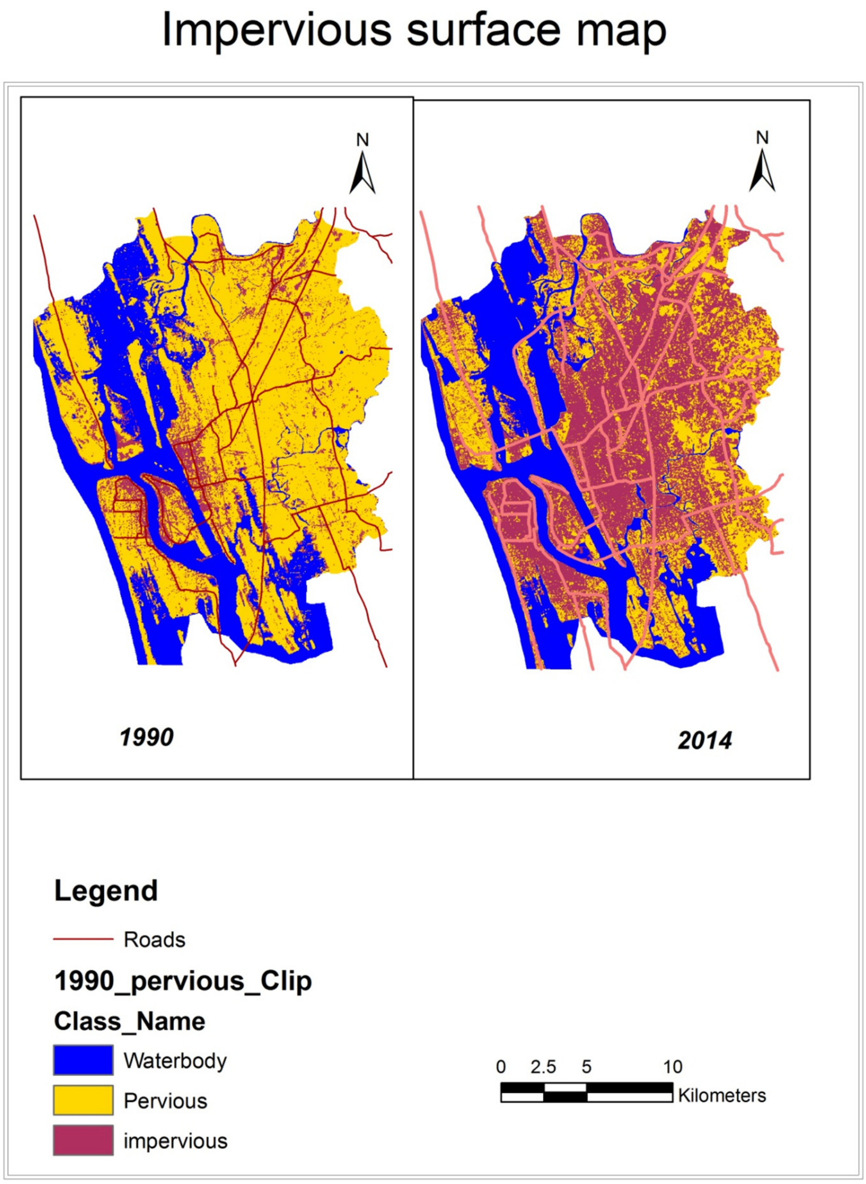


Map 3.3. Map showing Temporal Changes in Land Cover from 2009-2014

3.5.1. Spatio temporal changes of impervious surfaces

Spatio temporal analysis of impervious cover over Kochi shows that along with the increase in urbanization, there is a corresponding decrease in water bodies and vegetation. Analysis of satellite data shows that the impervious coverage of 53.74 km^2 in 1990 increased to 154.63 km^2 by 2014, while there was a corresponding decrease of pervious areas from 183.70 km^2

to 87.25 km^2 during the same period. Also, it can be seen that this change is not only contributed by conversion of pervious lands into built up area, but also by land reclamations of the backwaters (map 3.2 and 3.3). This trend was visible from 1944 to 2009 as shown by Dipson et al (2014). Only, this trend seems to accelerate in the present decade.



Map.3.4. Total Impervious Area Map

3.6. Conclusion

There are many potential applications for the impervious surface maps prepared from this study. Spatially explicit imperviousness estimates and their trends provide urban planners useful data to assist in their decision making and implementation of management strategies. Applications in this field include urban ecological modelling as well as urban climatological studies. Above all, expansion in impervious surface serves as an indicator of increasing Urban Heat Island (UHI) effect. Geospatial data of impervious surfaces and its change can be used not only as a critical input for urban hydrological modelling but also as an indicator for water quality assessment. Increasing imperviousness plays a big role in degrading water quality and quantity.

This study reveals the rapid increase in impervious coverage concurrent with the development of the Kochi metropolis. This calls forth, the urgent implementation of strict land use policies and planning as well as Best Management Practices for the smooth functioning of the city infrastructure and future city development policies. The frequent disruptions of traffic and other public services after heavy rainfalls have become a part of the city life not only in Kochi, but also in most of the cities in the tropical developing countries. This emphasizes the need to develop planned cities at least in emerging metropolises.

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Chapter

4

IMPACTS OF IMPERVIOUS SURFACES ON LAND SURFACE TEMPERATURE

Contents

4.1. Introduction

Elements of built environment such as rooftops, sidewalks, asphalt, brick & lawns individually and cumulatively provoke changes to natural processes. They absorb and store solar energy and reradiate it, keeping the urban environment hotter than its surroundings causing heat island effect. Urban Heat Islands (UHI) refer to the phenomenon of higher atmospheric & surface temperatures occurring in urban areas than in the surrounding rural areas due to urbanization (Voogt and Oke, 2003). There are concerns that rising temperature over developed areas could lead to decreasing the living comfort, increasing the environmental footprint, particularly the energy and carbon foot print and can have other negative environmental impacts within city boundaries. The urban air temperature is gradually rising in all major cities of the world usually called the Urban Heat Island (UHI) Effect. The reasons behind it are the environmental factors such as diminishing green areas, low wind velocity due to high-building density, change of street surface coating materials and even contributed by the sea-level rise due to the Global Warming (Takahashi et al;

2004). The change of land use from green areas to impervious surfaces results in changes of the natural surface phenomenon on the earth. The land cover changes will affect the absorption, radiation and reflection of solar radiation and thereby alter the thermal properties of land surface as well as the microclimate. Buildings, roads and paved surfaces store heat during the day and then release it back slowly during the dark hours making the urban areas hotter than their peripheries. Further, other anthropogenic heat sources such as combustion processes from vehicles, domestic and industrial sources as well as heat escaping from commercial and domestic air-conditioning etc. contribute to higher air and surface temperatures within the city.

The major contributor to the UHI is impervious surfaces which have higher absorptive power of solar radiation compared to that of the green surfaces. Also, such surfaces prevent the infiltration of water into the soil thus drastically altering the natural hydrological cycle. The UHI occurs due to differences in thermal, and radiative properties of urban surface materials from those of natural surfaces, multiple reflection and absorption of sunlight by urban building facades (due to their specific geometry), anthropogenic heat sources and lack of evapotranspiration in urban surfaces.

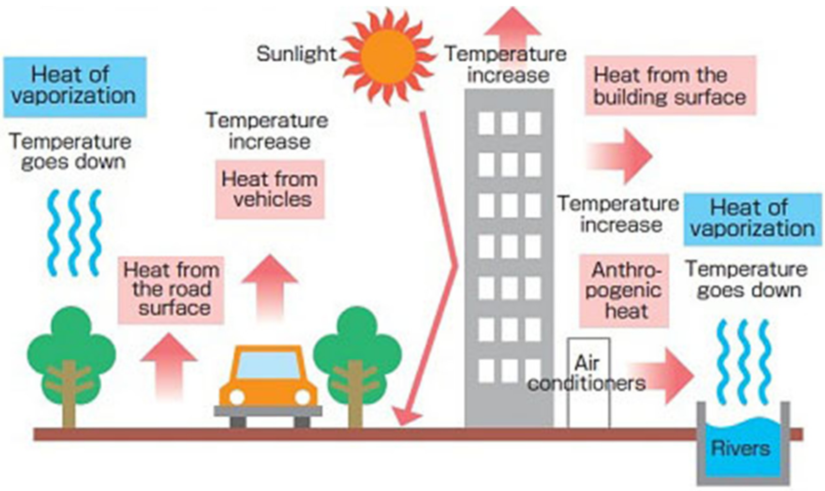


Fig 4.1. A diagram showing heat island phenomenon

Although UHI's are associated with all cities and developed areas, the intensity of its effects may vary significantly depending on the geographical positioning as well as green coverage. The intensity of the UHI in the order of 4 to 6 ^{0}C influences air pollution dispersion as well as energy demand for cooling in urban areas. Charabi and Bakhit (2011) studied the canopy layer urban heat island of Oman and found that urban parks reduce local air temperature by 0.5–5 ºC. Also, each 1ºC drop in air temperature could lower the peak electric power demand by 2 - 4% (Akbari and Taha; 1992). Shabeer and Mahesha (2011) reported the prevalence of HI effect in Kochi using Modis data.

4.1.1. Role of Remote Sensing and GIS in the study of LST

Ideally, the signature of a UHI is the temperature difference at a given location within the city compared to the temperature that would be measured at that same location without the presence of the city (Magee et al, 1999). Since such a measurement is not possible, the heat island magnitude can be approximated by taking the simultaneous temperature difference between an urban locale and any nearby rural location with similar geographical settings. This technique is acceptable for determining the magnitude and detailed characteristics of the heat island at any given time, and can be derived from satellite images. Another approach analyse the trends of differences in the climatological records between a station within the city and neighbouring rural locale. This approach will reflect long-term fluctuations in heat island, but ground-based observations reflect only local thermal condition around the station.

Application of remote sensing enables the researcher to derive the thermal signature for each pixel in the image. To estimate the temperature of a land surface from a satellite image, it is necessary to find the relationship between the surface temperature, surrounding topography and LULC (Weng, Q., 2009). To estimate the LST from satellite thermal data, the digital number (DN) of image pixels needs to be converted into spectral radiance using the sensor calibration data (Markham, B. L and Barker, J. L, 1987). However, the radiance converted from DN does not represent the true surface temperature but a mixed signal or the sum of different fractions of energy. These fractions include the radiant energy as ground emissions, atmospheric emissions, as well as the upwelling radiance from the sky integrated over the hemisphere. The present study attempts to find the temporal and seasonal variation of LST using satellite data.

Three types of heat island effects are usually identified. They are the **canopy, boundary** and **surface** layer heat islands (Oke, 1979, Voogt, 2004). The heat islands happen in various layers or parts of the urban atmosphere. **The Canopy Layer** refers to the buildings which the layer of air in proximity to the city surface extending up to their average height. The canopy layer includes the air between the rough items such as streets with an upper boundary exactly under the roof level. In UHI studies, canopy-layer air temperatures are usually measured at about the height of people or the lower stories of buildings, between 1.5 and 3 m above ground. If that temperature is warmer than the temperature at the same height in nearby rural areas, then this is termed the urban canopy layer (UCL) heat island (Oke, 1976, 1995).

The heat island (HI) that forms in the atmospheric boundary layer above the city is the **Urban Boundary Layer (UBL) Heat Island** (Oke, 1987, 1995). This atmospheric layer could range from 100 meters in thickness at night to 1 km during the day (Voogt, 2004). The canopy layer is located at the bottom of the boundary layer, with the higher influence of boundary subject to the urban surface (Weng & Taylor, 2003). The remotely sensed Surface Urban Heat Island (SUHI) is surveyed by using thermal infrared data, which allow to compensation of land surface temperatures. Normally, the relationship between the near surface air temperatures and land surface temperatures have found so close. Thus, the surface UHI is a trustable indicator of the atmospheric UHI (Schwarz et al, 2012). Canopy layer - SUHI is the remotely sensed urban heat island. It is derived from the satellite thermal infrared imageries that allow the retrieval of LST.

Two issues are addressed in this chapter. One is the study of the UHI within about one and a half decades 1990 to 2014) and the current scenario of seasonal and diurnal variations of LST in Kochi which gives a clear picture of the Surface Urban Heat Island Effect (**SUHI**) of the region. The progressive intensification of SUHI in Kochi is studied analysing the 1990 and 2014 January imageries. Another environmentally relevant study included in this chapter is a comparative study of SUHI phenomenon during 2014 January imageries of selected coastal cities in Asian tropical region with similar geographical settings, which sheds light on the necessity of adopting proper environmental management strategies.

4.1.2. The Negative Impacts of Increased Temperature in Urban Areas

4.1.2.1. Poor Air Quality

Urban temperature rise results in the increase of electricity demand to drive instruments and facilities needed to cool buildings such as air conditioners, air coolers and refrigerators. This results in correspondingly higher levels of greenhouse gas emissions. Many plants and animals are sensitive to the increased temperatures. Increased temperatures can interfere with photosynthesis—and the warmer temperatures can result in more water being used for irrigation to support stressed vegetation. The amount of smog pollution increases roughly 3 percent with every 1°F increase in temperature. Increased air temperatures resulting from the urban heat island effect only exacerbate these conditions.

4.1.2.2. Increased Heat Related Illness

Higher temperatures result in increased incidence of heat related illness, such as heat exhaustion, heat cramps and heat stroke (also known as sun stroke). The increased incidence of mosquito borne diseases such as malaria and dengue fever, results as the elevated temperature promotes the growth and reproduction of mosquitos. Dengue is the world's most important vector borne viral disease trasnsmitted by urban Aedes mosquitos. Aedes mosquitos especially the Aedes Aegypti often live in close proximity with humans in tropical urban areas. The effects of future climate change on the rates of Dengue transmission is complex. On the one hand, areas with higher rainfall and higher temperatures can expect higher rates of Dengue transmission because the mosquitos thrive in warm moist environment. Rate of Dengue transmission may increase in regions that are projected to become more prone to drought. This is because Aedes mosquitos which carry dengue breed in containers used for household water storage, and because the need for such water storage containers will increase in areas prone to drought as climate continues to change.Some vectors have higher survival at higher latitudes and altitudes with higher temperatures. Temperature increases the activity of some vectors but reduce activity of others. Temperature changes the rate of vector population growth as well as increases the biting rate and host contact of mosquitos. Also it is seen that extrinsic incubation period of pathogen in vector is decreased at higher temperatures.

4.2. Data Used:

Landsat 5 and 8 images as well as MODIS images were used for the study. Both Landsat 5 and 8 images were orthorectified, radiometrically corrected and downloaded in GeoTIFF data product with cubic convolution resampling technique. Modis LST products were derived by processing the MODIS band 32 data. The MODIS/Terra LST/E daily L3 Global 1km grid product (MOD11A1) is tile based and gridded in the sinusoidal projection and produced daily at 1 km spatial resolution It is reprojected in Universal Transverse Mercator (UTM) co-ordinate system with World Geodetic System (WGS)-84 datum. Modis/Terra LST/E (Land Surface Temperature / Emissivity) products provide per-pixel temperature and emissivity values in a sequence of swath based to grid-based global products.

Table 4.1. Images used to study the temporal and seasonal variations in LST

Space-craft	Acquisition Dates	Sensor	Bands	Spatial Resolution (Meter)	Radiometric Resolution (Bits)	Source	Image Details	Level of Processing
Landsat-8	26-01-2014	ALI	10	30	16	GLCF	Path-143, row-53	Geo rectified, radiometrically corrected.
Landsat-8	11-02-2014	ALI	10	30	16	GLCF	Path-143, row-53	Geo rectified, radiometrically corrected.
Landsat-8	11-02-2014	ALI	10	30	16	GLCF	Path-143, row-53	Geo rectified, radiometrically corrected.
Landsat 5	24-01-1990	TM	10	30	8	GLCF	Path-144,Row-53	Geo-Rectified
MOD11A1	16-01-2014	Terra	32	1000m	12	USGS	Path-143, row-53	Radiometrically corrected
MOD11A1	15-01-2013	Terra	32	1000m	12	USGS	Path-143, row-53	Radiometrically corrected
MOD11A1	15-01-2012	Terra	32	1000m	12	USGS	Path-143, row-53	Radiometrically corrected
MOD11A1	15-01-2011	Terra	32	1000m	12	USGS	Path-143, row-53	Radiometrically corrected
MOD11A1	15-03-2011	Terra	32	1000m	12	USGS	Path-143, row-53	Radiometrically corrected

Table 4.2. Landsat 8 Imageries used for comparative study of SUHI phenomenon of selected cities

Acquisition Dates	Image Details	Region	Lat-long
26-01-2014	Path-143, row-53	Kochi	9.9700°N, 76028°E
21-01-2014	Path-141, row-55	Colombo	6.9271°N, 79.8612°E
27/06/2013	Path-148, row-41	Singapore	1.3°N, 103.8°E
19/12/2014	Path-122, row-64	Jakarta	6.174°S, 106.8227°E
16-01-2014	Path-129 Row-50	Bangkok	13.7563°N, 100.5018°E
6-01-2014	Path-148 Row-47	Mumbai	19.076°N, 79.8612°E

4.3. Methodology

4.3.1. Temporal Variation of LST

Temporal variation of LST was studied using the thermal bands of Landsat images for the year 1990 and 2014. Both the images pertain to the month of January. Raw DN values from the satellite images are converted into the black body temperature in Degree Celsius using Model builder in Erdas Imagine. The generic term for pixel values is Digital Number or DN. It is commonly used to describe pixel values that have not yet been calibrated into physically meaningful units. DN values are first converted to spectral radiance and then to temperature in Kelvin. It is then converted to temperature in Celsius by subtracting 273°C.

Landsat 5 TM data set has seven spectral bands, of which the 7th band records emitted energy in the thermal infrared portion of the spectrum and gives information about the thermal characteristics. Landsat 8 Thermal Infrared sensor (TIRS) acquires data in Thermal region. It acquires data in 10th and 11th bands.

i). Conversion of the Digital Number (DN) to Spectral Radiance (L)

Radiance is the amount of radiation coming from an area. To derive a radiance image from an uncalibrated image, Spectral Radiance Scaling Method (Chander et al, 2009) can be used. Radiance includes radiation reflected from the surface, bounced in from neighbouring pixels, and reflected from clouds above the area of the pixel. Radiance is also affected by the source of the radiation, which for optical imagery is the sun.

For a Landsat 5 image

$$\mathbf{L_{\lambda} = L_{MIN} + (L_{MAX} - L_{MIN}) * DN / 255}$$

Where, **L** = Spectral radiance,

L_{MIN} = 1.238 (Spectral radiance of DN value 1)

DN = Digital Number.

ii) Conversion of Spectral Radiance to Temperature in Kelvin.

$$T_b = K_2 / \ln((K_1/L_\lambda) + 1)$$

Where,

K_1 = Calibration Constant 1 (607.76)

K_2 = Calibration Constant 2 (1260.56)

T_b = Surface Temperature

For any satellite the variables Lmax, Lmin, K1 and K2 can be obtained from the corresponding image metadata.

iii) Conversion of Kelvin to Celsius.

$$T_b = T_b - 273$$

iv) Mean urban temperature was found out using *zonal statistics as table* tool in ArcGIS spatial analyst. Zonal statistics was calculated after masking the river and water bodies in the image. Zone fields were digitized as different layers and mean temperature was found out from LST in Celsius.

4.3.2. Seasonal Variations in LST

Seasonal variations in LST were studied applying the above-mentioned method using Landsat 8 images taking 2014 as a recent representative year. Three distinctly different seasons – January - February; April - May and October – November were chosen for this analysis. LST study during June - July, 2014 might have been desirable, but images were not available due to the overcast conditions.

4.3.3. Diurnal Variations in LST

Diurnal variations of LST were studied using the MODIS Land Surface Temperature and Emissivity (LST/E) products for the year 2014, 2013, 2012 and 2011. All the images available from 2011 to 2014 were analysed but only the images for January and a few images for March were found cloud free. Hence images for January alone were selected for the study. Both the day-time as well as night-time images for the same date were analysed. The MODIS/Terra LST/E products were mossaiced and reprojected to UTM projection and converted to temperature values by multiplying it with the scale factor (0.02) (Zhengming Wan, 2006).

$$\text{Temperature in Celsius} = (DN \times 0.02) - 273$$

4.3.4. Comparison of Heat Islands of various Tropical Coastal Asian Cities

The cities selected for the study are Kochi, Mumbai, Colombo, Jakarta, Bangkok and Singapore. These cities were selected, as they are tropical Asian cities, having proximity to sea, and with a comparable climate scenario as that of Kochi. Except Singapore, all the other Asian cities are characterised by haphazard urban development. Hence, they are selected for this study to highlight the necessity for adopting proper urban planning and management strategies to ameliorate the UHI effect.

- Mumbai has a tropical savanna climate with dry winters. Over the course of the year, the temperature typically varies from 19°C to 34°C and is rarely below 16°C or above 36°C.

- The weather of Colombo is fairly temperate throughout the year. The average temperature in Colombo is 28°C with a maximum of 31°C. The temperature drops down to an average of 22°C between November and March.
- Jakarta has a tropical monsoon climate, with just two distinct seasons; wet and dry. The wet season takes up the majority of the year, from October to May, with the dry season typically running from June to September. Temperature hover around 28-30°C round the year and rarely falls below 25°C.
- The weather in Bangkok is dominated by a tropical monsoon climate with three distinguishable seasons; hot season from March to June, rainy season from July to October and cool season between November and February. Daytime temperature goes up above 30°C.
- Singapore lies just north of Equator. Singapore has a tropical climate and stays hot and humid throughout the year. Average temperature is around 31°C.

Landsat 8 images for the month of January for all the six cities for the year 2014 were collected from USGS. Since, Singapore and Jakarta are lying close to the Inter Tropical Convergence Zone (ITCZ), only a few images were found cloud free round the year. For Singapore, the only image found cloud free was that of 24-06-2013 and for Jakarta it was for 13-09-2014. Hence these images were used. Temperature maps were prepared for all the six cities as per the method mentioned in Section 4.3.1. Land cover maps were prepared using unsupervised classification technique. Temperature scenario of the urban region is compared with the temperature of rural area of the same image and its mean temperature was determined using zonal statistics in ArcGIS.

4.4. Results and Discussion

4.4.1. Temporal Variation in LST

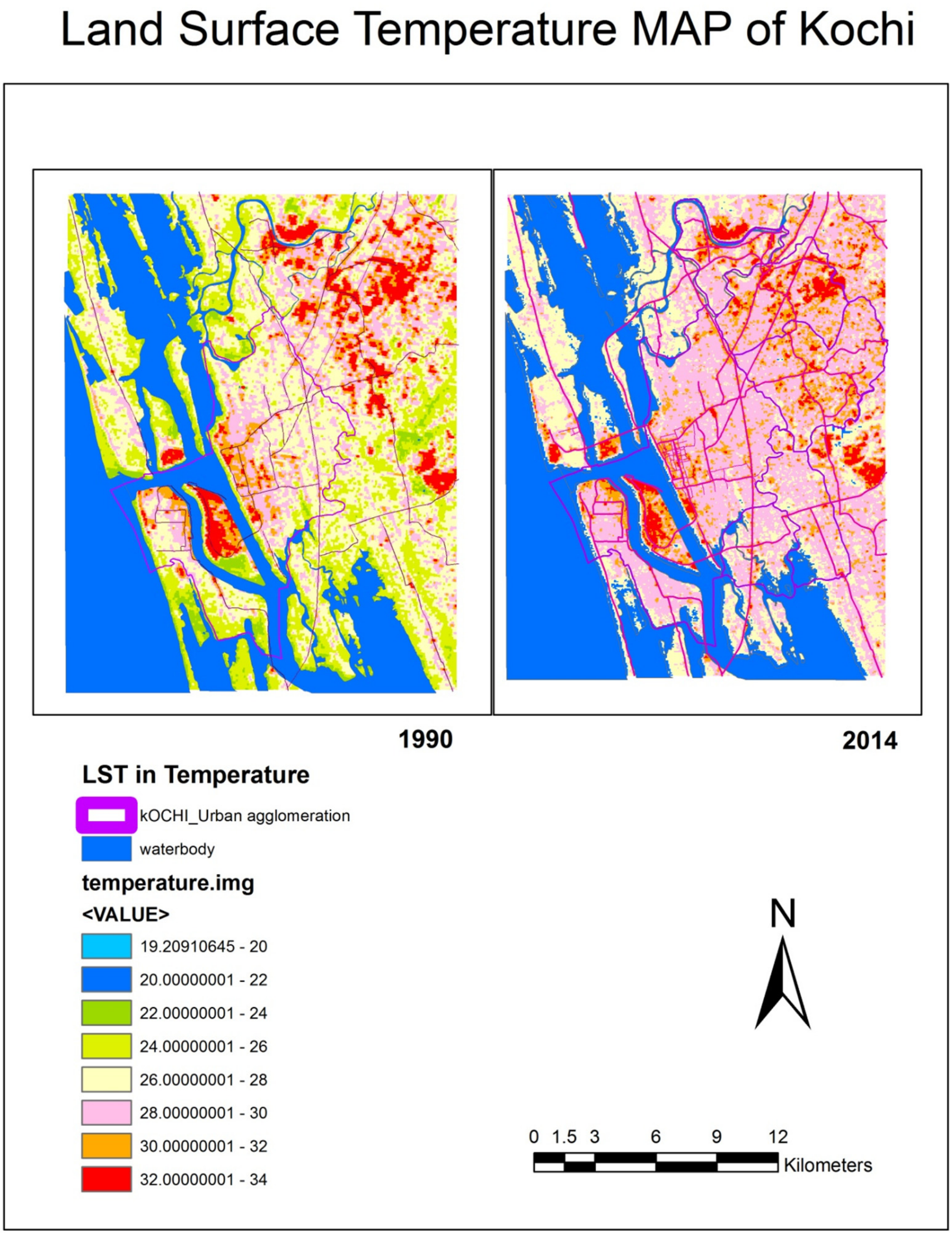
On the basis of the analyses, it is seen that the mean LST of Kochi has shown a significant increase between 1990 and 2014 (Map. 4.1). The comparison of all LST scenarios suggests that the transformation of the land cover to the built-up do bear its signature in the accumulation of the heat. This in time has already contributed to the formation of the heat island. It is also observed that the vegetation and water body patches are having relatively low temperature, which acts as heat sinks. It reveals that the land use change has high impact on the temperature regime of the area.

4.4.1.1. Land Surface Temperature in 1990

During 1990, Kochi is having a total built-up area of 53.74 km^2, far less compared to 2014 (154.63 km^2). Most of the land area is having a LST in the range of 26-28°C. Wellington island is showing a comparatively higher temperature, despite the presence of the tree cover and proximity to sea (Fig. 3.4). This is due to the presence of wharfs and godowns mostly roofed by materials of higher emissivity like asbestos or corrugated metal sheets. Similarly a few north-eastern regions of the study area show elevated temperatures partly due to the presence of such highly absorbent roofing materials and partly due to the existing geography, since these areas are covered by exposed laterite outcroppings in an undulating terrain without treecover. The low built-up areas such as Vypin and Edakochi are showing lower temperatures, even though they are geographically close to the city. Also it can be seen that the industrial areas such as Eloor and Ambalamukal are showing extreme temperatures (34°C). The highly urbanized areas near to M.G. Road, Marine Drive, Ernakulam South, Pulleppady, Mattancherry, Fort Kochi etc are showing comparatively higher temperatures than the surrounding rural areas.

4.4.1.2. Land Surface Temperature in 2014

In 2014, most of the Kochi mainland is having an average temperature 28°C to 30°C. A comparatively lower temperature in the range of 26°C-28°C can be seen in Vypin, Vallarpadam, Edakochi and Panangad all with low-built up areas (Map 4.1.). An interesting observation is that there is an elevation in temperature in the periphery of roads due to the high absorption and emission of asphalt. Peak temperatures are seen in industrial areas of Eloor and Ambalamukal, and in the northern side of Wellington Island. High temperature in northern Wellington Island is due to the presence of asbestos roof tops, unlike the southern side where there is a good tree cover, and is having normal temperature. Interestingly, in the north eastern region of the mainland LST during 2014 is found to be less compared to the LST in 1990. This is because the urban expansion has replaced the exposed laterite hillocks in that area.



Map.4.1. Land Surface Temperature map with roads shown – A comparison of 1990 and 2014 scenario.

In 1990, the mean urban temperature was 2.08°C higher than the rural temperature. Whereas by 2014, this difference increased to 2.61°C. Comparing the mean urban temperature of 1990 and 2014, there is a considerable increase of 2.65°C (Table 4.3). The mean rural temperature also has increased by 2.12°C between 1990 and 2014. As per the reports published by Oak Ridge National University and Cochin University of Science and Technology in 2003 a mean annual (atmospheric) temperature increase of 1°C is reported and an another 1°C raise is expected if the temperature continue to rise for another 50 years. But the present study shows an increase of around 2°C in Land Surface Temperature. From both these studies it can be approximated that the temperature of Kochi as well as surrounding regions are increasing. In the previous study it is stated that this temperature difference is due to its geographical location, having proximity to sea. Meanwhile, forecasts of global climate change (IPCC, 2001a) show expectations of an increase in global average surface temperatures of 1.4–5.8°C by 2100, with median projections in the range of an increase in the range of 3°C. Locations nearer to the equator and nearer to the oceans are expected to have temperature increases, less than the global average, which suggests that effects of this global change on Kochi would be below the average. If, however, an increase of 1 to 2°C as a result of climate change is added to rising temperature trends detected even in the absence of climate change, Kochi could be warmer by 2050 than at present by several degree Centigrade. This expectation is in line with forecasts from other sources of temperature changes in Kerala from climate change (e.g., Lal, 2002). From the present study it can be seen that there is already an increase of 0.53°C in urban and rural temperature difference while comparing the scenario of 1990 and 2014. This indicates that apart from the temperature rise due to geographical factors, there is a rise of 0.53°C due to urbanization. The reason behind this difference is that the temperature is increasing in urban areas due to presence of building materials having high emissivity.

Table 4.3. Statistical comparison of rural and urban temperature in 1990 and 2014.

Mean Land Surface Temperature of Kochi			
Zone	**1990**	**2014**	**Temperature difference**
Urban	27.75	30.4	2.65
Rural	25.67	27.79	2.12
Difference	2.08	2.61	

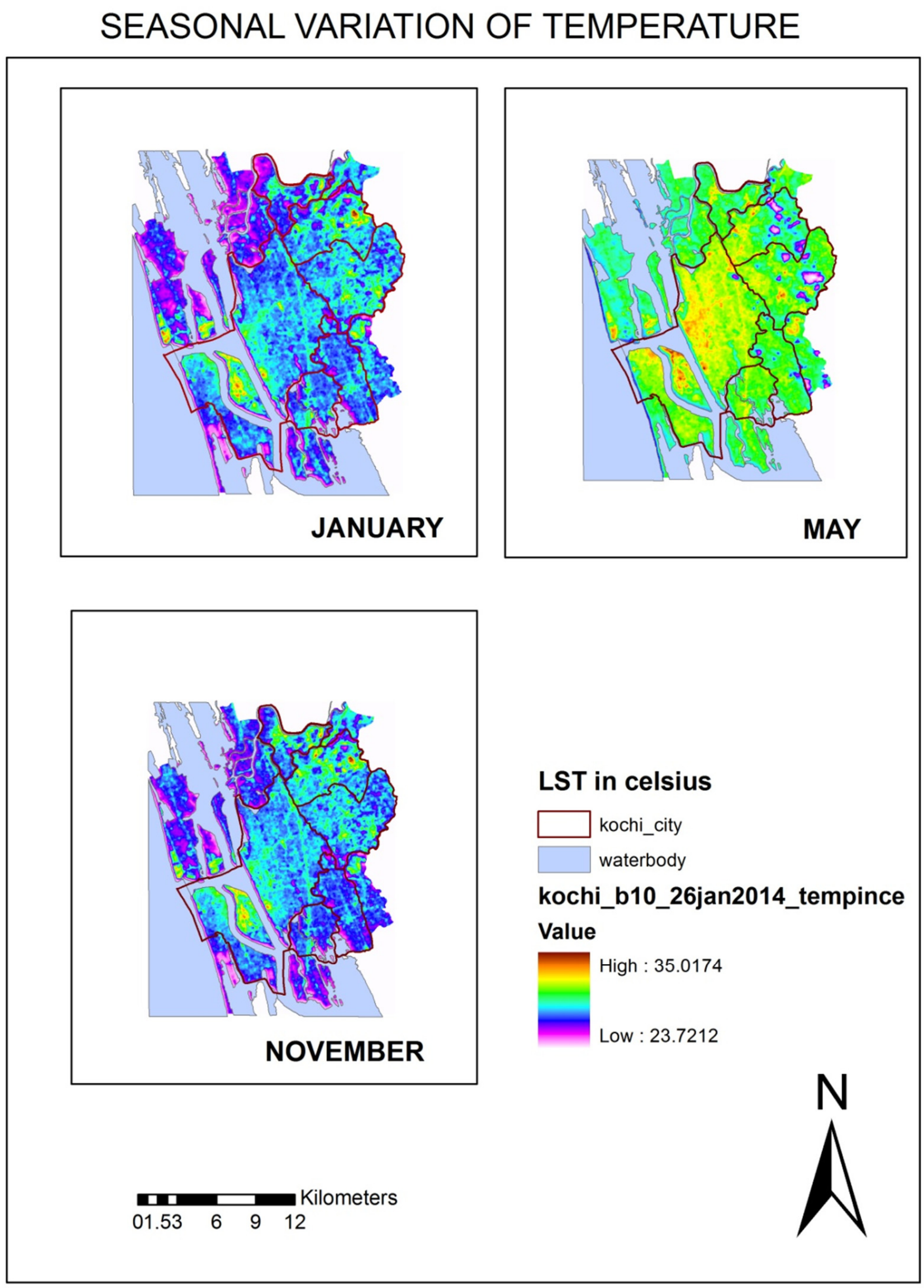
The mean LST as per the image statistics in 1990 is 26.71°C and in 2014 is 29°C. During 1990, most of the area in Kochi is having an LST of 26°C to 28°C. But in 2014 the average temperature has risen from 28°C to 30°C. Right from 1990, the formation of a distinct UHI is seen in the central city location and industrial areas, which has spread considerably by 2014 as the heavily urbanised areas expanded its footprint to cater to the social, economic, industrial and commercial needs.

While vegetation reduces surface temperatures, thereby producing a cooling effect in the urban microclimate, concrete built-up areas add to the existing high temperatures. This calls forth for the requirement of a diligently planned growth of vegetation, intermixed with the concrete structures and paved roads can pay a significant part in ameliorating the formation of heat islands within the urban areas. Most field studies support the argument that a lack of vegetation in the city would tend to result in elevated daytime air temperature, and concomitantly, a large-scale tree planting may lead to a reduction of the daytime urban heat island (Erell et al., 2011). Apart from enhancing beauty and greenery, the natural vegetation and tree cover have a significant function of maintaining the ecological balance as well as air quality. The natural process of evapotranspiration enables a cooling effect on the surroundings. A proper eco-friendly urban settlement design is the need of quickly developing new built up areas. Trees impact hydrology by allowing the percolation of water to the ground and thereby increasing ground water recharge.

Public parks and vegetation groves serves as the lungs of the city. The urban tree canopy removes carbon monoxide, sulphur dioxide, nitrogen dioxide, ozone, particulates and other pollutants that degrade the quality of air. Trees absorb these gaseous pollutants via their leaf stomata (the tiny pores on leaves) and break them down into less-harmful molecules during photosynthesis. Though scattered individual trees can absorb pollutants, urban forests provide the greatest advantage. “Parks with higher proportions of their area covered by healthy trees will provide the greatest impacts (Roddy Sheer, 2001). AlsoTrees can muffle noise. Planting "noise buffers" composed of trees and shrubs can reduce noise by 5 to 10 decibels for every 30 m width of woodland, especially sharp tones, and this reduces noise to the human ear by approximately 50% (Kotzen, B. 2004).

4.4.2. Seasonal Variation of LST

The seasonal variation of LST was studied using the Landsat Images for 2014, durin three seasons- January-February, April-May and October-November. June-July months were not considered as no cloud free images could be obtained. The result shows that, in May the temperature reaches up to about 34°C. In January and November, even the areas within urban boundary are having temperature in the range of 28°C to 29°C whereas in May, even the rural areas are having temperature above 30°C. Roads and urban areas are showing temperature above 32°C. In January and September the scenario is almost similar with a little variation.



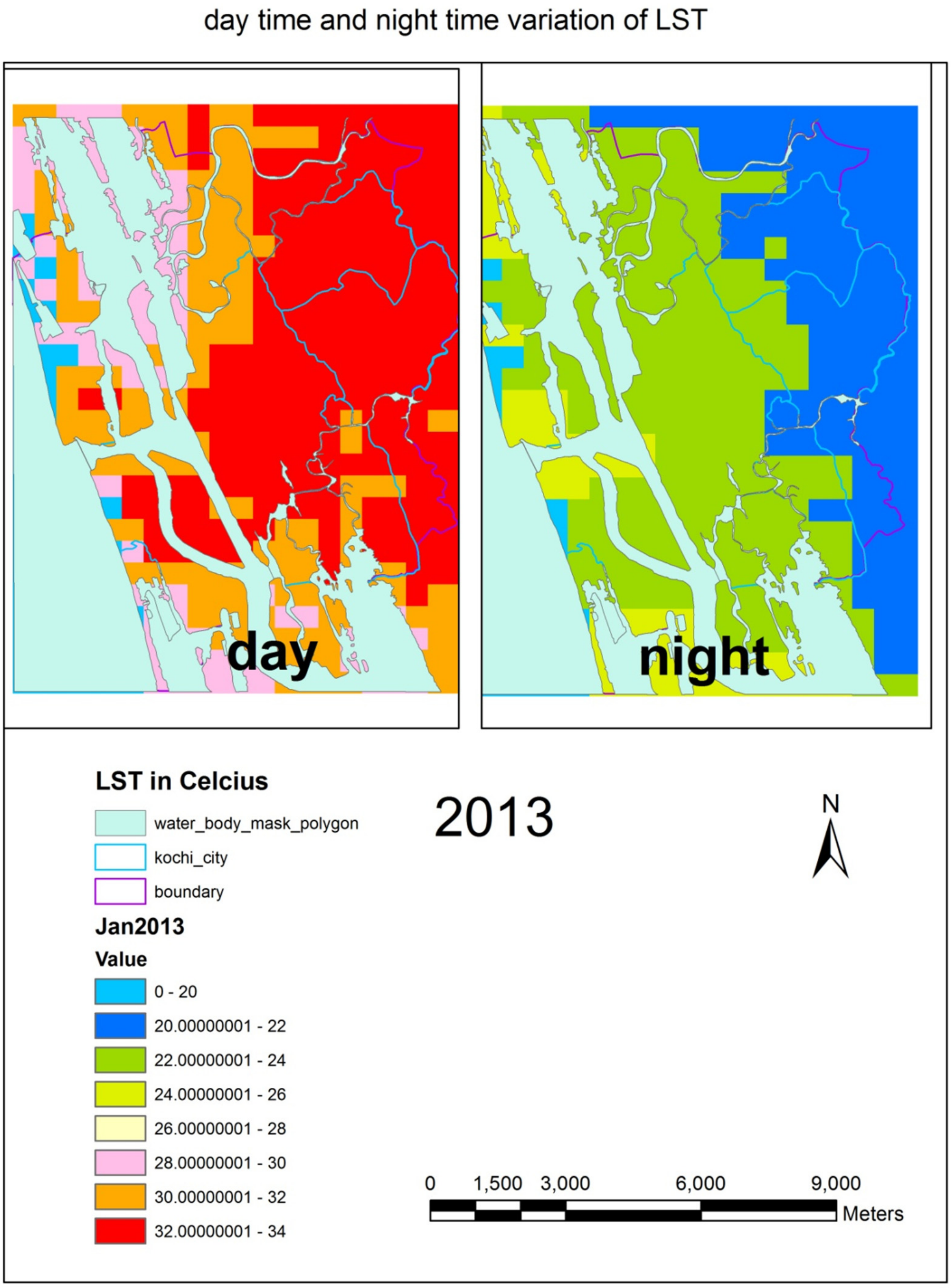
Map 4.2. Map showing seasonal variation of LST of Kochi.

Table 4.4. A Comparison of Mean LST of three different seasons

Month	Mean Urban Temperature	Mean Rural Temperature
January	29.9	27.6
May	32.3	29.6
November	27.7	24.6

4.4.3. Diurnal Variation of Land Surface Temperature

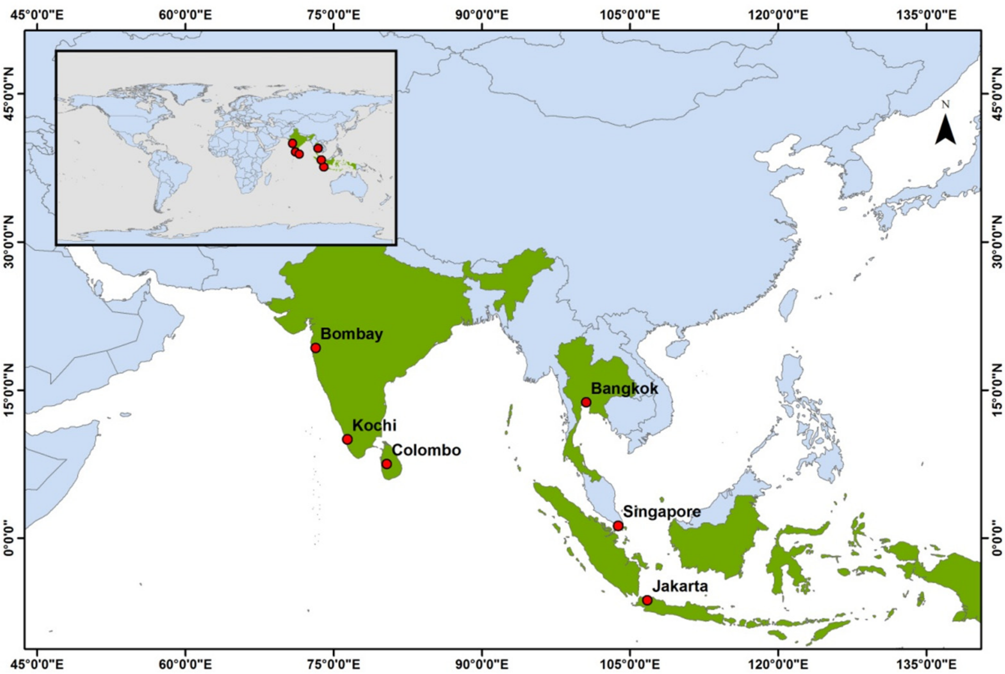
Even though the images for 2011, 2012, 2013 and 2014 were analysed only 2013 images were of good quality. The diurnal variation of temperature in 2013 was studied taking the day-time and night-time MODIS images of 15th January 2013. While analysing the daytime image, the central urban area and the north-eastern region are having elevated temperature (32°C to 34°C) and suburban regions shows a temperature in the range of 30°C to 32°C. The suburban regions of Vypin and Edakochi are having temperature between 28°C and 30°C. The highest night-time temperature is 24°C to 26°C, which is observed in most of the region within the mainland. The north-eastern region is having a low temperature, below 22°C. The night time temperature of the main land is between 22°C and 24°C. Mean day-time urban temperature observed for the scene is 33.6°C and mean rural temperature observed is 29.7°C. It was not possible to get any generalization about the diurnal variation in temperature, as the observations were of a single year.



Map 4.3. Diurnal variation of LST in 2013

4.4.4. Comparison of Land Surface Temperatures of Various coastal Asian Cities

It is interesting to study the Land cover change and the corresponding LST variations in all major cities over the globe. Studying all the cities is beyond the scope of this work; hence, we selected a few major coastal Asian cities. A brief description of the city, along with its land cover map and the corresponding LST scenario is given below. The limit of administrative boundary is taken as the frontier between urban and rural areas and it is shown in the Land Cover maps. An exception is there in the case of Singapore. It is a small island nation and there is no distinct urban-rural divide. Hence the central water catchment and the western water catchment, the areas having little anthrapogenic intervention is taken as rural area. A location map showing the relative position of all the cities selected is shown in Map 4.4.

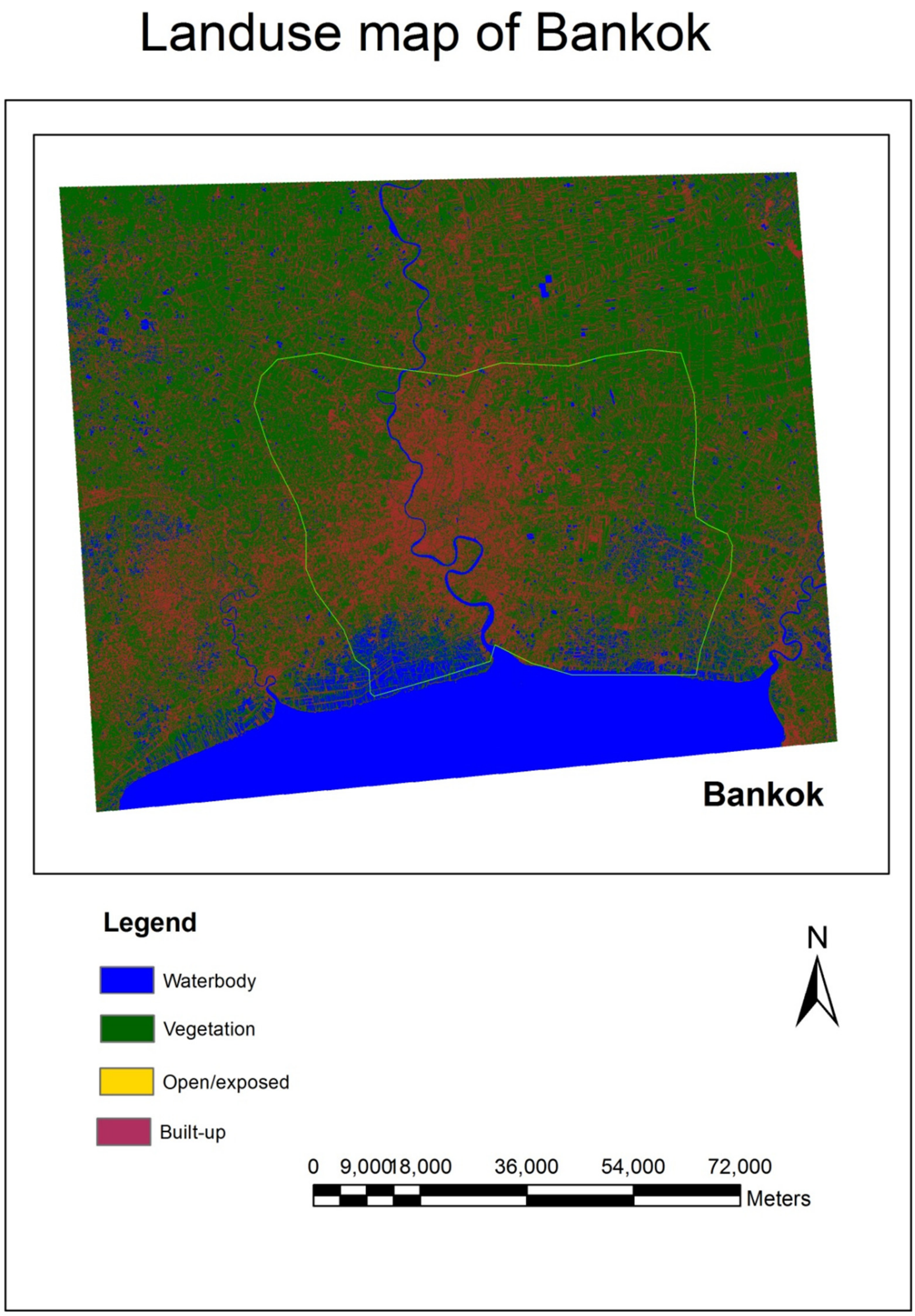


Map 4.4. Location map of the cities selected

4.4.4.1.Bangkok

4.4.4.1.1. A Brief Profile of the City

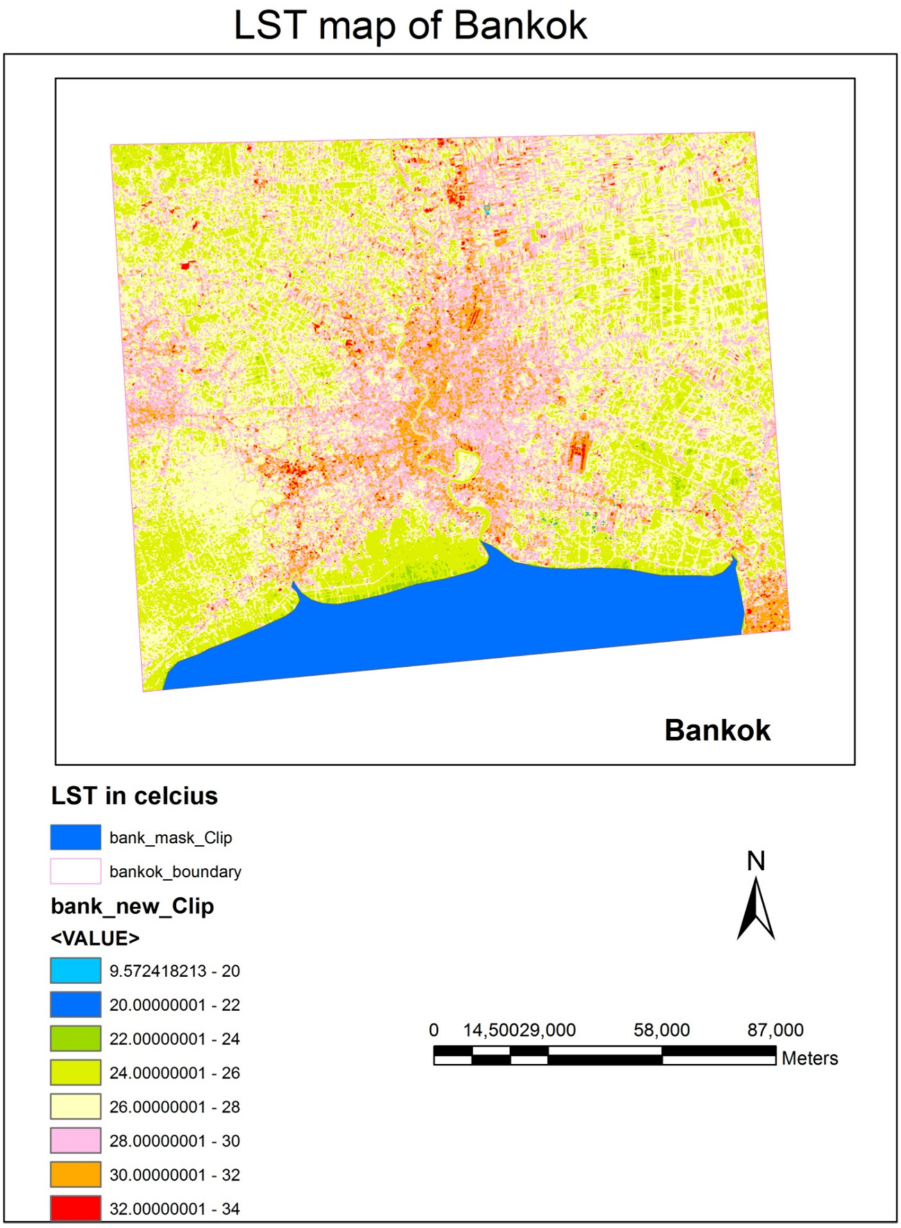
Bangkok is the most populous city of Thailand, its capital. The city occupies 1568.7 km^2 in the Chao Phraya River delta, and has a population over 8 million. The central city region is the area surrounding the Chao Phraya River. The geology of the Bangkok area is characterised by a top layer of soft marine clay known as Bangkok clay, averaging 15 meters. The area is flat and low-lying, with an average elevation of 1.5 meters above sea level. There are fears that the city may be submerged by 2030 due to sea level rise as well as subsidence. Subsidence has already resulted in increased flood risks, as Bangkok has always been prone to flooding due to its low elevation and inadequate drainage infrastructure. Rapid urbanization has added to the existing woes. The city now relies on flood barriers and augmenting the drainage canals by pumping and building drain tunnels. Still, parts of Bangkok and its suburbs are regularly inundated by flooding. Heavy downpours result in urban runoff overwhelming the drainage systems supplemented by the heavy runoff discharge from upstream areas. The rapid urbanization in Bangkok led to several environmental problems such as air and water pollution, land subsidence as well as the problems derived by urban heat island such as temperature rise, high energy consumption and biophysical hazards.



Map 4.5. Landuse map of Bankok

4.4.4.1.2. Heat Island Phenomenon in Bangkok

Boonjawat et al (1998) first reported the presence of a heat island in Bangkok. Numerous studies are reported on the heat island effect on Bangkok as well as other major cities of Thailand.



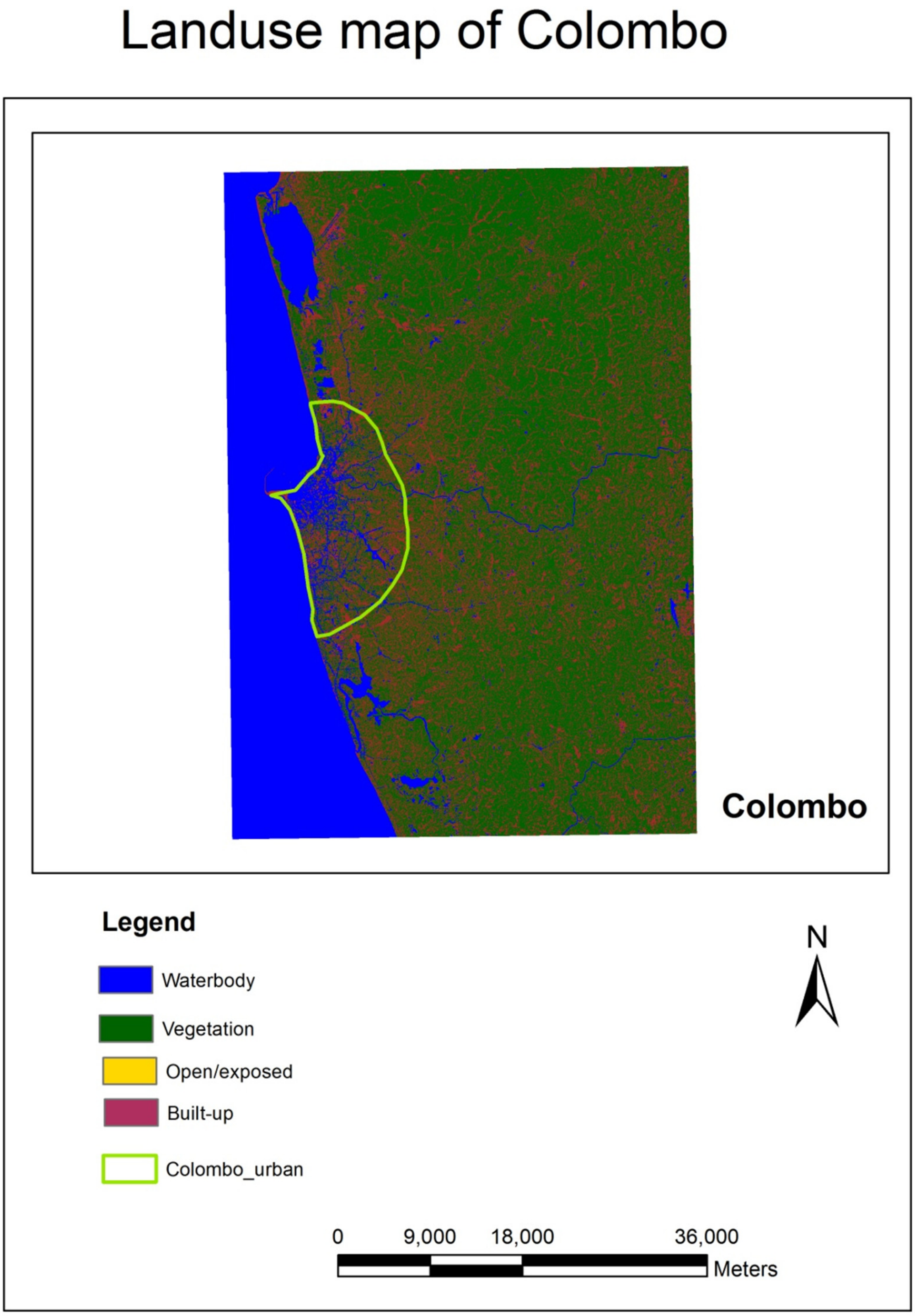
Map 4.6. LST Map of Bankok

From the above-given Land use and LST maps (Figs 4.5. & 4.6), it can be seen that Bangkok is severely affected by the rigors of heat island effect. The mean urban temperature is 28.84°C, while the rural temperature is 27.16°C, showing a difference of 1.675°C between them. The temperature is quiet high over the high built-up area and low over the rural areas. The Central City region is having a temperature in the range of 28°C to 32°C whereas the low built-up areas are only in the range of 22°C to 26°C. In 2012, the maximum temperature difference between urban and rural areas of Bangkok was 7°C, which is the highest in the last 10 years (Arifwidodo and Tanaka, 2015). LST distribution corresponded relatively well to different land use types, which can be seen by comparing land use with temperature maps (Map 5,6).

4.4.4.2. Colombo:

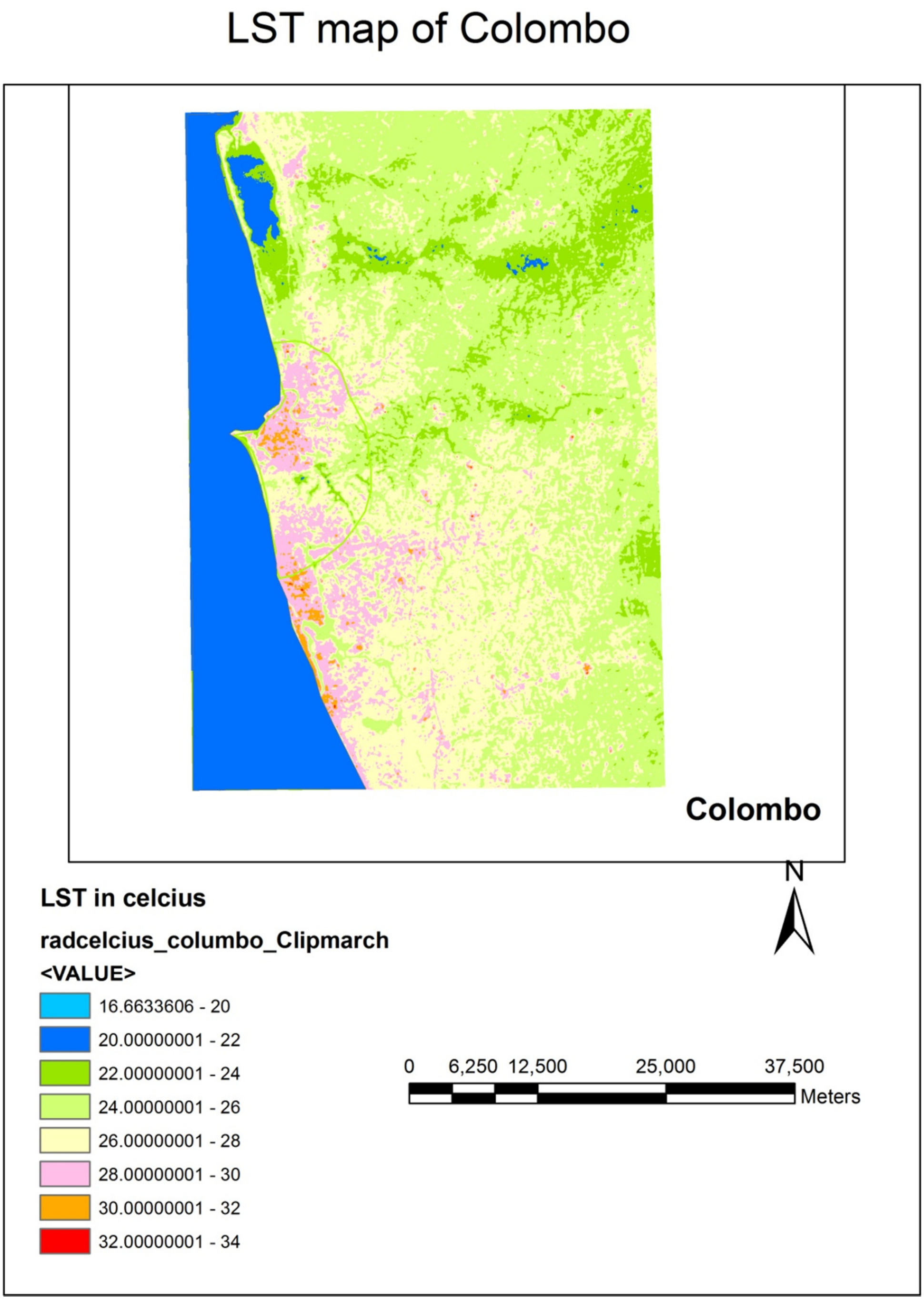
4.4.4.2.1. A brief profile

Colombo is the commercial capital and largest city of Sri Lanka and spans over an area of 698 km^2. The northern and north eastern border of the city of Colombo is formed by the Keleni River. Colombo is a low-lying land intertwined by several canals with the Beira Lake in the centre. The climate is fairly temperate throughout the year. From March to April, the temperature averages around 31°C maximum, with little diurnal variation. During monsoon seasons, from May to August and October to January, the city suffers from heavy down pour. Mean annual rainfall is 2400 mm.



Map 4.7. Land use map of Colombo

4.4.4.2.2. Heat Island Phenomenon in Colombo



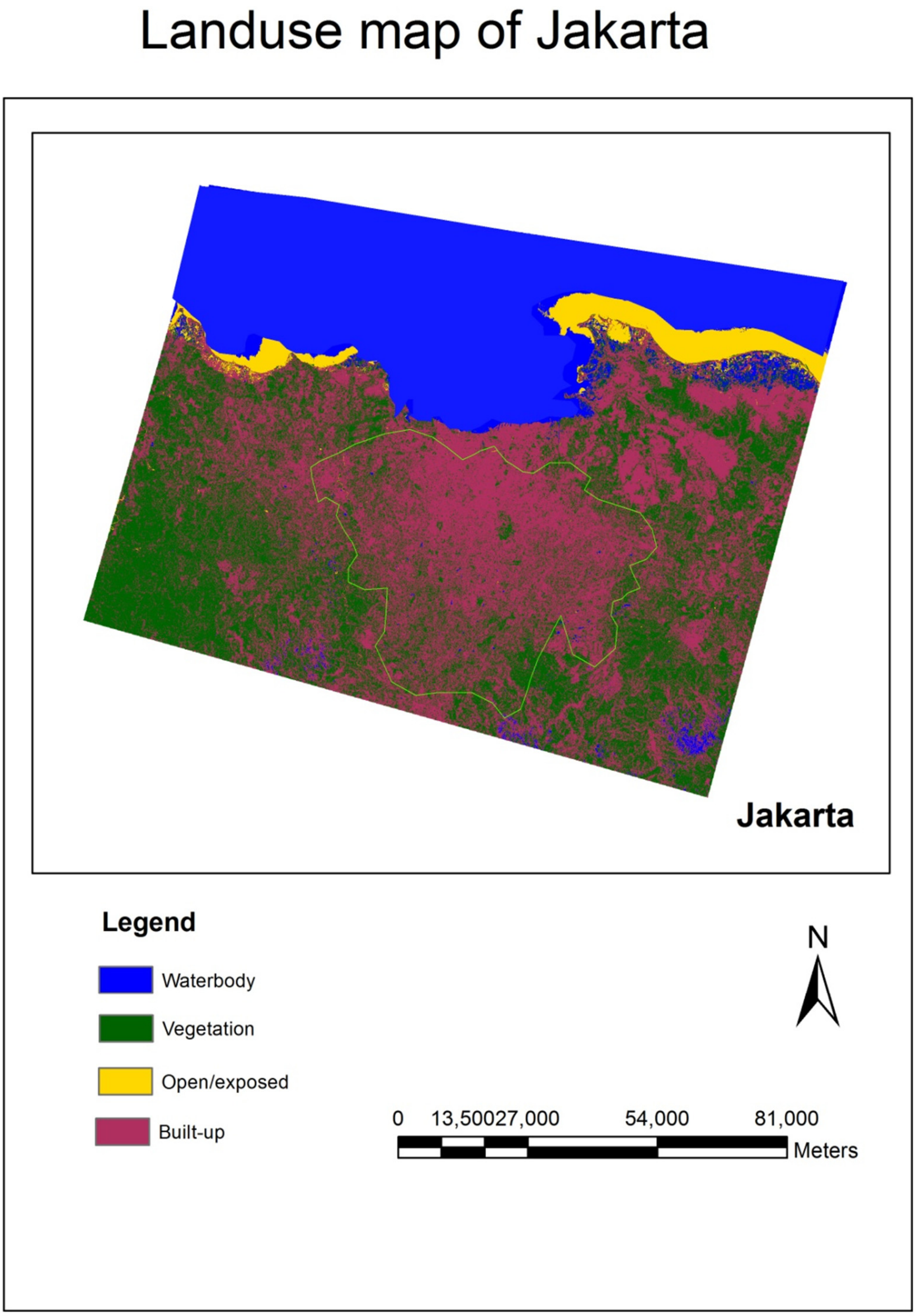
Map 4.8. LST map of Colombo

The land cover map prepared by unsupervised classification shows that Colombo is having a high building density. The mean urban temperature is 29.79°C and that of the rural areas with 26.37°C, with a difference of 3.42°C. The temperature in the main urban agglomeration is in the range of 28-30°C, with a few hotter areas with a temperature around 32°C, while the areas with low building density are only in the range of 26-28°C. Not much studies are reported on the heat island phenomenon of Colombo.

4.4.4.3. Jakarta

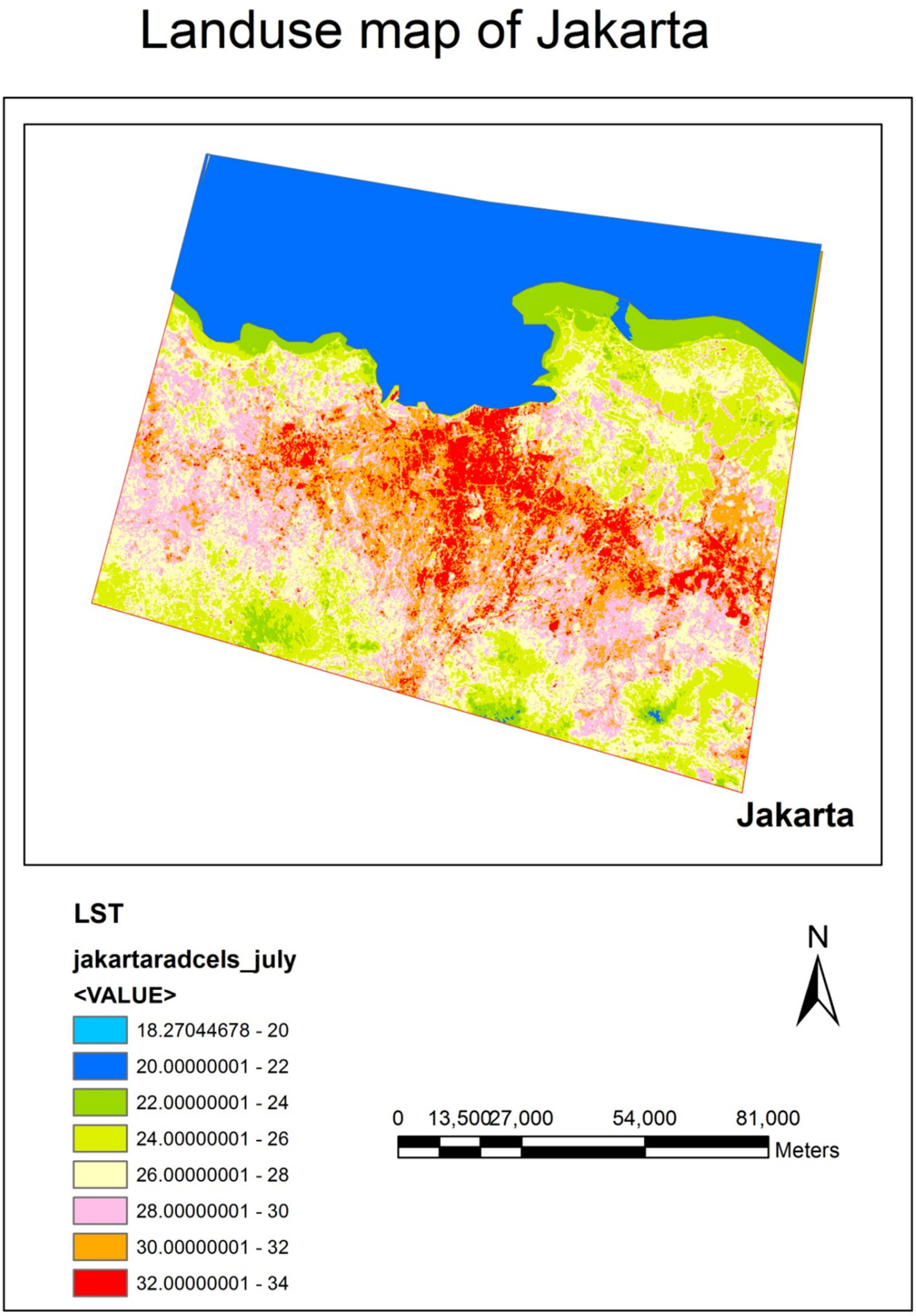
4.4.4.3.1. City Profile:

Jakarta, the capital and the largest city of Indonesia is located on the northwest coast of Java, at the mouth of the Ciliwung River on Jakarta Bay, which is an inlet of the Java Sea is officially known as the 'Special Capital Region of Jakarta'. The official metropolitan area comprises of Jakarta, Bogor, Derpok, Tangerang and Bekasi. The area of Jakarta special capital region is 662 km^2. Jakarta lies in a low, flat basin with an average elevation of 8 meters MSL and 40% of Jakarta, particularly the northern areas, is below sea level, while the southern parts are comparatively hilly. Rivers flow from the Puncak highlands to the south of the city, across the city northwards to the Java Sea; the most important is the Ciliwung River, which divides the city into the western and eastern principalities. Other rivers include the Sunter, and Pesanggrahan. All these rivers, combined with the wet season rains and insufficient drainage, make Jakarta prone to frequent flooding. Jakarta currently pumps an estimated 180–250 million m^3 of groundwater per day. This extraction of deep groundwater under has accelerated the compaction of overlying clays. As a result, Jakarta is sinking about 5 to 10 cm each year, even up to 20 cm in the northern coastal areas (Schmidth, 2015).



Map 4.9. Landuse map of Jakartha

4.4.4.3.2. Heat Island Phenomenon in Jakartha



Map 4.10. LST map of Jakartha

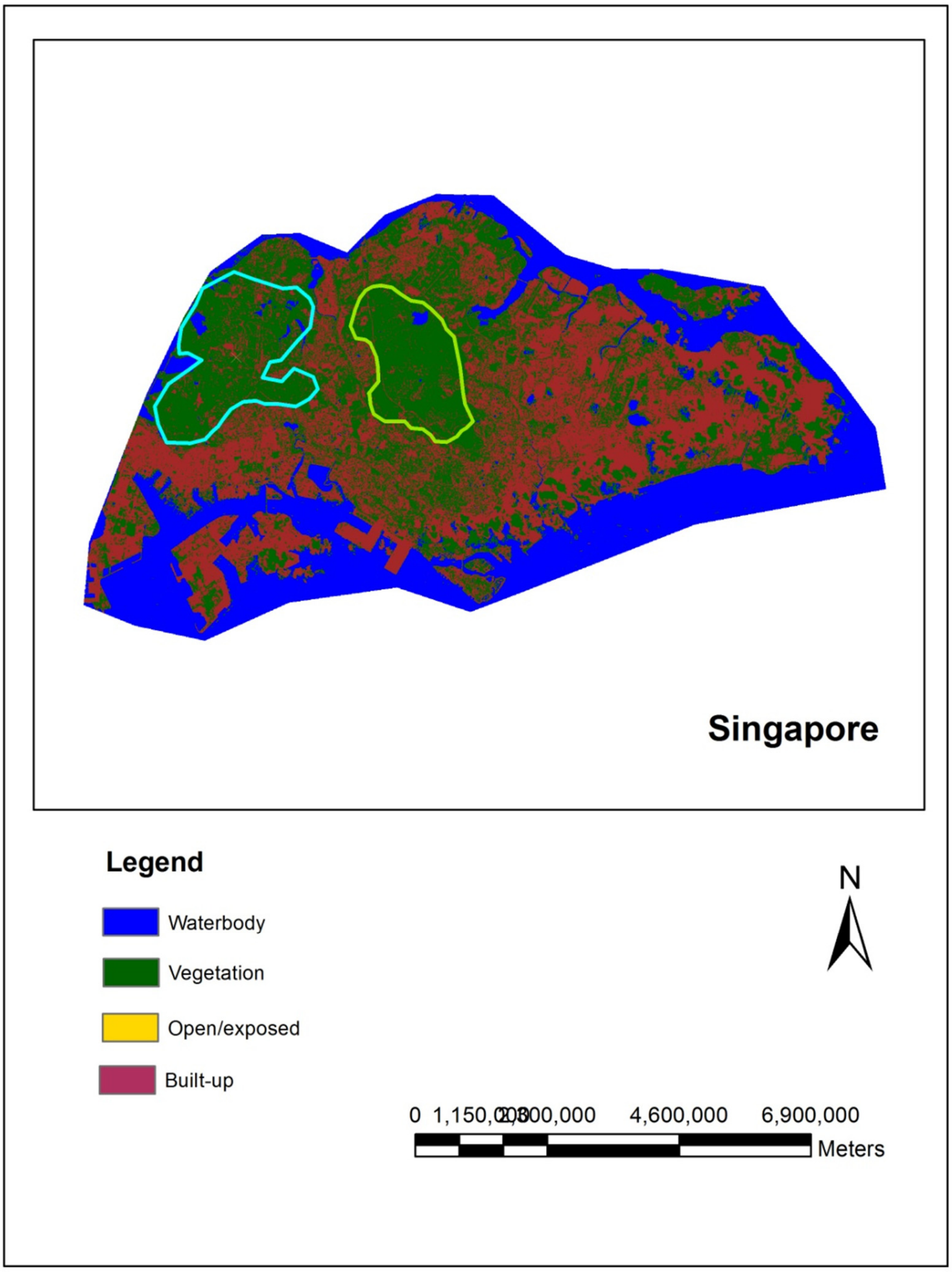
The mean urban LST of Jakarta is 33.39°C and that of rural areas is 26.96°C, which is a difference of 6.43°C. The temperature of main urban agglomeration is more than 30°C whereas in the suburban regions, it is in the range of 26 to 30°C. Rural areas are having temperature less than 26°C.

4.4.4.4. Singapore:

4.4.4.4.1. A Brief Profile of the City

Singapore, a tiny city state lying just one degree north of the equator, at the southernmost tip of Asian continent is officially the 'Republic of Singapore'. It's territory consists of the diamond shaped main land, Pulou Ujong or Singapore island and 62 small islands. Only the mainland is being considered in this study. The city's greening policy has covered the densely populated island with tropical flora, parks and gardens. Nearly 10% of Singapore's land area has been set aside for parks and nature reserves. The network of nature reserves, parks, and tree lined roads and other natural areas have enhanced the sense of green space in the city. This is a result of 50 years of persistent greening efforts, and deligent town planning strategies which began in 1963. The aim was to soften the harshness of urbanization and improve the quality of life. The initiative continued into the 1970's and 1980's under the parks and recreation department, renamed as the National Parks Board in July 1996. Due to these efforts, Singapore was ranked fourth in the 2014 Environmental Performance Index which measures the effectiveness of state policies for Environmental Sustainability.

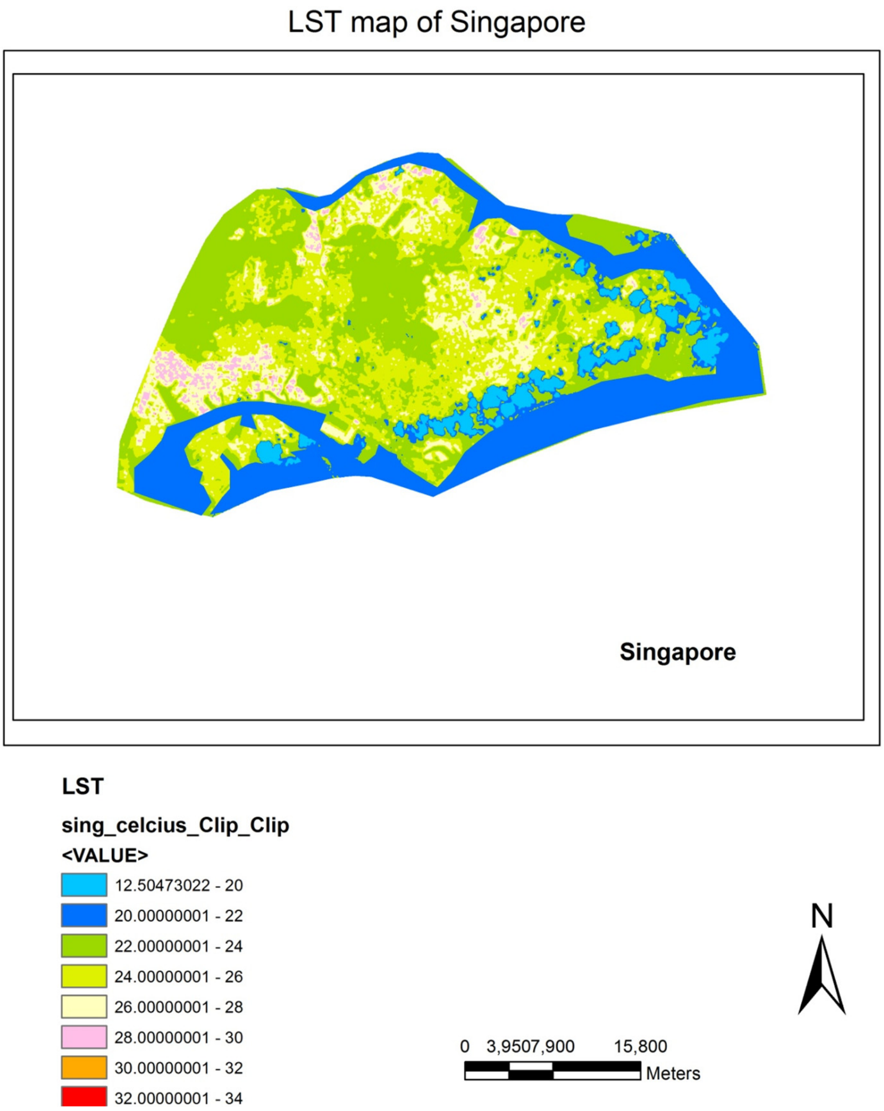
Landuse map of Singapore



Map 4.11. Landuse map of Singapore

Land cover map of Singapore shows the presence of green vegetation within the city. Bukit Timah Nature Reserve, Labrador Nature Reserve and Sungie Buloh Wetland Reserve are situated in close proximity to the city. Apart from this a good number of Nature parks, coastal parks and community parks are situated within the city.

4.4.4.4.2. Heat Island Phenomenon of Singapore



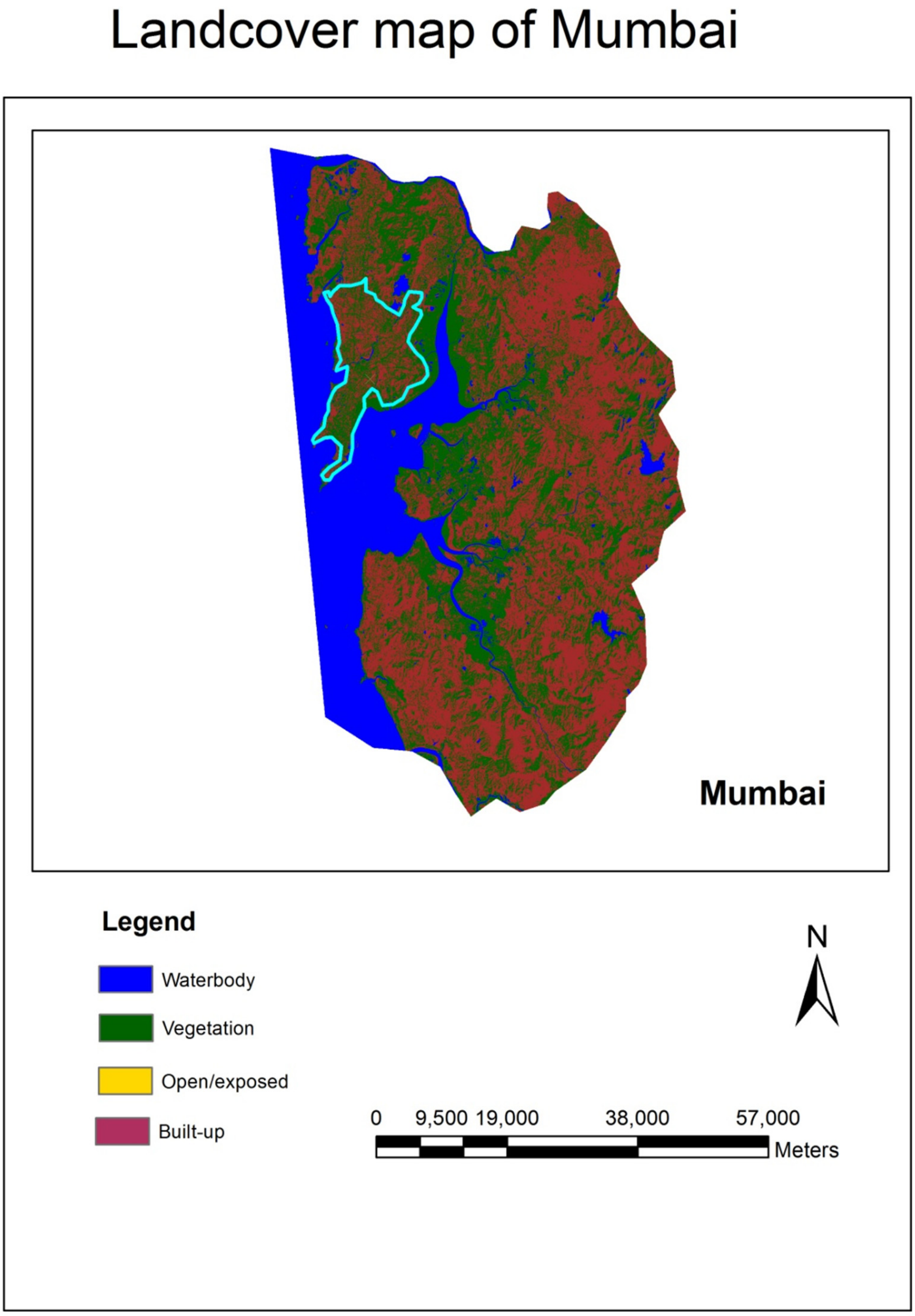
Map 4.12. LST map of Singapore

The mean urban temperature of Singapore is 27.47°C and the mean rural temperature is 22.87°C. The difference between urban and rural temperature is 4.6°C. The temperature of main urban agglomeration is 28°C to 30°C Most of the region are having temperature in the range of 24°C to 28°C. No area is having temperature greater than 30°C. Even though heat island is visible, the magnitude and extend of heat island is quiet low.

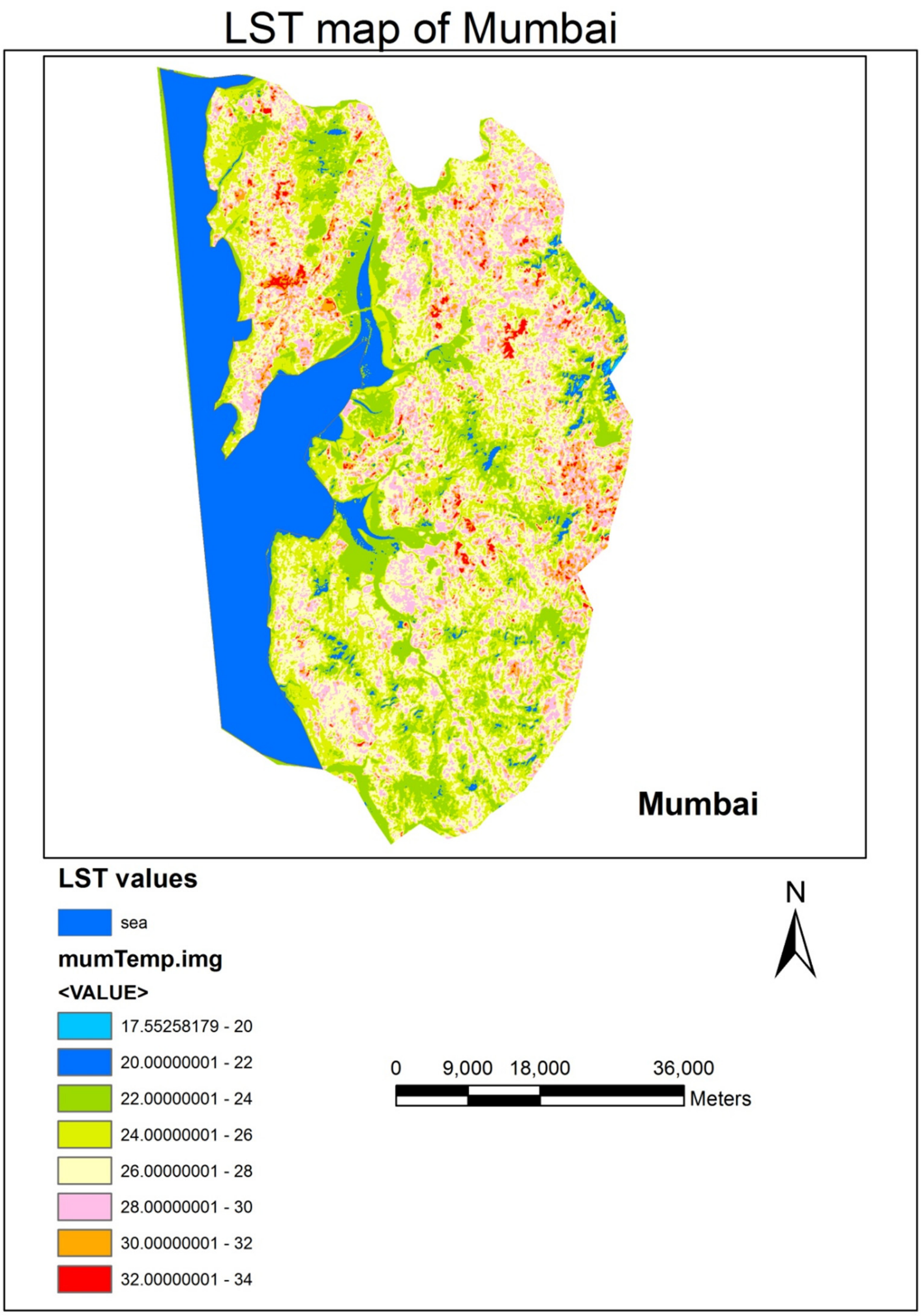
4.4.4.5. Mumbai

4.4.4.5.1. A brief Profile of the City

Mumbai is the capital city of the Indian state of Maharashtra, which is the most populous city in India. Mumbai lies at the mouth of the Ulhas river on the Western Coast of India. Many parts of the city lie just above the mean sea level, with elevations ranging from 10 to 15 m. Northern Mumbai is a hilly region. The coastline of the city is indented with numerous creeks and bays, stretching from the Thane creek on the east to Madh marve on the west. Seasonal flooding is a major environmental problem faced by Mumbai. In July 2005, severe flooding paralysed the city for several clays and resulted in hundreds of deaths.



Map 4.13. Landuse map of Mumbai



Map 4.14. LST map of Mumbai

4.4.4.5.2 Heat island phenomenon of Mumbai

The mean urban temperature of Mumbai is 29.39°C and rural temperature is 24.03°C. There is a difference of 5.36°C between mean urban and rural temperatures. The city and the surrounding urban areas are growing at a faster rate, that the urban-rural divide is quiet low. The temperature of urban areas is in the range of 26°C to 30°C with a few areas having temperature greater than 32°C. The vegetated areas are having temperatures in the range of 24°C to 28°C.

A comparison of all the cities studied and their comparative LST scenario are given in Table 4.5.

Table 4.5 Comparison of mean LST scenario of all selected cities.

City	Area (km^2)	Population Density per Km^2	Mean elevation	Mean LST		Urban-Rural Difference
				Urban	Rural	
Bangkok	1,568.737	5300	1.5 m	28.84	27.165	1.675
Singapore	719	7987	15m	24.27	22.67	1.6
Jakarta	661.5	10500	8 m	31.5	29.6	1.9
Mumbai	603	21000	14	26.05	23.92	2.13
Kochi	94.88	6340	1m	30.4	27.79	2.61
Colombo	37.31	3438	1 m	26.79	24.33	2.46

From the above table it is seen that Mean urban LST is also lowest in Singapore. Urban and rural temperature difference is the lowest in Singapore and the highest in Kochi. While comparing the population density, Kochi and Singapore are having comparable scenario. But while coming to the environmental aspect, both the cities are entirely different. Singapore records the lowest urban LST, while Kochi records the highest, next to Jakarta. This is due to the difference in urban management. Singapore took deliberate steps to keep up the greenness within the city. They maintain a proportion between the built-up and urban greenary. Also they use eco-friendly strategies for urban management like green roofs and pervious pavements. Kochi is hovered by indiscriminate and uncontrolled development and its impact reflects in the climate and environment. If the situation persists, Kochi will no longer be a better place to dwell.

4.5. Conclusion

Surface temperature could be directly derived from remotely sensed data, which provides a powerful way in monitoring urban environment and human activities. This study highlights that a planned growth of vegetation, intermixed with the concrete structures, can significantly control the formation of heat islands within the urban areas as well as reducing the carbon and energy footprints. A proper eco-friendly urban settlement design is the need of quickly developing new built up areas for a sustainable development. The prevalence of heat island is not always necessarily be associated with every cities identified in the developing countries, but the continuous monitoring of the variation in the land surface temperature may give us the probable zone of UHI at the early stage of MUHI (Micro Urban Heat Island) which may lead to formulating appropriate environmental management strategies.

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Chapter

5

IMPACTS OF IMPERVIOUS SURFACES ON SURFACE WATER HYDROLOGY

Contents

5.1. Introduction

Across the globe, human populations are becoming increasingly urban, with approximately 50% of the world's population now living in urban areas (Cohan, 2003). By 2030 this percentage will rise to more than 60% (UN population division, 2007). Urban development is associated with the construction of building facilities and infrastructure to inhabit enlarging future population, leading to higher levels of impervious land cover. Grim et al. (2008) noted that imperviousness is among the most important land cover modifications affecting stream conditions in urban areas. Land cover modifications alter the watershed hydrology and affect both surface and sub-surface water bodies.

The impacts on water bodies include increased stress on stream hydrology, channel morphology, water quality and stream ecology imposed by changes in storm water quality and quantity, and changes in the eco-hydrological diversity of watersheds. Further impacts include reduced infiltration, increased surface runoff, and higher peak discharge in streams, shorter travel time and more severe pollutant loads influencing both surface water quantity and quality. Land cover modifications have a powerful effect on runoff response. As a watershed changes from forested state to 10-20% impervious surfaces, runoff increases 2-fold, 35-50% impervious cover increases runoff 3-fold and 75 to 100% increases surface runoff more than 5-fold over forested catchments (Arnold and Gibbons, 1996).

5.1.1. Hydrologic Impacts of Impervious Cover

Increased impervious cover generally results in more storm water runoff and less ground water recharge. The shift away from infiltration reduces ground water recharge lowering water tables. This threatens water supplies and reduces the ground water contribution to stream flow, which can result in intermittent or dry stream beds during the flow periods. More runoff, in turn, increases stream flows during storm periods. Stream banks erode, more sediment is carried into the streams from surrounding lands, and aquatic habitats are disrupted and degraded. Less recharge means less ground water discharges, known as base flow to streams during dry periods. High levels of impervious cover are associated with dense development, which sends greater pollutant loads to runoff flow channels.

The rain water, after interception reaches the ground and a part of it, which infiltrates into the soil, is available to recharge the groundwater storage. When a storm exceeds the infiltration capacity, water spills and flows down the slope as overland flow. When it reaches a stream channel, it is called as storm runoff or direct runoff. If this exceeds the capacity of the stream, there will be flooding. Man's activities may impact this process in two major ways, firstly urbanization reduces permeability, so that runoff increases as less water is infiltered into the ground. Runoff rates are also increased as depression storage is reduced and velocity increased due to smoother surfaces in artificial drainage conduits. The major difference between urban and rural areas from a hydrologist's point of view is the reduced infiltration potential of urban area and the fast response in generation of surface runoff.

The primary impacts of watershed development on watershed hydrology are as follows:

Increased runoff volume.

Increased peak discharge rates.

Increased magnitude, frequency and duration of bankfull flows.

Diminished base flow.

Johnson K. in 2004 summarised the impacts of impervious surfaces on hydrology as follows;

1. Increase in storm water run-off and flood frequencies.
2. Reduction in stream base flow and ground water recharge.
3. Increase in erosion and stream bank sloughing.
4. Decrease in water quality conditions.
5. Decrease in species diversity and riparian habitat.
6. Alteration to stream geometry.
7. Increase in ambient stream temperature.

The effect of urbanization on runoff is elevated in watersheds with sandy and gravel rich soils having high infiltration rates compared to watersheds predominantly of silts and clays having low infiltration rates. Urbanization can result in mixing or removal of native soil profiles or can result in landfill materials from other areas. Hence, any alteration in a soil profile can significantly change the infiltration characteristics leading to changes in runoff.

Benjamin in 1998 reported that many of the environmental problems of Cochin are hydrologic in origin because Kochi is a land lying close to the sea intertwined with a complex network of tidal canal system. Kochi is developing at a faster rate both in population and associated urban development. Also it is known that hydrologic cycle gets drastically modified during urbanization. Hence it is a point of importance to study the impacts of urbanization on the surface water hydrology of Kochi. Archana et al in 2015 studied the impact of temporal variation of Landuse on surface run-off of Kochi, taking corporation area alone. A significant finding in her study is the observation that there is approximately a 24% increase in the average runoff volume over last forty years and it emphasizes the need to study the problem in detail. The present study also focuses on runoff volume, extending to Kochi and surrounding urban agglomeration.

5.2. Data Used

Landsat images for the year 1990 and 2014.

5.3. Softwares Used

ArcGIS 10 and ArcGIS extension of SWAT (Soil and water assessment tool) namely ArcSwat are used in this study. SWAT is a river basin scale model developed to quantify the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The main components of SWAT include weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond & reservoir storage, crop growth & irrigation, groundwater flow, reach routing, nutrient & pesticide loading, and water transfer. ArcSwat is the ArcGIS extension of SWAT.

5.4. Methodology

Watershed delineation was done using Automatic watershed delineation tool in ArcGIS extension of SWAT. The watershed delineated was found to be more accurate with ArcSWAT (Vimal et al., 2012). Creation of Flow Direction Raster shows the direction of the steepest downslope neighbour for each cell by colour coded direction. Run-off calculations were done in ArcGIS.

5.4.1. Estimation of Surface Runoff using SCS-CN Method.

The Soil Conservation Service Curve Number (SCS-CN) method, (SCS, 1956), is an event-based and lumped rainfall run-off model. The assumption of SCS curve number is that, for a single storm event, potential maximum soil retention is equal to the ratio of direct run-off to available rainfall. To compute the run-off, the first step to be followed is to delineate and measure the drainage area tributary to the point of analysis. Next, the Curve Number (CN) is determined. Curve number is a dimensionless number which is a function of the ability of soils to allow infiltration of water, land use and the antecedent soil moisture condition. Soils of the study area were identified from the soil type map provided by the NBSS & LUP. Hydrologic soil groups (HSG) (Table 5.2) were assigned to the study area based on comparison of the soil texture with profiles of soils already placed into hydrologic soil Group. Each soil type is assigned a hydrologic soil group of A, B, C or D depending on its characteristics of infiltration potential.

Table 5.1. Table showing Hydrologic soil groups

HSG	Soil Textue
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay or clay.

In order to derive the CN, Antecedent Moisture Condition (AMC) should be determined. AMC refers to the water content present in the soil at a given time. Initial abstraction and infiltration for a particular rainfall event is governed by AMC. Three types of AMC (I, II and III) are recognized by SCS for consideration in all practical applications as given in Table 5.2.

Table 5.2. Antecedent Moisture Condition

AMC type	Total rainfall in previous 5 days	Actual surface condition
I	Less than 36 mm	Soil is apparently dry but not to the wilting point.
II	36 to 53 mm	Soil is moist but not saturated.
III	More than 53 mm	Saturated soil

In the present study, CN was calculated for the AMC condition II. The conversion of CN_{11} to other AMC conditions can be made through the following co-relation equation.

For AMC I, CN_{11} / (2.281-0.01281 CN_{11}) ------------------------ 1

For AMC III, CN_{11} / (0.427+0.00573 CN_{11}) --------------------- 2

The equation for surface runoff is given by

The potential maximum soil retention is calculated for each vector as

S=25400/CN-254 -- 3

The CN values may vary from 1 to 100. Higher values of CN indicate higher run-off. For different land uses, the value of curve number varies within the area. The details of curve number assigned to each hydrological group are given in table 5.3.

Table 5.3. Details of curve number assigned to each hydrological Soil Group

Land use class	Curve number assigned to each Hydrological Soil Group			
	A	B	C	D
Water body	100	100	100	100
Roofs, roads (built-up)	98	98	98	98
Vegetation	30	48	65	73
Open/ exposed	77	85	90	92

The assumption of SCS-CN method is that, for a single storm event, potential maximum soil retention is equal to the ratio of direct runoff to available rainfall.

$$Q=(P-I_a)^2 / (P-I_a+S) \text{--} 4$$

Where, Q is the accumulated runoff or rainfall excess in mm, P is the Rainfall depth in mm, I_a is the Initial abstraction in mm and S is the Potential maximum soil retention in mm. The potential maximum soil retention is equal to the ratio of direct run-off to available rainfall. Initial abstraction is the amount of water before runoff, such as infiltration or rainfall interception by vegetation, and it is generally assumed as

$$I_a = 0.2 \times S \text{--} 5$$

On substitution,

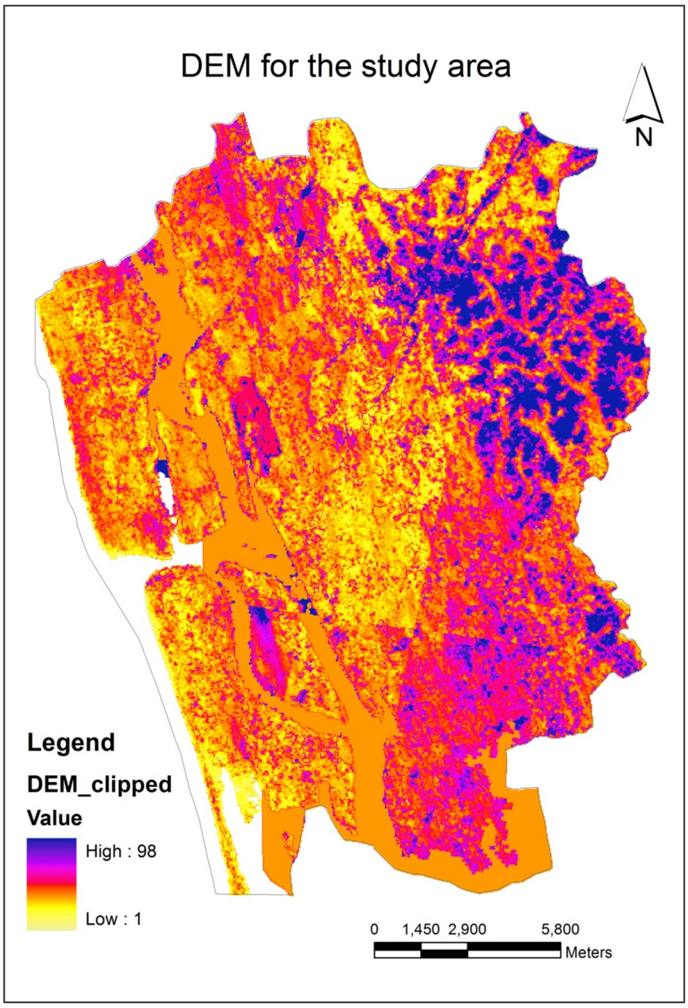
$$Q=(P-0.2S)^2 / (P-0.2S+S) \text{---} 6$$

$$Q=(P-0.2S)^2/(P+0.8S) \text{---} 7$$

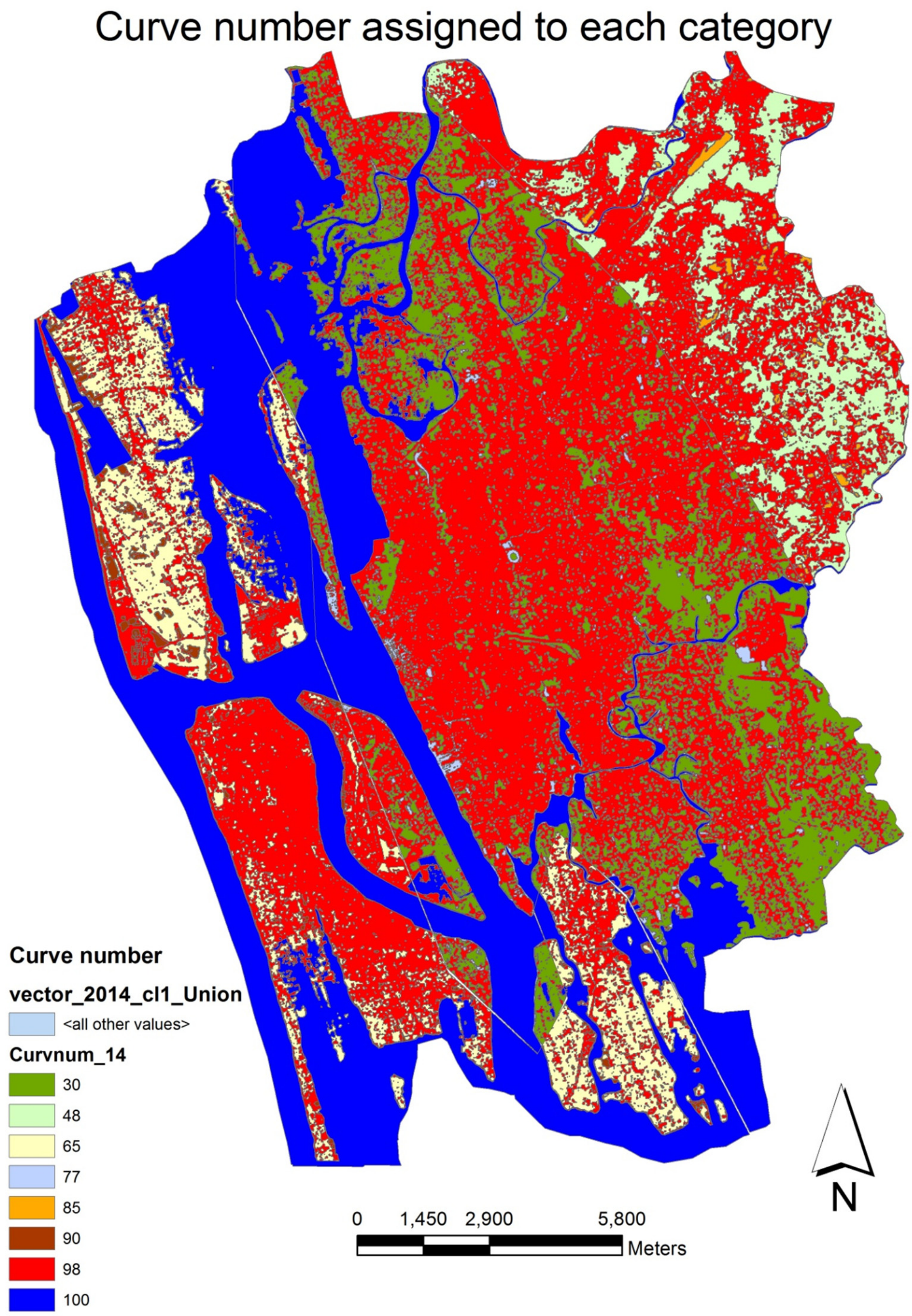
In this study, the run-off depth is estimated for an event rainfall of 10cms

5.5. Results and Discussion

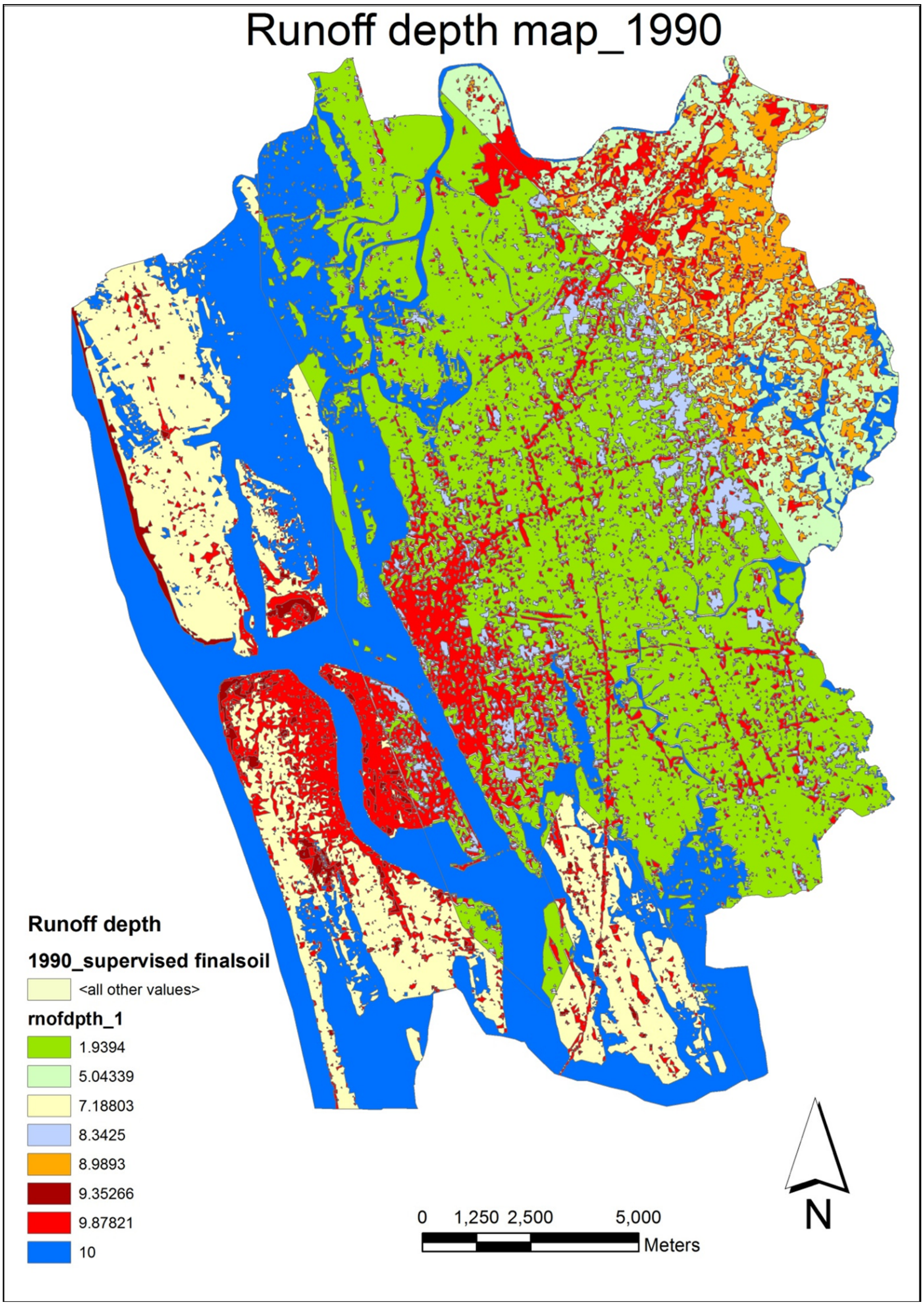
Runoff depth maps were prepared from the land cover maps for the year 1990 and 2014 and runoff volume was calculated. The land cover maps used for the present study are given in map 3.2 and 3.3. Major canals of Kochi were mapped by digitizing in ArcGIS and their length were found out. Depth of the canal were obtained from the data provided by Cochin Corporation. Breadth of the canals were measured from Google Earth. Discharge of existing canals were calculated using the Manning's formula.



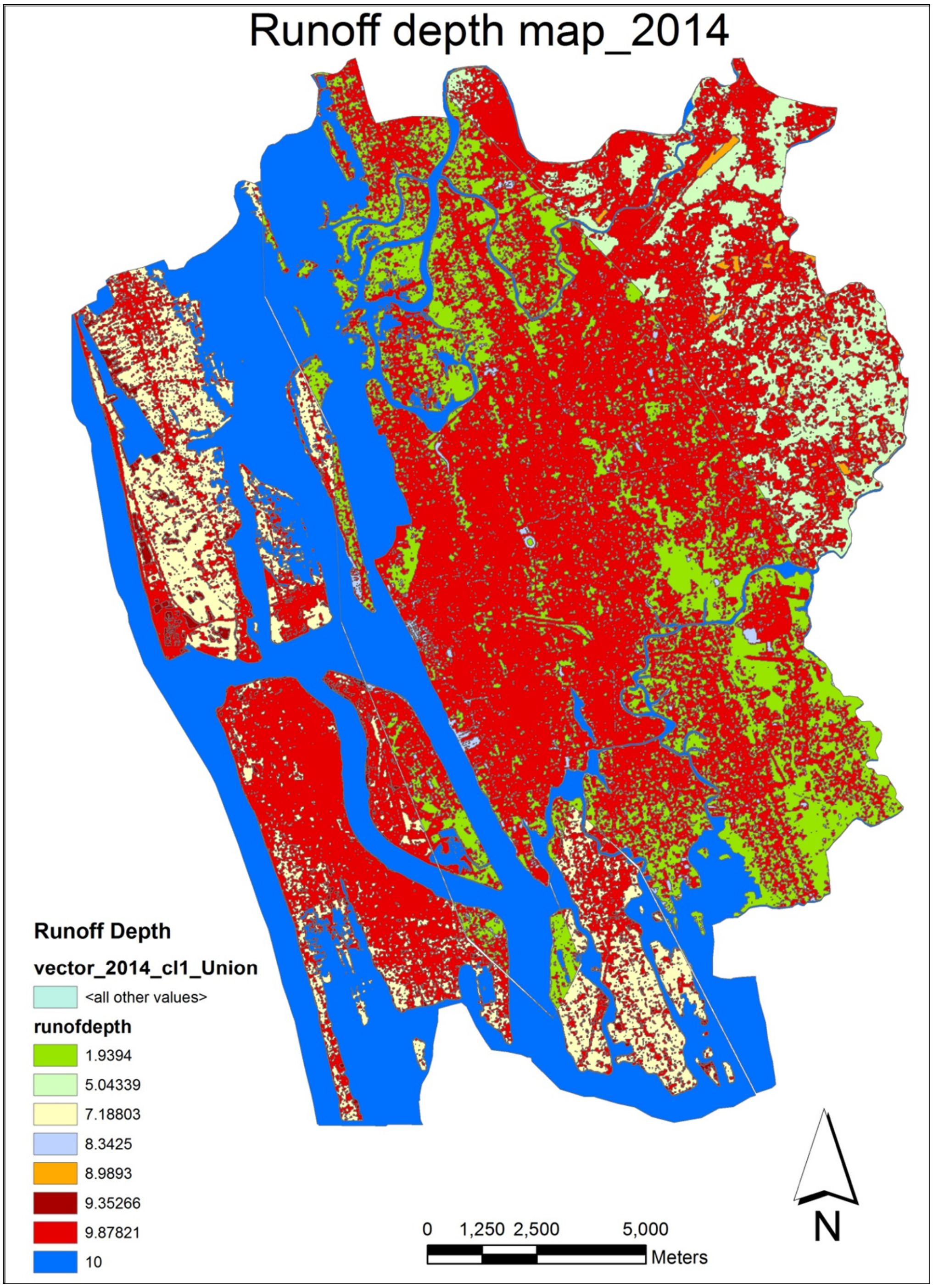
Map 5.1. Digital elevation model of the study area



Map 5.2 Map showing the curve number assigned to each land cover soil class.



Map 5.3. Runoff depth map for 1990.



Map 5.4. Runoff depth map for 2014.

Table 5.4. Runoff volume for changing landuse pattern in 1990

Land cover class	HSG	Curve number	Initial abstraction	Runoff depth(cm)	Area(m)	Runoff volume
Built-up	A	98	0.204082	9.87821	29.621	292.602
Open/ exposed	B	85	1.76471	8.9893	12.6053	113.313
Built-up	B	98	0.204082	9.87821	9.43285	93.1797
Open/ exposed	A	77	2.98701	8.3425	10.2435	85.4564
Water body	B	100	0	10	2.86626	28.6626
Vegetation	B	48	10.8333	5.04339	21.6759	109.32
Water body	A	100	0	10	38.2172	382.172
Vegetation	A	30	23.3333	1.9394	94.0002	182.304
Open/ exposed	C	98	0.204082	9.87821	13.2541	130.927
Vegetation	C	65	5.38462	7.18803	43.0809	309.667
Water body	C	100	0	10	52.2736	522.736
Open/ exposed	C	90	1.11111	9.35266	3.27418	30.6223
Total runoff volume for a 10 cm rainfall						2280962 m^3

Table 5.5. Runoff volume for changing landuse pattern in 2014

Landcover class	HSG	Curve number	Initial abstraction	Runoff depth (cm)	Area (Km^2)	Runoff volume
Water body	B	100	0	10	0.591725	5.91725
Water body	A	100	0	10	37.2079	372.079
Water body	C	100	0	10	52.9561	529.561
Open/ exposed	B	85	1.76471	8.9893	1.63305	14.68
Built-up	B	98	0.204082	9.87821	27.8919	275.522
Vegetation	B	48	10.8333	5.04339	16.5498	83.4671
Vegetation	A	30	23.3333	1.9394	39.4001	76.4126
Built-up	A	98	0.204082	9.87821	92.4471	913.212
Open/ exposed	A	77	2.98701	8.3425	3.46693	28.9229
Built-up	C	98	0.204082	9.87821	33.773	333.617
Vegetation	C	65	5.38462	7.18803	22.6434	162.761
Open/ exposed	C	90	1.11111	9.35266	3.17393	29.6847
Total runoff volume for a 10 cm rainfall						2825834.509 m^3

Manning's formula is expressed as,

$$Q = AV \text{---} (8)$$

Here, A is the cross sectional area of the drain and V is the flow velocity.

Flow velocity is calculated as,

$$V = (1/n)AR^{2/3}S^{1/2} \text{---} (9)$$

Where v = Velocity, (m/s)

A = Flow Area, (m^2)

n = Manning's Roughness Coefficient

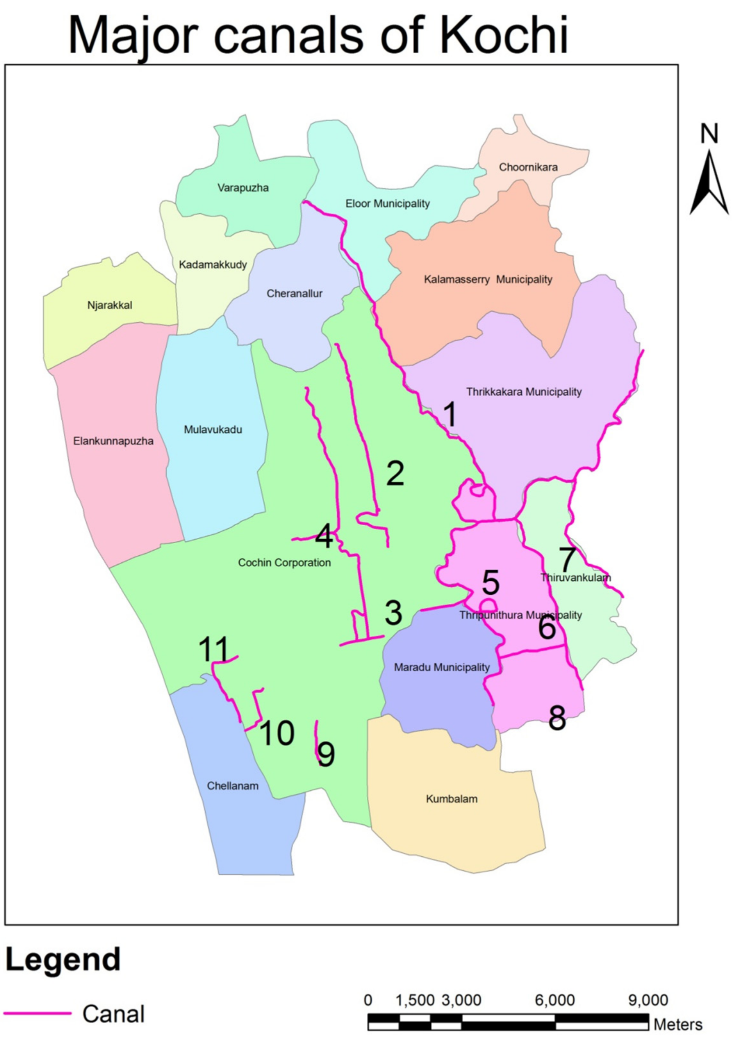
R = Hydraulic Radius, (m)

S = Channel Slope

Canal map of Kochi is shown in Map 5.5 and the dimensions of the canals are given in table 5.5.

From the calculation of flow rate it is seen that only 1587.986 m3 of water can flow through the canal system per second. From the calculation of runoff volume generated it can be seen that, the total run-off volume generated for a 10 cm rainfall in 2014 is 2825834.509 m^3. The result shows that that the runoff volume increased as a result of increase in impervious surface as can be seen from table 5.3 and 5.4.For a 10cm rainfall there is an increase of 544872 m^3 in runoff volume. Hence in the present scenario it will take 29.66 minutes to carry all the runoff to the neighboring estuarine system.

The topographic analysis of the drainages shows that a good number of drainages are either blocked due to natural sedimentation or due to construction activities. The flow at many places are interrupted due to piling up of wastes from houses located along the canals. Elsewhere, the entire canal system was found clogged due to indiscriminate disposal of solid wastes (including plastic wastes, bottles etc.) into the canals. Kaniyampuzha canal stretches over four kilometers. The channel has remained chocked with water hyacinth for several years, and over a period of time, it has turned into an easy repository for raw sewage and breeding ground for mosquitos. The rising level of pollution has blackened its water, posing serious threat to the river's ecosystem. In some natural canals flow is obstructed by buildings or land filled for constructions. The major problems faced by these canals have been mentioned in other reports also, such as the Development Report of Cochin Corporation (Vikasana Rekha) and Sustaining Cochin (2001-2002).



Map 5.5. Map showing major water flow channels within the study area.

Table 5.6. List of canals shown in the map

1- Edappally thodu	7- Karingachirapuzha
2-Changadampokkuthod) / Karanakkodam thod	8- Andhakaran thod
3- Thevara-Perandoor canal	9- Pashni thod
4- Mullasserry canal	10- Pallichal thod
5 Chithrappuzha / Pooripuzha	11- Rameswaram canal
6- Kaniyampuzha	

Table 5.7. Dimensions of the canal system

Canal_name	Length (m)	Width (m)	Depth (m)	volume (m3)
Thevara-Perandoor canal	12.0448	14	7	1180.3904
Changadampokku thodu	8.30053	6	2	99.606369
Mullassery canal	1.29819	2.2	2	5.712036
Andhakaran thodu	2.1876	12	5	131.25598
kaniyampuzha	6.30956	14	2	176.66768
Pashni thodu	1.4413	10	2	28.826
Rameswaram canal	3.06084	10	1	30.608398
Pallichal thodu	1.93567	10	2	38.713402
Karingachirapuzha	4.96406	11	2	109.20932
Chithrapuzha	25.404301	35	5	4445.7524
Edappally thodu	13.4032	15	3	603.14404

The major problems in the drainage of Cochin Corporation, identified in the studies and status reports mentioned above can be summarised as follows, which corroborates this study also.

- Indiscriminate disposal of solid wastes (including plastics, bottles etc) into the canals at many locations and the direct discharge of untreated waste water from the industries and households located on the banks posing the biggest threat to community health and smooth functioning of the Canal System.

- Encroachment is seen in many places with huts/houses built after filling the banks of canals, resulting in reduction in width and hence flow constrictions.
- In many places the culverts and bridges across the canals have been constructed with reduced waterway causing flow obstruction and high afflux.
- The invert levels at the exit of many of the lateral drains that discharge water into the canal are lower than the low tide level in the backwaters. Such submerged outlets prevent positive flow and even water back-up during high tides and increase siltation.
- Inadequate vent-ways causing water back-up preventing navigation (country boats).
- The blockage in the canals making the water stagnant resulting in foul smell and mosquito breeding in many areas in the City. At times, water tops the banks and inundates the nearby areas.
- The result of water quality analysis revealed high degree of pollution in the canals. The analysed parameters such as turbidity, pH, conductivity etc. exceed the permissible limits for any class. The high levels of faecal coliform may infiltrate into the nearby wells and seriously affect the health of the residents in these areas.

Flooding has been one of the major problems faced by Kochi. The geography of Cochin contributes greatly to this problem. Girija Devi in 2005 studied the environmental impacts of drainage system in the central area of Cochin city. She conducted a topographic analysis and located the areas prone to water logging. The areas identified as water logging areas are Ernakulam

North, Ernakulam South Railway station area, M.G. Road area and Pulleppady. She has also added a few suggestions for the reconstruction of canals. Cochin is crisscrossed by a network of canals that were earlier used for navigation purposes. Today, many of these canals have become waste water drains. The canals show high level of pollution, clogging due to weeds, disposal of plastics and other wastes, encroachment and filling of many reaches, finally resulting in floods during the monsoon season. This also is the main reason for one of most nagging problem in the City - the mosquito menace.

5.6. Conclusion

The low impact development (LID) approach has been recommended as an alternative to traditional storm water design. Research on individual LID practices such as bio retention, pervious pavements, and grassed swales has increased in recent years. Low Impact Development was developed as a way to mitigate the negative effects of increasing urbanization and impervious surfaces. The preservation of the pre-development hydrology of a site is the overall goal of LID. Cluster layouts, grass swales, rain gardens/ bio retention areas, and pervious pavements all reduce the "effective impervious area" (Booth and Jackson 1997) of a watershed, or the area that is directly connected to the storm water system.

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Chapter

6

SUMMARY AND CONCLUSION

Contents

This study focuses on the following aspects of urban development and sprawl of a rapidly developing metropolis - the Kochi City.

- Temporal expansion of Kochi during the last 24 years (1990 to 2014).
- Impervious surface coverage is taken as a representative indicator of the various environmental impacts of urban expansion.
- The resulting increase in Urban Heat Island (UHI) effect is studied in detail.
- A comparison of the UHI in a few fast developing tropical cities with similar geographical settings - Kochi, Mumbai, Colombo, Jakarta, Bangkok and Singapore is done for the sake of identifying the necessary Environmental Management Plans (EMPs) to ameliorate the UHI effect.
- The effect of impervious surfaces on the urban hydrology of Kochi is studied in detail to help the city planners to identify the storm water

drainage bottlenecks and reduce the frequent flooding observed in the city, seriously affecting the infrastructure. This is of particular significance in view of the severe human tragedy witnessed by Chennai city during December 2015 cloud burst.

Cities, particularly in developing countries are growing at an alarming rate and green areas are diminishing proportionately. The present study reveals the importance of pervious surfaces – especially vegetation and green areas in urban planning. Increase in the impervious surfaces associated with urbanization have resulted in increased runoff velocity, increased surface runoff (Hollis 1977; Mishra 2011), decreased time of concentration (Leopold 1968), and decreased water quality (Makepeace et al. 1995; US EPA 1983) and also impact urban micro climate in the form of heat island effect. The climatic changes in turn increase the power consumption. Careful steps should be taken in order to mitigate those impacts. In view of the environmental status quo as well as the future developmental scenarios as projected by various governmental agencies, important strategies have to be envisaged for a sustainable urban development. A few of such measures are mentioned below.

Can we go Green?

It is well established from various previous studies conducted at different parts of the world that certain environmental planning as well as some design considerations can mitigate to a great extent such impacts and increase human comfort. From the present study as well as from the earlier studies it is clear that vegetation in urban areas minimizes the environmental problems due to urbanization. Trees intercept rainfall, mitigate pollution and reduce wind speed. They also provide shaded areas and decrease temperature by evapotranspiration. According to a study reported by Taha et al in 1997, 15% increase in albedo would decrease air temperature by 2 to 5ºC, over the Los Angeles urban region. In order to improve external climatic conditions, in urban areas it is good to landscape the surrounding areas.

Ecofriendly roofing systems, pavements, raingardens etc. can give a positive impact in reducing temperature and storm water runoff. It is good to improve the building design with more, open spaces and more exposure to greenery etc. particularly more ventilations windows in tropical cities. The surroundings of community places, offices, hospitals, and schools and colleges should have more greenery and open spaces. Also, it is important to create awareness among urban population about the importance of trees, forests and exposure to green spaces. A few environmental and design considerations for mitigating environmental impacts due to urbanization are discussed in this chapter in the light of existing literature.

6.1. Green Roofs

Rooftops often represent one of the greatest impacts on urban runoff (Cornelly et al. 2006). On developed urban lots, the building foot print is typically the largest portion of impervious area (Metro Vancouver, 2008). Green roofs basically consist of a vegetation layer, a substrate layer (where water is retained and in which the vegetation is anchored) and a drainage layer (to evacuate excess water). A modern green roof is a conventional roof structure with layers of drainage and vegetated growing medium installed on top of a waterproof membrane.

Roofs consisted of a thick soil layer with plants, grass, and / or trees, and extra structural support was required. These "intensive" green roofs are being replaced by "extensive" green roofs, which have a much thinner, lighter media (thus fewer structural requirements), and different plants (Davis and McCuen, 2005). Living, or green roofs have been shown to increase sound insulation (Dunnett and Kingsbury, 2004), fire resistance (Köhler 2003), and the longevity of the roof membrane (Porsche and Köhler, 2003). Other potential benefits include green-space amenity, habitat for wildlife, air-quality improvement, and reduction of the UHI effect (Getter and Rowe, 2006). They can reduce the energy required for the maintenance of interior climates (Del Barrio, 1998), because vegetation and growing plant media intercept and dissipate solar radiation. Green roofs can also mitigate storm-water runoff from building surfaces by retention of precipitation on a green roof is a combination of storage in the media and evapotranspiration by plants. Research has shown that by using a green roof, 60–70% reductions in storm water runoff volume from a roof are to be expected. This finding may have particular relevance in cities where space for storm water treatment is costly and limited.

Cool roofing products are made of highly reflective materials that can remain approximately 18° to 28°C cooler than traditional materials during peak summer weather (U.S. EPA).

Advantages of cool roofs are

- it reduces heat gain, to lower indoor temperatures
- reduces energy use and costs
- can extend a roof's life by up to three times

6.2. Rain Gardens:

Rain gardens, or Bio-retention areas, are depressed areas in the landscape that are designed to accept storm water. They can be used in residential and commercial settings, and are typically planted with shrubs, perennials, or trees, and covered with shredded hardwood bark mulch. The benefits of bio-retention areas include decreased surface runoff, increased groundwater recharge, and pollutant treatment through a variety of processes.

6.3. Pervious Pavements

Implementing alternatives to traditional asphalt and concrete paving seems to be an eco-friendly option. There are mainly four types of pervious pavements - concrete blocks or grids, plastic grids, pervious asphalt and pervious concrete. The high flow rate of water through a pervious concrete pavement allows rainfall to be captured and to percolate into the ground, reducing storm water runoff, recharging groundwater, supporting sustainable construction, providing a solution for construction that is sensitive to environmental concerns. In spite of the high voids content, properly placed pervious concrete pavements can achieve strengths in excess of 3000 psi (20.5 MPa) and flexural strengths of more than 500 psi (3.5 MPa). This strength is more than adequate for most low-volume pavement applications (Pervious concrete pavements, PCA, 2004).

6.4. Cool Pavement

The term “cool pavement” denotes materials and construction techniques selected to reduce the absorption, retention and emitting of solar heat. For homes, the paved areas to consider include driveways, sidewalks, parking areas, patios and paths.

Cool pavements are light in colour, and may have special reflective components and properties. They can be made of porous material, which traps less heat and allows water to seep into the ground below.

Air pockets allow air and water to flow and circulate through the material and lower the pavement’s temperature. Pervious pavements include gravel driveways, porous concrete, or parking area pavers that have openings for grass.

Reduces the heat island effect - helps to lower air temperatures, improve air quality, and quality of life during the heat of summer

- Keeps surfaces more comfortable to the touch
- Promotes cooling, through increased air filtration and evaporation.
- Porous / permeable paving reduces storm water runoff and the need for storm water retention.
- Reduces heat released back into the air at night.

Water sensitive urban design (WSUD) is an approach to the planning and design of urban environments that supports healthy ecosystems, lifestyles and livelihoods through smart management of all our waters.

6.5. Water Sensitive Urban Design (WSUD)

Water sensitive urban design is a set of principles that can be applied to sustainably manage water, providing opportunities for development. The National Water Commission of Queensland defines water sensitive urban design as ensuring "that urban water management is sensitive to natural hydrological and ecological cycles. It integrates urban planning with the management, protection and conservation of the urban water cycle". WSUD is a term used in the Middle East and Australia and is similar to low-impact development (LID), the term used in the United States; and sustainable urban drainage systems (SUDS), a term used in the United Kingdom.

It represents a fundamental shift in the way water and related environmental resources and water infrastructure are considered in the planning and design of cities and towns, at all scales and densities. WSUD aims to see all streams of water being managed as a resource, as they have quantitative and qualitative impacts on land, water and biodiversity, and the community's aesthetic and recreational enjoyment of waterways. This applies at all levels of urban water governance, i.e. community, institutional and governmental.

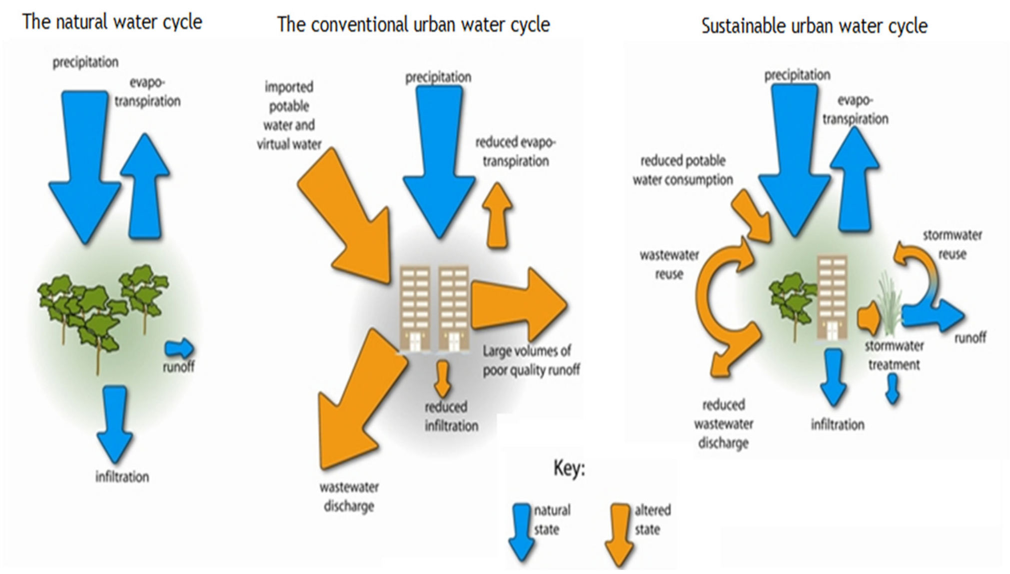

Figure 6.1. The natural water cycle, the conventional urban water cycle and the sustainable urban water cycle (Healthy Waterways, 2011)

Major concepts WSUD are

1. The use of water efficient appliances and water reuse as alternative sources of water to conserve potable water supplies.
2. Detention, reuse, storage and infiltration of storm water rather than rapid conveyance.
3. Use of vegetation for storm water filtering purposes.
4. Water-efficient landscaping to reduce potable water consumption
5. Wetland conservation.
6. Minimizing hazardous waste disposal to streams without treatment.

6.6 Limitations of the Present Study

As mentioned by Cohen, undertaking research on urbanization in the world especially in developing countries presents major challenges. The most basic problem is that there are no global standards for the classification of urban environments. In the case of Kochi, the Corporation area along with five adjoining urban agglomeration is taken the urban area, whereas studies of other cities - Singapore, Jakarta, Bankok, Colombo and Mumbai, urban and rural classification is made on the basis of land cover maps. Another limitation is that, while there are a large number of impacts due to the increase in impervious surfaces, only the impacts on land surface temperature and only one major impact on hydrology are covered under this study. Studying all impacts (both primary and secondary), does not comes under the scope of this study.

6.7 Scope for Future Work

Apart from the few major impacts discussed in this study, there are several secondary impacts, such as the impact on human health and comfort, ecosystem changes, and rise in stream temperature and their impacts on aquatic ecosystem etc. have to be studied for formulating a comprehensive urban plan for a sustainable development, which are beyond the scope of this work. Health related impacts include changes in the propagation of disease causing vector, spread of contagious diseases like Chikungunya and Dengue and heat related illnesses. Increased temperature can cause the extinction of some less heat tolerant organisms, and sometimes cause habitat loss and fragmentation, and may even affect the food web. The quantification of urban imperviousness using a fine resolution data or LIDAR can give more precise results. Such quantifications can be applied to investigate the quantity of rainwater that can be harvested from the roof tops.

More studies with imageries of sharper resolutions can shed light on various environmental aspects of urban problems, which can lead to better planning. The fast progress in the satellite availability and sophistication of sensors thanks to our own space technology will provide researchers and planners with more frequent and better data.

Above all, more than mere rectification efforts of existing problems, careful planning of various environmental problems in view of the impending greenhouse warming can be of immense help in the future survival of urban conglomerates as well as the entire mankind.

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ANNEXURE

Annexure 1. Calculation of Discharge of existing major drains using Manning's formula

Canal_name	LENGTH (m)	WIDTH (m)	DEPTH (m)	volume (m3)	Area (m2)	Perimeter (m)	Roughness, R=A/P)	Hydraulic radius	Slope	$S^{1/2}$	Velocity (m/s)	Discharge (m3/S)
Thevara-Perandoor canal	12.0448	14	7	1180.3904	98	28	3.5	2.3	0.001	0.032	3.68	360.64001
Changadampokku thodu	8.30053	6	2	99.606369	12	10	1.2	1.129	0.001	0.032	1.8064	21.6768
Mullassery canal	1.29819	2.2	2	5.712036	4.4	6.2	0.709677	0.7956	0.001	0.032	1.27296	5.60102
Andhakaran thodu	2.1876	12	5	131.25598	60	22	2.727273	1.9485	0.001	0.032	3.1176	187.056
kaniyampuzha	6.30956	14	2	176.66768	28	18	1.555556	1.3425	0.001	0.032	2.148	60.144001
Pashni thodu	1.4413	10	2	28.826	20	14	1.428571	1.2685	0.001	0.032	2.0296	40.591999
Rameswaram canal	3.06084	10	1	30.608398	10	12	0.833333	0.8855	0.001	0.032	1.4168	14.168
Pallichal thodu	1.93567	10	2	38.713402	20	14	1.428571	1.2685	0.001	0.032	2.0296	40.591999
Karingachirapuzha	4.96406	11	2	109.20932	22	15	1.466667	1.2907	0.001	0.032	2.06512	45.432598
Chithrapuzha	25.404301	35	5	4445.7524	175	45	3.888889	2.4729	0.001	0.032	3.95664	692.41199
Edappally thodu	13.4032	15	3	603.14404	45	21	2.142857	1.6621	0.001	0.032	2.65936	119.671
											Total Discharge	1587.985417

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Estimation of Effective Impervious Surface Area of Cochin using Satellite Images

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Abstract

Urbanization refers to the process in which an increasing proportion of a population lives in cities and suburbs. Urbanization fuels the alteration of the Land use/Land cover pattern of the region including increase in built-up area, leading to imperviousness of the ground surface. With increasing urbanization and population pressures; the impervious areas in the cities are increasing fast. An impervious surface refers to an anthropogenic ally modified surface that prevents water from infiltrating into the soil. Surface imperviousness mapping is important for the studies related to water cycling, water quality, soil erosion, flood water drainage, non-point source pollution, urban heat island effect and urban hydrology. The present study estimates the Total Impervious Area (TIA) of the city of Kochi using high resolution satellite image (LISS IV, 5m. resolution). Additionally the study maps the Effective Impervious Area (EIA) by coupling the capabilities of GIS and Remote Sensing. Land use/Land cover map of the study area was prepared from the LISS IV image acquired for the year 2012. The classes were merged to prepare a map showing pervious and impervious area. Supervised Maximum Likelihood Classification (Supervised MLC),which is a simple but accurate method for image classification, is used in calculating TIA and an overall classification accuracy of 86.33% was obtained. Water bodies are 100% pervious, whereas urban built up area are 100% impervious. Further based on percentage of imperviousness, the Total Impervious Area is categorized into various classes.

Keywords: Urbanization, Impervious surface, Remote Sensing and GIS.

Introduction

With increasing urbanization and pressure of population, the impervious areas in the cities are increasing. An impervious surface refers to an anthropogenic surface modification that prevents water from infiltrating into the soil[1]. Impervious surfaces are defined in watershed management as surfaces that prohibit the movement of water from the land surface into the underlying soil. Buildings and paved surfaces (e.g., asphalt, concrete), roads, parking lots etc. are considered impervious covers. Natural conditions such as bedrock close to the surface, very dense soil layers such as hard pan that restrict water movement etc. are not considered “impervious cover”. Major driving force towards the increase in impervious cover is the Land use/ Land cover changes occurred as a result of urbanization[2]. As the area of impervious surface increases, the time of concentration and runoff travel time are decreased and the degree of hydraulic connection is increased[3].

In watershed management, the term “impervious cover” refers to the conditions that are created by human action. Natural conditions are addressed in other ways, such as through theassessment of ground water recharge, soil and rock analysis etc. One major benefit to the focus on humanstructures is that buildings and pavements are fairly easy to identify using satellite imagery/aerial photographs while subsurface or natural conditions are not obvious. The common types of impervious surfaces can be categorized into two primary categories: the rooftops and the transport system (roads, sidewalks, and parking lots)[4]. The environmental impacts of impervious surfaces have been discussed in many previous studies[4-6] which include impacts on water cycling, water quality and erosion of construction sites, non-point source pollution, stream health, and the urban heat island effect. Satellite remote sensing images integrated with GIS have massively been applied for studying various spatial aspects due to their relatively low cost and suitability for large area mapping which can be used for impervious surface identification and estimation .[7-10]

Various GIS methods had been applied successfully for impervious surface extraction in previous research, including spectral mixture analysis, regression tree, artificial neural network, multiple regression and sub-pixel classification[6, 11-22]. The present study aims at extracting impervious surface data from satellite imagery with 5 meter resolution using supervised Land use classification method. The negative impacts of increased impervious cover (IC) on receiving water bodies as increased runoff and pollution load have been well documented[22-24]. Due to the acceptance of this inverse relationship, IC has frequently been used in watershed and site design efforts as a chief indicator of environmental degradation. Impacts of urbanization on the environment can be well established by an Impervious Surface map. But not much effort has been done in India, to map impervious cover.

Reasons for concern about impervious cover: Environmental Impact of Impervious cover lies in the fact that increased impervious cover degrades the environment. Impervious Cover

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is used as an indicator of Environmental degradation. The hydrologic changes and non-point source pollutant loading from impervious land cover cause most of the environmental degradation than the environmental cover itself. High levels of impervious cover are associated with dense development.

The distribution of impervious surfaces influence urban climate by altering sensible and latent heat fluxes within the urban surface and boundary layers; it increases the temperature of urban regions by causing heat island effect. Strong correlation between imperviousness of a drainage basin and the quality of its receiving streams has been reported. For example, stream quality usually starts to degrade if more than ten percent of the area of a watershed is impervious.

Material and Methods

Materials used: IRS LISS IV image for the year 2012, with spatial resolution of 5 m was used for the study. The image was processed using Erdas Imagine 9.3 software. GIS Analysis and map composition was carried out in ArcGIS 9.3.

Study area: Cochin City is one among the fast growing urban centers in the southern states of India. It is located between 76° 10' 30" and 76° 25' 29.30" East latitude and 10° 6' and 9° 49' 30" North longitude. Physiographically, this area is unique as the entire area is a product of fluvial-estuarine agencies modified by human activities in terms of reclamation. Due to uncontrolled reclamation and urbanization, the impervious cover of the city is increasing. The area experiences a humid climate. In general, four seasons are identified; (i) Summer season from March to May (ii) South-west monsoon season from June to September (iii) North- east monsoon season from October to December and (iv) Winter during January and February. Mean annual rainfall is about 3500 mm.

Methodology: The methods depict the degree of imperviousness from 0 to 100% at the pixel level. Land use/ Land cover map of the study area was prepared using LISS IV imagery acquired for the year 2012, in an Erdas Imagine environment. The map was prepared with supervised classification technique using mean distance to minimum classifier. Supervised classification yields the best results when proper ground information is available. Classification accuracy was determined by preparing error matrix.

The classified image has five classes- built-up, open / exposed area, plantation, vegetation and water body. These classes were merged to prepare the Total Impervious Area (TIA) layer. A map was composed from this layer to show the total pervious and impervious area under the city.

The TIA layer was gridded with 1000 m grid. The TIA layer was then transferred to a GIS environment and the area under previous surface, impervious surface and water bodies were calculated. As there is no confined water bodies in the study area, water bodies does not add to the infiltration, but only increase in the runoff. Hence water bodies were excluded from the area calculations. Percentage imperviousness of the area under each grid was calculated as;

Percentage imperviousness = {Impervious Area/ (Impervious area+ pervious area)} ×100

Percentage imperviousness of each grid is expressed as the Effective Impervious Area (EIA) of the study area

Results and Discussion

The land cover map of Kochi is prepared from the LISS IV. An overall classification accuracy of 86.33% was obtained. The classified map is given in figure 1.

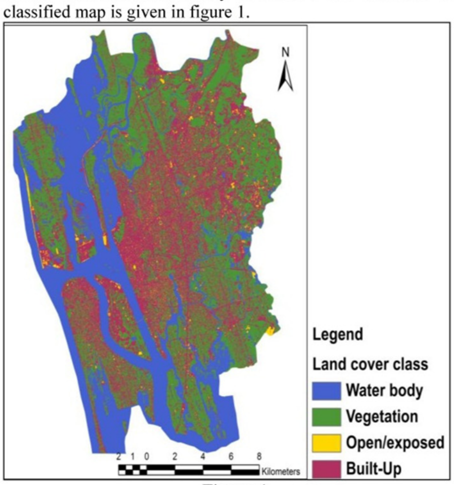

Figure-1
Land cover map of Kochi

An anthropogenic impervious surface map was prepared for Kochi by merging the above classes.

The results show that 114.44 square kilometers of the total area of the city is under impervious cover. The raster representation of percentage imperviousness is given in figure 3.

From the map, it can be seen that the maximum imperviousness in the grid (one square kilometer area) is 88%.

Conclusion

Supervised classification proved to be a good method in mapping impervious surfaces provided the number of land use classes in the region is less and proper ground knowledge is

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available. Total Impervious Area and Effective Impervious Area of the city are mapped and it is observed that 114.44 square kilometers of the total area (330 sq.kms) of the city is under impervious cover. Maximum percentage imperviousness observed is 88% per square kilometer.

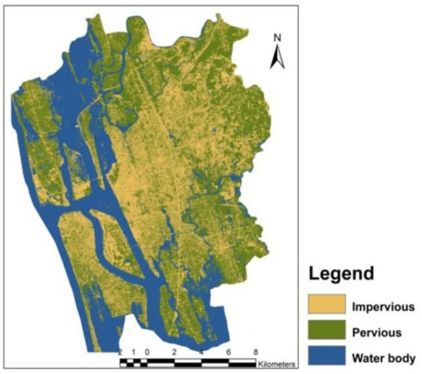

Figure-2
Map showing total impervious area of Kochi

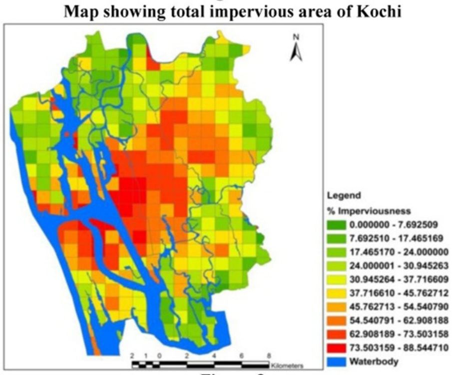

Figure-3
Map showing effective impervious area

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MAPPING AND CHANGE DETECTION OF BUILT-UP IMPERVIOUS SURFACES IN AND AROUND KOCHI USING GIS

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ABSTRACT

Urbanization fuels the alteration of Land use / Land cover (LULC) pattern of the region including increase in built-up area, leading to imperviousness of the ground surface. Impervious surface mapping is inevitable for studying urban hydrological aspects like water cycling, water quality, soil erosion, flood water drainage, non-point source pollution as well as in urban climatic studies like heat island effect. Among the different methods of impervious surface classifications, Supervised classification is found to be the most suitable method. In this study, temporal variations in impervious surface coverage is studied using Landsat images for the years 1990 and 2014, LISS III images for the years 1998 and 2007 and LISS IV image for the year 2012. Effect of spatial resolution on the mapping of impervious surface is studied using LISS IV images for the year 2012 having 5.6 m resolution and PAN sharpened Landsat 8 image for the year 2014 having 10 m resolution. Comparative analyses of satellite images for the years 2009 and 2014 show that there is a fast expansion of impervious surface of more than 100 km^2 in area.

Keywords: LULC, Impervious Surface, Remote Sensing, GIS, Image Classification,

1. INTRODUCTION

Scientific studies of the relationship between landuse and impervious surfaces began in the field of urban hydrology during the 1970's [1]. In earlier studies, imperviousness was evaluated in four ways: 1) Identifying impervious areas on aerial photography and then measuring them using a planimeter; 2) overlaying a grid on an aerial photograph and counting the number of grids of impervious surfaces among various land uses; 3) supervised classification of remotely sensed images and 4) an empirical method of equating the percentage of urbanization with the percentage of imperviousness. Later on, numerous research efforts have been devoted to quantify the urban impervious surfaces more precisely using ground-measured and remotely sensed data [2,3]. The methodologies range from multiple regression [4-6], spectral mixture analysis ,artificial neural network [7], classification trees [8], integration of remote sensing data with geographic information systems [9] and digital image classification. Among these, Digital Image Classification is used in the present study, which shows considerable accuracy for the studies of large areas.

Many factors must be taken into account in selecting an image processing method. A review of the literature on remote sensing of impervious surfaces during the past decade reveals that spatial resolution of remotely sensed data is an important aspect in the selection of image processing methods. Also, factors to be considered are the user's need, research objectives, availability of remotely sensed data, image processing algorithms and computer software, compatibility with previous work and time constraints [10]. Among these, the selection of suitable remote sensing data is the major factor for a successful application [11]. Since remotely sensed data vary in spatial, geometric, radiometric, spectral, and temporal resolutions, complete understanding of the strengths and weaknesses of various types of data is key to a proper data selection.

1.1. Digital Image Classification

Image classification is one of the widely used methods in the extraction of impervious surfaces [12-14] but results are often unsatisfactory while dealing with low/medium resolution imagery, due to mixed pixel problems arising out of spectral similarity of various features in an image and the heterogeneity of urban landscapes. Such problems arise due to several reasons and makes it difficult to process the data using conventional classification techniques. Use of high resolution images in mapping impervious surfaces enables the separation of dark impervious surface areas from surfaces shadowed by buildings and areas shaded by tree crowns and water bodies [15]. In cases of mixed pixel problem, sub-pixel classification can be used. Traditional image classification methods using high resolution imageries have been employed in a good number of studies [10,15]. Some researchers have applied image classifications to aerial photographs and LiDAR data too. A few works compared the performance of per-pixel maximum likelihood classifier, ISODATA, and a rule-based classification algorithm applied to digitized aerial photos and LiDAR data in Richland County, South Carolina, and found the maximum likelihood classifier yielded the highest accuracy while the ISODATA the lowest accuracy [13].

In the present study, we have used high resolution data for the years 2012 and 2014. However, for understanding the temporal variations in impervious surface coverage, medium resolution data, which only is available, is used for other years (Table. 1).

2. MATERIALS USED

2.1. Data used for the study

IRS LISS images for the years 2007, 2009 and 2011 were procured with minimum cloud cover with the help of NRSC image browsing facility. The images for 1990, 1998 and 2014 were downloaded from GLCF and 1973 image was downloaded from USGS. The details of the data used are given in the table 1.

Table 1: List of Satellite Images used in this study

Space-craft	Acquisition Dates	Sensor	Bands	Spatial Resolution (Meter)	Radiometric Resolution (Bits)	Source	Image Details	Level of Processing
Landsat-8	11-02-2014	TM	2,3,4, PAN	10	16	GLCF	Path-143, row-53	Geo rectified, radiometric corrected.
IRS-P6	08-02-2012	LISS-IV	2,3,4	5.6	16	NRSC	Path-99, Row-67	Geo-rectified, radiometric corrected.
IRS-P6	01-02-2011	LISS-III	2,3,4	24	7	NRSC	Path-99, Row-66 (70% Shifted to Row 67)	Radiometric corrected
IRS-P6	20-12-2009	LISS-III	2,3,4	24	7	NRSC	Path-99,Row-66 (70% Shifted to Row 67)	Geo-Rectified
IRS-P6	07-12-2007	LISS-III	2,3,4	24	7	NRSC	Path-99,Row-66 (70%Shifted to Row 67)	Radiometric corrected
IRS-IC	04-01-1998	LISS-III	2,3,4	24	7	GLCF	Path-99,Row-66 (70%Shifted to Row 67)	Radiometric corrected
Landsat 5	24-01-1990	TM	2,3,4	30	8	GLCF	Path-144,Row-53	Geo-Rectified
Landsat 1	10-02-1973	MSS	2,3,4	60	6	USGS	Path-155 Row-53	Radiometric corrected

2.2. Study Area

The Kochi city lies near the western coast of Kerala, the south-western state of India. The city and the surrounding rapidly urbanizing area comprises about 330 km^2 extending from 9º 49' to 10º14'N latitudes and 76º 10' E to 76º 31'E longitudes. Kochi is geographically linked with the wetlands of Vembanad estuary. Kochi has a tropical climate with intense solar radiation and abundant precipitation. Like the rest of coastal Kerala, Kochi experiences warm climate and the annual temperature ranges between 20°C and 35°C. Being a coastal metropolis, majority of the Kochi region lies within the low land regions of the state. The average altitude of the land is less than 1 m. above MSL and hence requires proper urban planning and is also most susceptible to the impacts of climate change. The whole of the land slopes gradually from east to west. The flat terrain of the central city interspersed with a network of canals provide the link to the backwaters (Figure 1). The secondary canals serve as natural conduits to the city for the drainage of flood waters.

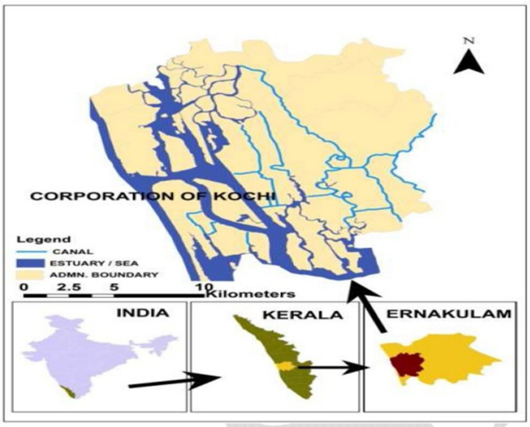

Fig 1: Study Area

3. METHODOLOGY

3.1 Pre-processing of Satellite Images

All the LISS III, LISS IV, Landsat MSS and Landsat TM images were co-registered or geometrically corrected using image to image registration with reference to geometrically corrected 2014 Landsat 8 image using first order polynomial equation with nearest neighbour resampling techniques. The Image was projected to UTM WGS 84, zone 43 N projection. All the images were co-registered to < 0.5 pixel accuracy. All the image processing were done in ArcGIS 9.3 and Erdas Imagine 9.1. Atmospheric correction was done using minimum pixel subtraction method [16-18]. All the images were georectified and subsetted using the subset tool in data preparation menu in the ERDAS imagine software.

3.2 Selection of a Suitable Method for the Preparation of Impervious Surface Map

Land cover maps having four classes - Water bodies, Vegetation, Open/Exposed and Built-up areas are prepared using IRS LISS IV image for the year 2012 having 5.6 m. spatial resolution using three different digital image classification techniques and three supervised classification algorithms. The different techniques tried are supervised and unsupervised classifications, as well as NDVI. There are mainly three classification algorithms for supervised classification. Mean distance to minimum, Mehalanobis distance and Maximum likelihood classifier (MLC). Unsupervised classification is done with Iterative Self-organizing Data (ISODATA) Algorithm. In this study, the image is subjected to unsupervised classification with a cluster size of 30 clusters. After classification, each of these 30 clusters is assigned with one of the four land use classes by correlating the classified image with ground reference. After the classification, accuracy assessment to each classified image is done using the accuracy assessment tool in Erdas Imagine. Sampling points (300) were selected at random and the accuracy assessment is done for all the classified images, supported by ground information collected using a Garmin-60 hand held GPS system. Google Earth is also used to obtain the current spatial scenario.

Among all these classification techniques and algorithms 'Supervised Maximum Likelihood Classification (MLC) yielded the highest classification accuracy and was selected for further estimates. The classification accuracy is in the following order; Supervised MLC > Unsupervised classification > NDVI > Mean distance to minimum > Mehalanobis Distance.

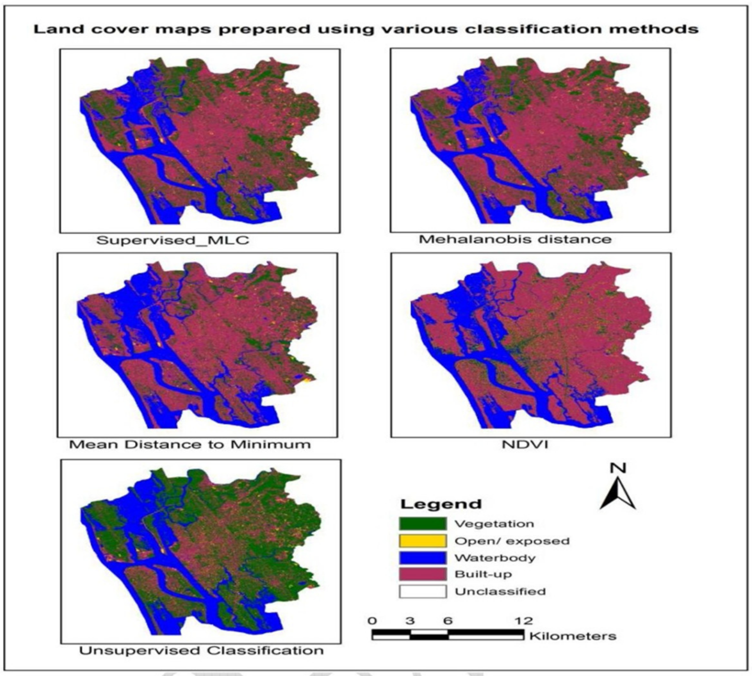

Fig 2: Landcover Maps prepared using various Classification Methods

3.3 Preparation of 'Total Impervious Surface (TIA)' Maps

Land cover classified layers for the years 1973, 1990, 1998, 2007, 2009, 2012 and 2014 having the four classes were prepared using supervised MLC classification. Vegetation and Open / Exposed land is considered as pervious and Built-up areas alone is taken as impervious. Confined water bodies, which adds to the perviousness, are absent in the study area. There are only flowing water bodies, which do not add to the infiltration (perviousness) but only increase the run-off. Hence, they are considered neither as pervious nor impervious and hence are left alone as water bodies in the Figure 5. Total Impervious Area (TIA) maps for the city were composed from these layers.

3.4 Spatio- Temporal Analysis of Impervious Surfaces

Spatio temporal analysis of TIA is performed by considering the image differences of 2014 and 1990 TIA layers. Even though data for the year 1974 was available, a comparison between 1974 image with 72 m. resolution and 2014 image with 15 m. resolution can result in serious error. Hence only the 1990 image having 30 m. resolution is used for the comparison with 2014 data.

4. RESULTS AND DISCUSSION

Spatio temporal Changes of Impervious Surfaces

Spatio temporal analysis of impervious cover over Kochi shows that along with the increase in urbanization, there is a corresponding decrease in water bodies and vegetation. Analysis of satellite data shows that the impervious coverage of 53.74 km^2 in 1990 increased to 154.63 km^2 by 2014, while there was a corresponding decrease of pervious areas from 183.70 km^2 to 87.25 km^2 during the same period. Also, it can be seen that this change is not only contributed by conversion of pervious lands into built up area, but also by land reclamations of the backwaters (Fig 3). This trend was visible from 1944 to 2009 [19]. Only, this trend seems to accelerate in the present decade.

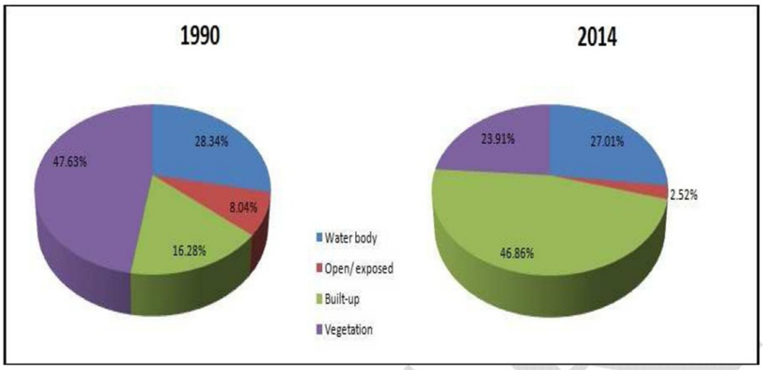

Fig 3: Landcover Pattern for 1990-2014

The impervious surface expansion mainly takes place along the periphery of new roads as can be seen in Fig. 4 & 5. Also, impervious cover of the city increased considerably with the onset of major developmental activities such as International container transshipment terminal (ICTT), Metro Rail, Liquefied Natural Gas (LNG) Terminal, Kochi International Airport, Smart City, Info Park etc. Construction of ICTT was started in 2005 and it became fully operational in 2011. Metro rail project started in 2013 also added its own share of impervious surface increase for its allied infrastructure developments. Change detection studies shows that impervious cover over the city is increasing at a very rapid pace. Land cover maps for the years 1974, 1990, 1998 and 2007 are given in figure 4 and that for the years 2009, 2011, 2012 and 2014 are given in the figure 5. Spatio temporal changes of impervious surface from 1990 to 2014 is given in figure 6.

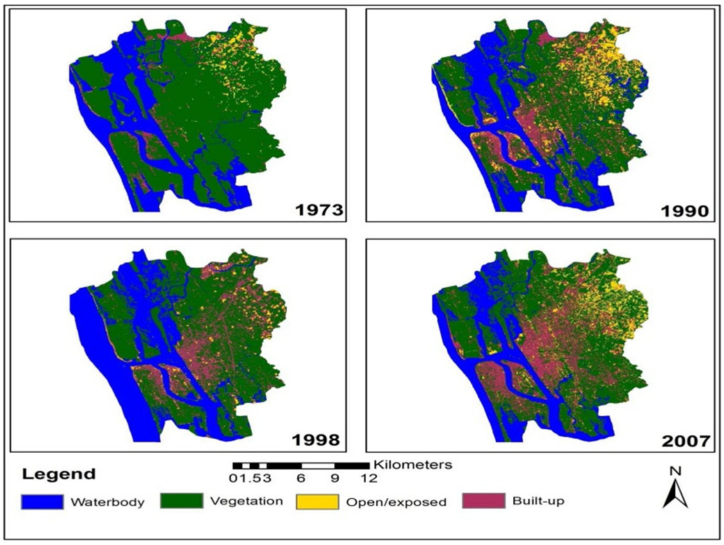

Fig 4: Map showing Temporal Changes in Land Cover from 1973-2007

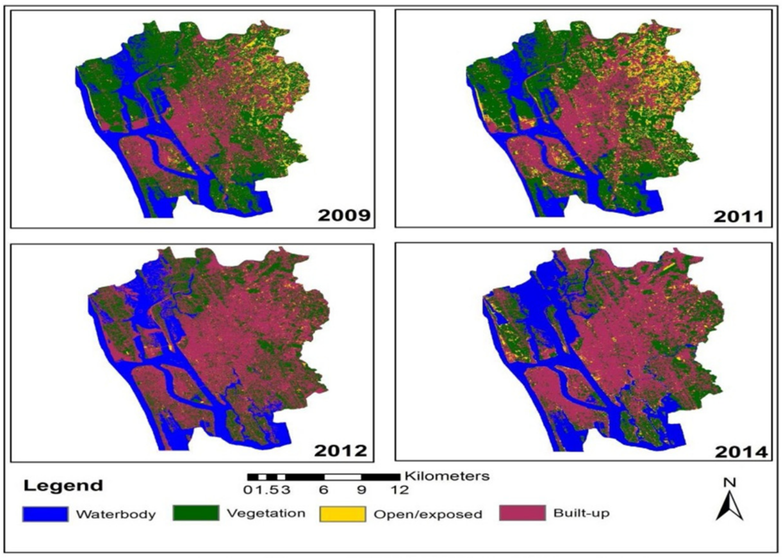

Fig 5: Map showing Temporal Changes in Land Cover from 2009-2014

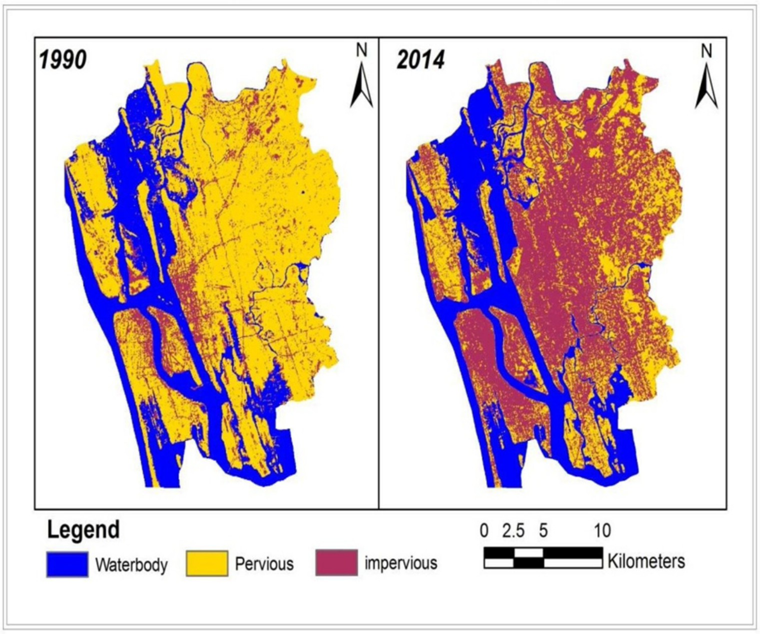

Fig 6: Total Impervious Area Map

5. CONCLUSION

There are many potential applications for the impervious surface maps prepared from this study. Spatially explicit imperviousness estimates and their trends provide urban planners useful data to assist in their decision making and implementation of management strategies. Applications in this field include urban ecological modelling and urban climatological studies. Above all, expansion in impervious surface serves as an indicator of increasing Urban Heat Island (UHI) effect. Geospatial data of impervious surfaces and its change can be used not only as a critical input for urban hydrological modeling but also as an indicator for water quality assessment. Increasing imperviousness plays a big role in degrading water quality and quantity [20].

This study reveals the rapid increase in impervious coverage concurrent with the development of the Kochi metropolis. This calls forth, the urgent implementation of Best Management Practices for the smooth functioning of the city infrastructure. The frequent disruptions of traffic and other public services after heavy rainfalls have become a part of the city life not only in Kochi, but also in most of the cities in the tropical developing countries. This emphasizes the need to develop planned cities at least in emerging metropolises.

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Impacts of Impervious Surfaces on the Environment

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Abstract: *Anthropogenic surfaces that prevent the infiltration of water into the underlying soil such as buildings and paved surfaces (asphalt, concrete), roads, parking lots are called impervious surfaces. Increasing urbanization and pressure of population stimulates the growth of impervious surfaces in the cities. Tremendous increase in impervious surfaces has far reaching effects on the landscape and environment of the region. Impacts of impervious surfaces on climate and hydrology are reviewed here. This review suggests that increasing impervious surfaces strongly alters the hydrology by reducing infiltration and increasing surface run-off. It increases the Land Surface Temperature (LST) by creating Urban Heat Islands (UHI).*
Keywords: *Impervious surfaces, pollution, water quality, Land Surface Temperature, Urban Heat Islands.*

I. INTRODUCTION

Impervious surfaces are defined as the surfaces that prohibit the infiltration of water from the land surface into the underlying soil. Imperviousness is the most critical indicator for analyzing impacts of urbanization on the water environment.[1,2] With the advent of urban sprawl, impervious surfaces have also become a key issue in growth management and watershed planning due to their impact on habitat health.[2] Impervious surface increases the frequency and intensity of downstream runoff and decreases water quality. Increasing urbanization has resulted in increased amounts of impervious surfaces - roads, parking lots, roof tops, and so on - and a decrease in the amount of forested lands, wetlands, and other forms of open space that absorb and clean storm water in the natural system.[3,4] This change in the impervious-pervious surface balance has caused significant changes to both the quality and quantity of the storm water runoff, leading to degraded stream and watershed systems.[5,6,7,8] Stream quality starts to degrade, if more than 10 percent of the watershed is impervious.[1]

A good number of researchers attempted to find the watersheds' response to land use/ land cover changes over time.[9,10] Many authors[11,12,13] have noted that an increase in impervious surface reduces base flow. This is because impervious surfaces prevent infiltration, thereby reducing groundwater recharge and base flow.[14] Impervious surfaces can be used as an alternate measure for the cumulative impact of urbanization on water resources without having to consider specific factors. The other benefit is that it can be measured by a variety of procedures.[2] Watersheds with large amounts of impervious cover may experience an overall decrease of groundwater recharge and base flow and an increase of storm flow and flood frequency.[8,15] Furthermore, imperviousness is related to the water quality of a drainage basin and it's receiving streams, lakes, and ponds. Increase in impervious cover and runoff directly impact the transport of non-point source pollutants including pathogens, nutrients, toxic contaminants, and sediment.[16] Increases in runoff volume and discharge rates together with non-point source pollution, will predictably alter in-stream and riparian habitats, and the loss of some critical aquatic habits.[17] In addition, the areal extent and spatial occurrence of impervious surfaces may significantly influence urban climate by altering sensible and latent heat fluxes within the urban areas.[18] As impervious cover increases within a watershed/administrative unit, vegetation cover would decrease.

Four basic qualities of imperviousness that make it an important indicator of environmental quality are:

(1) Although the impervious surface does not directly generate pollution, a clear link has been made between impervious surfaces and the hydrologic changes that degrade water quality;
(2) An impervious surface is a characteristic of urbanization;
(3) An impervious surface prevents natural pollutant processing in the soil by preventing percolation; and
(4) Impervious surfaces convey pollutants into the waterways, typically through the direct piping of stormwater[2].

The development of the scientific basis to establish the relationship between land use changes and the amount of impervious surfaces took place in the field of urban hydrology primarily during the 1970s. The majority of current impervious surface analyses rely on the methods of these original studies and subsequent studies that correlated percentage of impervious surfaces to land use largely by using estimates of the proportion of imperviousness within each class. A good number of studies estimate the percentage of Total Impervious Area (TIA) as well as Effective Impervious Area (EIA) by coupling remote sensing and GIS[10, 19].

II. HYDROLOGIC EFFECTS OF IMPERVIOUS SURFACES

The water cycle is the most critical processes in supporting life on this planet, and fresh water is central to all aspects of our lives. Hydrology is the study of the movement, distribution and quality of water on earth and urban hydrology is the interdisciplinary science of water and its interrelationships with man in an urban watershed. In urban areas, due to the intense alteration of natural environmental processes by human activity, the watershed response to precipitation are also significantly altered (e.g. reduced infiltration, decreased travel time, higher runoff, urban flooding etc.). Although urban areas are quiet small relative to un-urbanized land, they significantly alter hydrology, biodiversity, biogeochemistry and climate at local, regional and global scales. Land development causes pervious soft surfaces such as grass lands, water bodies and green vegetation being replaced by hard impervious surfaces. While forests capture much precipitation through interception and infiltration, even more is evapotranspired by the trees.[20] Open land, such as a pasture or cultivated land, allows less infiltration than forest, and is often more prone to runoff. Water enters into the soil through infiltration and the velocity with which water enters the soil is infiltration rate. Land use can have significant impacts on the amount and speed of infiltration in a basin. Impermeable surfaces, such as roofs, parking lots, and roads allow zero infiltration, forcing all water that falls onto them to runoff. The changing proportions of these land use types within a basin can have serious effects on discharge and response to storms, either increasing total yield of water, or decreasing and smoothing the hydrograph.[21] Increased impervious cover generally results in more storm water runoff and less ground water recharge. More runoff, in turn, increases stream flows during storm periods. Stream banks erode, more sediment is carried into the streams from surrounding lands, and aquatic habitats are disrupted and degraded. Less recharge means less ground water discharges to streams during dry periods. High levels of impervious cover are associated with dense development, which sends greater pollutant loads to runoff flow channels.

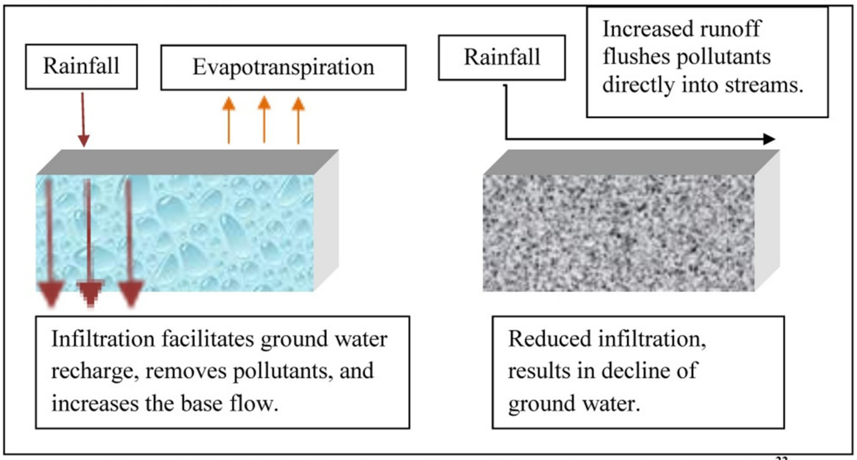

Figure 1. The Effects of Pervious surfaces and impervious surfaces on rainfall[22].

III. IMPERVIOUSNESS AND WATER QUALITY

Impervious surfaces serve as a key indicator for health of aquatic ecosystems.[2] Increased impervious cover is strongly related to increased degradation of aquatic ecosystems. Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other line and point sources. During storms, accumulated pollutants are quickly washed off and rapidly delivered to aquatic systems. As the area under impervious cover increases, more water reaches the ocean as surface water run-off. Storm water runoff is the rain or snowmelt that runs off streets, rooftops, parking lots, lawns and other land surfaces and eventually runs into our streams. Storm water also picks up pollutants as it flows across land surfaces. Pollutants include sediment, pesticides, asphalt, fertilizers, bacteria and disease-causing organisms from failing septic systems; petroleum products such as oil and grease. Sometimes pollutants (e.g., used oil, paint thinners, etc.) are illegally dumped directly into storm drains and waterways. Urban pollutant loads are linked to watershed imperviousness and it serves as a key predictive variable in most simulations and empirical models used to estimate pollutant loads. The simple method assumes that pollutant loads are a direct function of watershed imperviousness.[23]

Impervious surface affects the hydrology of a watershed, the geomorphology of stream beds, temperature, fish populations, macro invertebrates, microbes, algae, and macrophytes. Nutrients, toxins and sediment disrupt aquatic ecosystems and contribute to degraded water quality. The reduced stream flow and more extreme stream temperatures will stress aquatic ecosystems. The abundance and diversity of fish and macro invertebrate populations is harmed as the concentration of impervious surfaces increase.[24] A few works studied the impacts of urbanization on stream insect communities by taking Impervious Surface Area as an indicator.[25] They noticed a steep decrease in stream insect community structure as impervious surfaces increase above 6% of the total catchment area. Water temperature increased as total percentage of impervious surface increases.[26]

The expansion of urban areas is creating more impervious surfaces, such as roofs, roads, and parking lots, which collect pathogens, heavy metals, sediment, and chemical pollutants and quickly transmit them to streams, rivers, estuaries or sea downstream during rain. This non-point source pollution is one of the major threats to water quality and is linked to chronic and acute illnesses from exposure through drinking water, seafood, and contact recreation. Impervious surfaces also lead to pooling of storm water, thus increasing the potential breeding areas for mosquitoes, the disease vectors for dengue hemorrhagic fever, Chikungunya and other infectious diseases. Traditional strategies to manage storm water and treat drinking water require large infrastructure investments and face difficult technical challenges. Reducing storm water runoff and associated non-point source pollution is a potentially valuable component of an integrated strategy to protect public health at the least cost. Runoff from roofs, roads, and parking lots can contain significant concentrations of copper, zinc, and lead, which can have toxic effects in humans. Bioaccumulation of insecticides at levels considered harmful to organisms, raises concern about carcinogenic effects and disruption of hormonal systems in humans.

When storm water moves more quickly into streams, it also has a greater capacity to carry non-point source pollutants into the streams. Community drinking water supplies are commonly disinfected with chlorine and, if the source is surface water, it is filtered to remove sediment and associated pollutants. Several common disease carrying microorganisms are resistant to treatment with chlorine and filtration, although the effectiveness of the filters varies with their pore size. Suspended sediment in source waters further reduces the effectiveness of chlorine. Nitrogen also poses direct health threats. Exposure to nitrate in drinking water increases the risk of methemoglobinemia, causing shortness of breath and blueness of the skin, especially for infants. Consumption of water with elevated nitrate is also suspected to increase miscarriage risk. Major sources of nitrogen from urban and suburban areas may include fertilizers carried by storm water, vehicle exhaust, and septic systems. Fecal coliform bacteria in surface waters commonly exceed standards for recreation, and exposure to bacteria and parasites from swimming and other forms of recreation in water contaminated with urban runoff has caused numerous cases of illness, including ear and eye discharges, skin rashes, and gastrointestinal problems. Increasing impervious surface without storm water controls leads to increased runoff. Elevated fecal coliform levels also have been detected in suburban streams.

Impervious surfaces both absorb and reflect heat. During the summer months, impervious areas can have local air and ground temperatures that are 10 to 12 degrees warmer than the fields and forests that they replace. In urban areas, trees that could provide shade to offset the effects of solar radiation are usually absent. Other factors such as lack of riparian cover and ponds, were also demonstrated to amplify stream warming, but the primary contributing factor was impervious cover.[26]

IV. IMPERVIOUSNESS AND WEATHER CHANGE

Urban heat islands (UHI) refer to the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in the surrounding rural areas due to urbanization.[27] The prime driving force behind UHI is impervious surfaces. The UHI occurs due to differences in thermal, and radiative properties of urban surface materials from the ones of natural surfaces, multiple reflection and absorption of sunlight by urban surfaces (due to specific geometry), anthropogenic heat sources and lack of evapotranspiration in urban areas.[28] The Thermal properties of various urban surface types are given in Table 1. The UHI may greatly change the local climate and thus should be captured by climate models on local and regional scales.

Sl.No.	Surface Type	Emissivity	Absorptivity
1	Highly reflective roof	0.85-0.9	0.3-0.4
2	Galvanized roof sheets	0.25-0.28	0.85-0.9
3	Grass	0.97-0.98	0.7-0.75
4	White tile	0.9-0.95	0.1-0.5
5	Tar and Gravel	0.28	0.82-0.97
6	Brick or Stone	0.87	0.6-0.8
7	Asphalt	0.92	0.8-0.95
8	Concrete	0.9	0.65-0.9
9	Dense Canopy trees	0.95-0.99	0.82-0.85
10	Water	0.99	0.95-0.98
11	Black loamy soil	0.66	0.82-0.87

Table 1. The Thermal properties of various urban surface types[29]

Fei Yuan and Marvin E Bauer compared the Normalised Difference Vegetation Index (NDVI) and percent impervious surface as indicators of surface urban heat island effects by investigating the relationships between the Land Surface Temperature (LST), percent impervious surface area and the NDVI.[30] Landsat TM and ETM data were used for the study. They reported a strong linear relationship between LST and percent impervious surface for all seasons, whereas the relationship between LST and NDVI is less strong. Hua Li and Qinhuo Liu (2008) compared the normalized difference built-up index (NDBI) and Normalised Difference Vegetation Index (NDVI) as indicator of Surface Urban Heat Island (SUHI) effects in MODIS imagery by investigating the relationships between the Land Surface Temperature (LST), NDBI, NDVI from four different seasons for Changsha-Zhu zhou- Ziangtan (China) metropolitan area.[31] Scatterplots of NDBI, NDVI and LST for all the images were compared to find the relationships of LST to NDBI and NDVI. Results suggest that NDBI is an accurate indicator of SUHI effects and can be used as a complimentary method to the traditional NDVI. A good number of works reported the prevalence of heat island effect in various cities throughout the world.[29, 32]

Some authors have questioned the accuracy of impervious surface measures with regard to their impact on water quality and quantity.[33] For example, Total Impervious Area (TIA) includes all of the impervious surfaces in a watershed, regardless of what kind of connection exists between the impervious surfaces and the basin's water bodies. Most of the satellite based estimates calculates the TIA only. Effective Impervious Area (EIA) includes only the portion of a watershed that allows water to cross only an impervious pathway to reach the water. Years of scientific inquiry has firmly established impervious surface coverage as a "reliable and integrative indicator of the impact of development on water resources".[2] This combined with the fact that impervious surface is a measurable parameter, makes it an ideal substitute for measuring water quality in an urban environment.

Conclusion:

A good number of studies have commented on the impacts of impervious surfaces on urban hydrology. Impervious surfaces significantly reduce the water quantity and quality in a watershed. It is reported that the impervious surface degrades the watershed quality by greatly reducing the stream flow and increasing the stream temperature. They carry huge pollutant loads downstream, causing due harm to aquatic life. Surface urban heat islands are another phenomenon caused by impervious surfaces. Attempts have been reported from all over the world to quantify the area under impervious surfaces as well as its impacts.

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