

**BIOPHILIC URBANISM AS A TOOL TO MITIGATE URBAN HEAT
ISLAND-A CASE OF THIRUVANANTHAPURAM CITY**

THESIS REPORT

Submitted by

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in

Urban Planning



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THANGAL KUNJU MUSALIAR COLLEGE OF ENGINEERING**

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DECLARATION

I hereby declare that the project entitled “**Biophilic urbanism as a tool to mitigate urban heat island-a case of Thiruvananthapuram city**” is a bonafide record of the study done as part of thesis work under the supervision of Prof.Anjana Murali during the **Fourth Semester M. Plan (2023)** Post Graduate Degree Course in the Department of Architecture, Thangal Kunju Musaliar College of Engineering, Kollam. I declare that, to the best of my knowledge, the work reported here in does not form part of any other project report or thesis on the basis of which a degree or award was conferred on an earlier occasion to any other candidate.

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CERTIFICATE

This is to certify that the Dissertation Report “**Biophilic urbanism as a tool to mitigate urban heat island-a case of Thiruvananthapuram city**” submitted by **Anjana J Nair** (TKM21MUP004) of MUP (2021-2023) Batch, in partial fulfilment of the requirements for the fourth-semester final examination in PL6401–Planning Thesis, under the **APJ Abdul Kalam Technological University** is a bonafide work carried out under our guidance and supervision.

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ABSTRACT

A rising number of people are realizing how important everyday exposure to nature is for leading fulfilling lives. This influence of nature is recognized in the recent focus on biophilic urbanism as a planning approach. More focus must be placed on urban sizes, including developing "biophilic cities" and planning for them. In order to build social and landscape resilience in the face of climate change, a biophilic city must be created. The study outlines major pathways through which biophilic urbanism improves climatic conditions in Thiruvananthapuram city due to the micro climatic changes, loss of forest cover, increase in heat stress, loss of waterbody and increase in built density which leads to the formation of urban heat island. The urban heat island (UHI), which is defined by temperature differences between urban and rural regions, is a prime example of micro-climate changes brought on by urbanisation. The destruction of vegetation as a result of recent expansion has resulted in the loss of green land cover. Additionally, it has changed how land is used and is covered, which has made the Urban Heat Island (UHI) problem worse. This study aims to create a unique conceptual framework by interrelating the parameters of biophilic urbanism and urban heat island for arriving at strategic plans and proposals for the study area. First, the biophilic urbanism elements that can be integrated in the study area to mitigate the urban heat island is evaluated and analysed from the secondary data analysis to develop a framework. Second, the framework is quantitatively analysed considering the various scales of biophilic urbanism. Both phases, two types of data are employed in the study: land surface temperature readings of hotspot area at various time in a day and the spatial analysis considering the elements of biophilic urbanism depicted in framework for Thiruvananthapuram city. Finally, the study suggests strategies and proposals to be implemented at possible areas of Thiruvananthapuram city.

Keywords: *Biophilic urbanism, Climate Change, Urban heat island, green cover, Built Density, land surface temperature*

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ABBREVIATIONS

AHI-Atmospheric Heat Island

BU-Biophilic urbanism

CLHI-Canopy layer heat islands

EPA-Environmental protection agency

GI-Green Infrastructure

LST-Land surface temperature

NAPCC-National Action Plan on Climate Change

NDVI-Normalized Difference Vegetation Index Calculation

PCN-Park Connector Network

SGMP-Streetscape Greenery Master Plan

SHI-Surface Heat Island

SBEnrc-Sustainable Built Environment National Research Centre

UGS-Urban green spaces

UHI-Urban heat island

UHIPP-Urban Heat Island Pilot Project

CHAPTER 1 INTRODUCTION

This study explores the need for the study and the aim of the study. The chapter provides a brief summary of the significance strategy of reducing heat islands how studies are conducted to accomplish its objectives. The methodology, scope and limitations are also mentioned.

1.1 Background study

In recent years urban areas have been growing as a result of population expansion, which has increased the danger of overheating and produced unmanageable microclimate conditions in the urban region, comprehensive study of the urban heat island effect (UHI) and its reduction with a focus on biophilic urbanism. According to estimates, metropolitan areas will accommodate 68% of the world's population by 2050, up from 55% in 2018. This rapid population expansion affects the microclimate in urban areas, which will increase air temperature. Urban regions and cities will therefore be substantially warmer than the neighboring rural areas. Urban stakeholders and decision-makers are also responding to rising evidence that cities need to increase their density in order to reduce their environmental impact in the face of growing urban populations. Meanwhile, research is emphasising the importance of maintaining a balance between such density and urban nature in order to improve residents' health and welfare and to decrease the negative consequences of densely inhabited, impermeable metropolitan areas on the environment and the economy. (Krishnan, 2022)

Howard, urban climatology pioneer originally identified the “**Urban Heat Island (UHI)**” phenomena in his book ‘The Climate of London’. He demonstrated that downtown London's temperatures, in particular, were higher (by approximately 2 degrees Celsius) than those observed simultaneously in the neighbouring countryside. (Krishnan, 2022).

Urbanized areas known as heat islands typically endure greater temperatures than surrounding places. (EPA, United states environmental protection agency, n.d.) More than natural landscapes like trees and water bodies, structures like buildings, roads, and

other infrastructure reflect and absorb solar radiation. A metropolis that is much warmer than the rural areas around it is referred to as an urban heat island, or UHI. (National geographic organization)

In 1973, German psychotherapist Erich Fromm coined the word "biophilia," which he described as "love of life." Humans have an innate need to interact with nature and the natural world, according to later research on this topic by E.O. Wilson. We require nature in our lives to be happy, productive, and healthy; it is not an optional, but a necessary element of city living. (Totaforti, 2020)

The emerging concepts of biophilia, biophilic design, and biophilic urbanism, according to Wilson, Kellert Heerwagen, Mador, and Beatley, are mostly concerned with people's inclinations to associate with nature in urbanised environments like cities. (Cabane, 2020). Beatley claims that cities that adhere to the Biophilic Urbanism concept live within their means while leaving little of a negative ecological impact, work in ways that are similar to nature, and adhere to the principles of circular metabolism, such as waste recycling and waste water treatment. Cities that are environmentally friendly, economically self-sufficient, and that produce food and energy locally encourage residents to lead healthier, more sustainable lifestyles. According to **Kellert** (2008), biophilia is a natural human inclination for natural systems and processes that compels us to identify with other living things (Wilson, 1986). A city's fabric is made up of its crowded urban streets, which are characterised by numerous social networks. **Jane Jacobs** criticised methods that stressed private mobility over all other street activities. (Jacob, 1961)

The leaders like Peter Newman and Tim Beatley have helped to establish the topic of "biophilic urbanism" by studying how to apply this to urban design. It was soon understood that biophilic urbanism will play a significant role in the development of cities in Australia and throughout the world when the **Sustainable Built Environment National Research Centre (SBEnc)** was founded to emphasise areas of innovation in cities.

The word "**urbanism**" was coined in the late nineteenth century by the Spanish engineer-architect Ildefons Cerda, who wished to establish an independent activity centered on the spatial arrangement of cities. (Wikipedia)

"Biophilic urbanism" was introduced as a new approach to urban planning and architecture that intended to integrate nature into the urban fabric in a methodical way to transform lifeless urban landscapes into regenerative and livable spaces. (Cabanek, 2020).

The three important components of Biophilic Urbanism indicated by **UNESCO Chair in Sustainable Development** for Asia and Pacific as were **Energy and Materials, Water and Biodiversity, Urban Planning and Transport**, which deliver the background for division of the Biophilic Urbanism techniques.

The goal of "biophilic design" is to achieve the benefits of human-nature interaction within the context of the contemporary built environment by incorporating natural elements—both internal and external—into structures, built infrastructure, and urban areas. It is feasible to construct surroundings for people as biological creatures that restore or enhance their physical and mental health, fitness, and well-being by using the concepts of this design idea. Beatley (2011) expanded the idea of biophilic design to the urban scale in order to envision and promote biophilic cities. An innovative planning and urban design method called "biophilic urbanism" was established with the goal of methodically incorporating nature into the urban fabric and igniting the potential to transform lifeless urban landscapes into healing, livable spaces. (Cabanek, 2020).

The main objective of biophilic urbanism is to strengthen the bond between urban residents and urban nature as well as to promote nature as an essential element of daily urban life. This method increases opportunities for urban residents to regularly engage with nature through biophilic design and urbanisation. For the purpose of putting biophilic design theory into practice, biophilic theorists Stephen Kellert and Elisabeth Calabrese have created a set of biophilic experiences and attributes. These structures and urban settings enable urban residents to have both direct and indirect experiences with nature throughout their daily lives. The balanced design of biophilic urban environments is guided by these experiences and traits. (Cabanek, 2020).

1.1.1 Why Thiruvananthapuram

- Thiruvananthapuram is an Urban Agglomeration falling under the category of **Million Plus UA/City**, according to information provided by the Government of India for the **Census of 2011**
- The entire area of **green space** available in the city is around **2.2 square kilometers**. This represents only 0.01% of overall land use. Thiruvananthapuram's **per capita availability of green spaces is only 2.23sq m**, much below the 10- 12sq m/person standards set by the Ministry of Housing and Urban Affairs' guidelines for urban and regional development plans formulation and implementation. (Town and country planning office, 2022) (URDPFI,2014)
- The **unstructured green spaces are being turned into built-up land as the city grows**. Due to urbanisation, a large portion of the green spaces that the city was once proud of have been lost, **except for the grounds of museums and zoos, Veli and Akkulam, the city does not have many designed green spaces, according to the draft plan**. (Thiruvananthapuram Draft Masterplan 2040, 2022)
- Comparing the urban location, where the peak cooling rate was only 1.5 degree C/hr., the rural area reported a peak cooling rate of 3.4 degree C/hr. The **highest value of 2.4 degrees C** in the city centre indicates medium intensity UHI. (Atmospheric Science division of the Centre for Earth science studies, 2012)

1.1.2 Biophilic urbanism in climate change response

Natural space in cities also helps to improve cities' sustainability. It provides free environmental benefits like clean air and water, flood defence, and natural shade.

Green as well as blue resources with quite broad sizes (such as forest, wetland, river, and stream) are appropriate in the region and city range. They protect biodiversity to maintain the stability of natural systems, act as carbon sinks to bind greenhouse gas (GHG) emissions, and produce new as well as cool air for the metropolis. (Lee, 2021)

1.2 Need for the study

- **Draft master plan-2040 flags lack of green areas in city.** (The Times of India, 2021)
- **AMRUT project** in the city included four initiatives **for parks and green spaces** that would have cost Rs 5.85 crore. (Kumar, 2021)
- Thiruvananthapuram have been listed as one of the **highly vulnerable districts among the four as per SAPCC.**
- **Micro-climatic changes in three cities of Kerala** have been identified and a study to be undertaken by the **Institute for Climate Change Studies (ICCS), Kottayam** considering Thiruvananthapuram as one among the three cities. (The New Indian Express, 2017)
- As per the latest report of **Kerala Forest Department**, there is decline forest cover in three districts of kerala in which **23 sq km decline of forest cover in Thiruvananthapuram.** (The New Indian Express, 2020)

1.3 Research question

How can biophilic urbanism strategic plans and proposals be integrated in urban heat islands of Thiruvananthapuram city?

1.4 Aim of the study

To develop plans and proposals that integrate biophilic urbanism to reduce urban heat islands in Thiruvananthapuram city.

1.5 Objectives

1. To study biophilic urbanism concept and urban heat island impact on climate change and its mitigation measures in the study area.
2. To analyse the **issues and challenges** of urban heat island in Thiruvananthapuram city by taking an account of the green cover.
3. To estimate the effect of BU elements w.r.t UHI parameters by developing a framework

4. To develop strategic plans and proposals for distinct areas of urban heat island in the study area using BU.

1.6 Scope of the study

1. The strategies can be applied in **Climate smart cities assessment Framework** under smart city missions, **NAPCC, AMRUT**.
2. The **framework of biophilic urbanism allows for a systematic evaluation of biophilic elements according to various spatial ranges and biophilic approaches**, allowing for the identification and supplementation of a city's absence of biophilic elements which creates urban heat islands.
3. A **key feature of Smart City Mission** is preservation and development of open spaces - parks, playgrounds, and recreational facilities. (Ministry of Housing and Urban Affairs, n.d.)
4. Today, many governments and city planners set as **a policy aim creating climate resilient, low-carbon urban environments and assets**.

1.7 Limitation

1. The **biophilic urbanism elements w.r.t urban heat island parameters (based on literature study)** that can be identified in the study area at neighbourhood level is chosen for planning.
2. The study mainly relies on **satellite data and spatial data** analysis.

1.8 Methodology

The three phases of the approach are the initial phase, the intermediate phase, and the final phase.

Initial phase- We will go through the context (study area) need, and scope of the study (in Thiruvananthapuram city) where we will learn detail about the terms, their definitions and how can we apply it in the future, and feasibility of the study and the reasons for Thiruvananthapuram as a study area.

Intermediate phase- It involves carrying out a literature study by understanding the causes, impacts and factors causing UHI ,deriving elements,subelements and indicators of BU from various literature studies for developing a framework, case studies(Indian and international)and primary survey (Convenience sampling) where observation survey, questionnaire survey, focus group discussions, LST measuring in hot spots take place in order to compare BU components and UHI parameters and determine the most susceptible regions at different scales(Macro,Meso,micro) using the Landsat images by comparing it with the framework.

Final phase- We will eventually arrive at a framework, then derive strategies and proposals where there are area distinct proposals at different scales, understanding the current conditions of the area and implementing a proposal that can improve the area ecologically and environmentally, and finally come up with the conclusions mentioning how the BU elements can be interpreted in an urban heat island in Thiruvananthapuram city, who must be involved, the changes that can cause, and the future developments accordingly with the proposals.

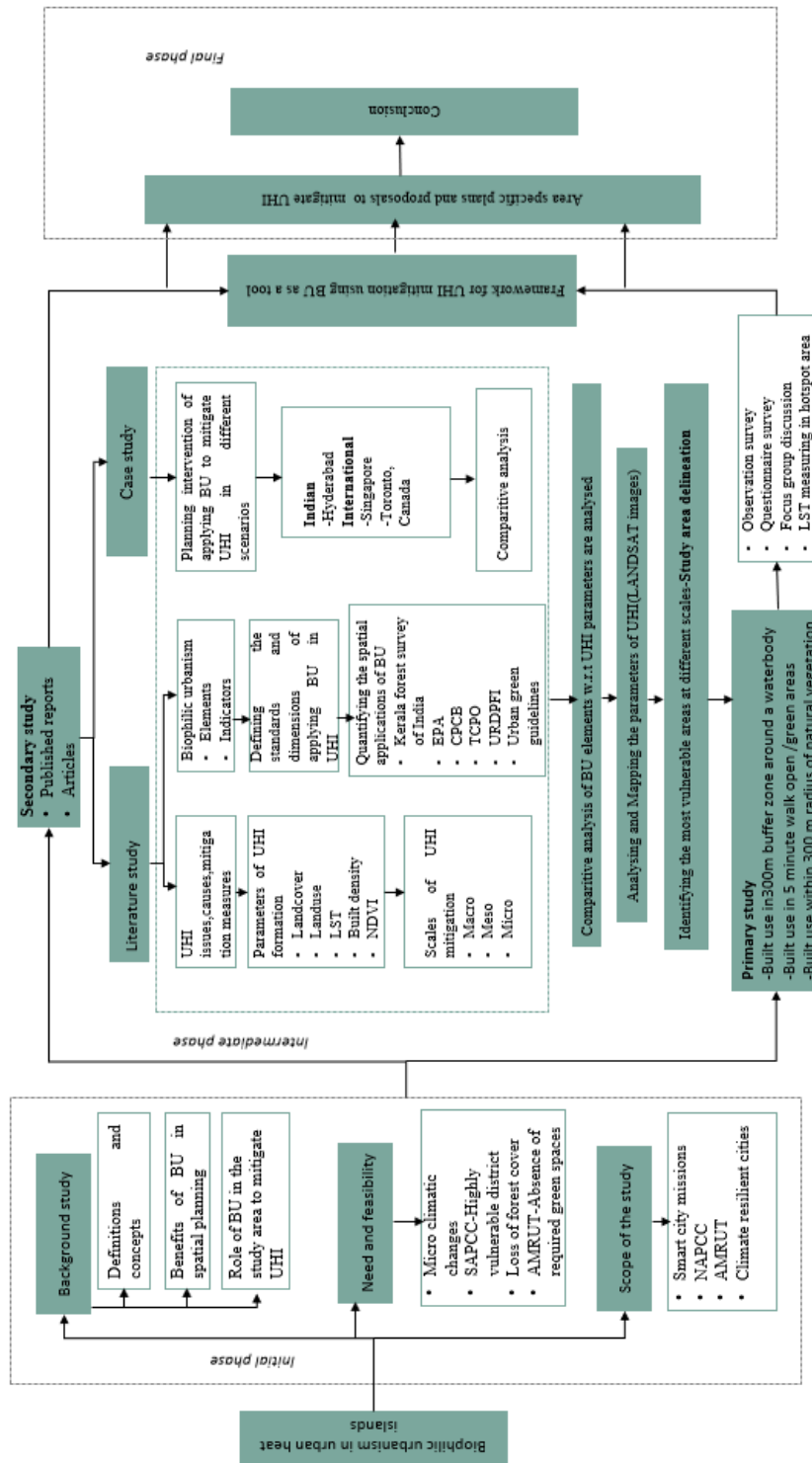


Figure 1. 1 Methodology
Source : Author generated

CHAPTER 2 LITERATURE REVIEW

This chapter explains the evolution of biophilic urbanism and urban heat island concepts. The various definitions and concepts of biophilic urbanism and urban heat island area identified. Biophilic urbanism to mitigate the urban heat island and the different methods and elements of biophilic urbanism are discussed.

2.1 Emergence of biophilic urbanism concept

Tim Beatley thinks that our best chance of tackling the environmental issues of today is through resilient and sustainable cities. Tim Beatley has spent more than 25 years researching, teaching, and writing on sustainable urban communities and innovative ways that cities and towns may significantly lessen their ecological footprints while improving their livability and equity. The American Planning Association designated Ethical Land Use as one of the "100 Essential Books in Planning" and he is the author or co-author of more than 15 books." Beatley's most recent work is centered on incorporating "biophilia" into urban architecture and planning. E.O. Wilson, a myrmecologist at Harvard University, coined the term "biophilia," which refers to the notion that people have a natural desire to interact with nature and a "love" for all living things. Beatley makes the case that cities can and should be planned to enable everyday contact with the natural world in his book *Biophilic Cities: Integrating Nature into Urban Design and Planning*. Beatley discusses the key components of a biophilic city and offers case studies and anecdotes of cities all over the world that have successfully included biophilic aspects, from the building level to the regional level.

A growing realisation that the majority of people on earth live in cities and that the globe is a single, interconnected, yet vulnerable system has emerged during the 1990s. By 2050, 70% of the world's population will reside in cities, according to demographic forecasts, which show that this tendency is accelerating. The 70% of people on the planet will reside in highly urbanised areas and large cities. The ecology is also greatly impacted by human increase and the exploitation of natural resources. It is now difficult to imagine that we will be able to maintain our existing output and consumption levels

without changing them to correspond to sustainable levels. In cities, sustainability is a common issue that is illustrated both theoretically and empirically. (Totaforti, 2020) In particular, it is possible to think about space in a way that supports the social and cultural ideals that are fundamental to urban living and the relationship between humans and nature. These ideals are quite dissimilar but unquestionably important for the growth of all foreseeable metropolitan frameworks. By creating new ways of living, biophilic design seeks to replicate the social reality that is a part of people's daily lives. It changes how we imagine nature, brings back the natural element, and encourages it.

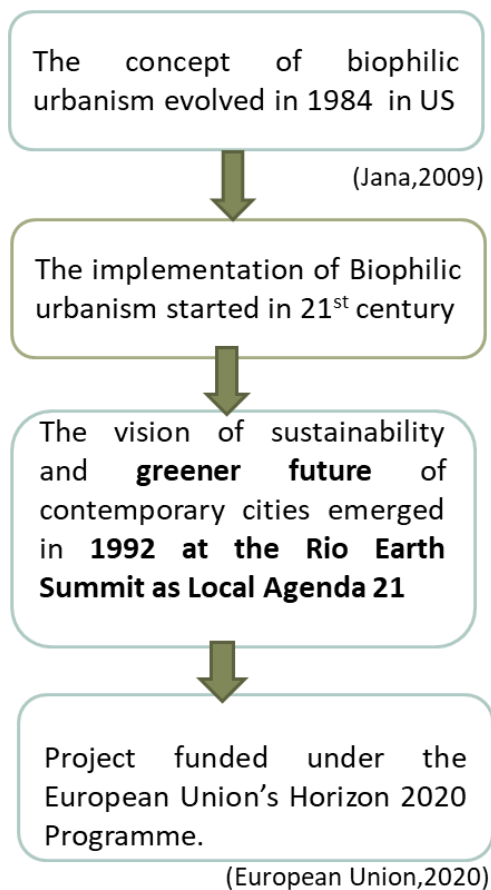


Figure 2. 1 Emergence of biophilic urbanism globally
Source: (Environment, 2011)

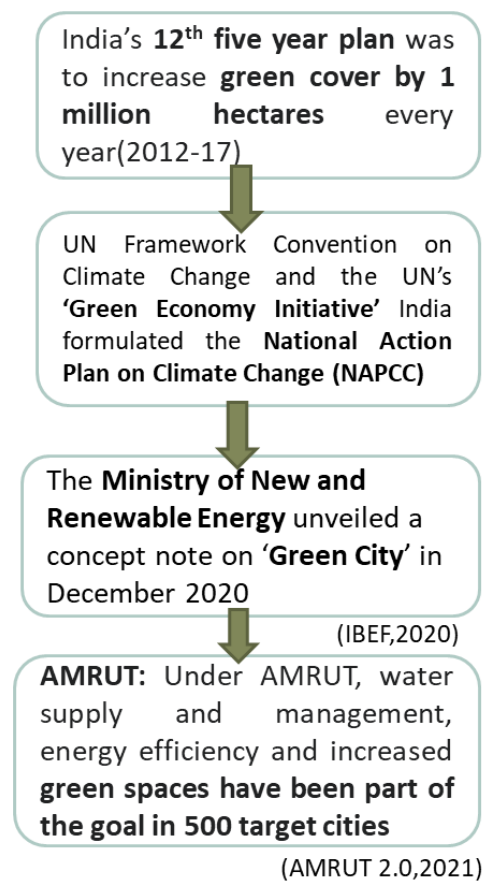


Figure 2. 2 Emergence of Biophilic urbanism in Indian context
Source: (Zaręba, 2022)

In the built environment, "Biophilic" elements like city and pocket parks, linear green space, and green roofs and walls are suggested as a design approach to help people

utilise nature intentionally and effectively. The idea of incorporating urban nature into cities is also introduced.

- The concept of biophilic urbanism evolved in 1984 in US
- In the 21st century, Biophilic urbanism was first put into practise.
- The vision of sustainability and greener future of contemporary cities emerged in 1992 at the Rio Earth Summit as Local Agenda 21 (Zareba, 2022)
- URBAN GREENUP is a project supported by the Horizon 2020 programme of the European Union. (URBAN GREENUP, 2020)

Adaptive solutions with a more holistic approach are being developed by architects, urban planners, and landscape architects in an effort to improve human health and wellbeing. Urban expansion, population explosion, a lack of equality and justice, vulnerability, risk, insecurity, and climate change are just a few of the unresolved issues that have a direct impact on creating a city that is healthy, sustainable, and resilient.

The ability to live and work in stress-free settings with improved general health and well-being is made possible by biophilic design. In reality, as urbanisation and environmental problems have become worse, reconnecting with nature has become more and more important in recent years. Design strategies that incorporate natural characteristics have emerged as a viable method of enhancing the human experience of the built environment in response to current concerns for individual and societal health and wellbeing, most notably occupational stress, cognitive function, and mental health.

2.1.1 Emergence of biophilic urbanism concept in Indian context

- India's 12th five-year plan was to increase green cover by 1 million hectares every year (2012-17)
- UN Framework Convention on Climate Change and the "Green Economy Initiative" of the UN India created a National Action Plan on Climate Change. (NAPCC)
- In December 2020, the Ministry of New and Renewable Energy presented a concept note on "Green Cities."
- AMRUT: In 500 target cities under AMRUT, the objective has included improved green space, energy efficiency, and water supply and management.

In a similar manner, it has been established that the goals of biophilic design support those of sustainable design and urban resilience. Finally, studies have revealed its strong connection to a healthy city.

2.1.2 Formation of a biophilic city

- Retain the concepts and qualities of biophilic design. Implementing these ideas and qualities into practice on a city-scale.
- Continuity. Ensuring transparency and coherence.
- Connectivity. Connecting several locations across the city.
- Utilize local resources and play to your strengths. Make a special, regional strategy. (Cabanek, 2020)

2.1.3 Indicators of biophilic cities

In the book *Biophilic Cities*, Tim Beatley proposed a set of indicators of a biophilic city and clustered them in three categories:

- Biophilic Infrastructure
- Biophilic spaces and places
- Community and people activity. (Nelson, 2013)

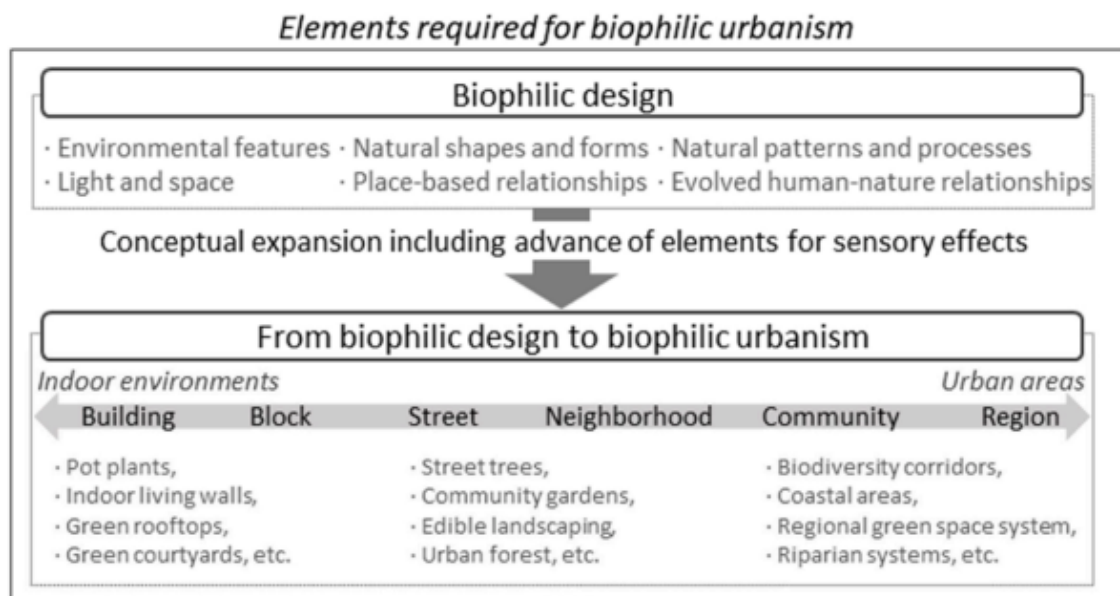


Figure 2. 3 Flowchart of biophilic urbanism

Source: (Lee, 2021)

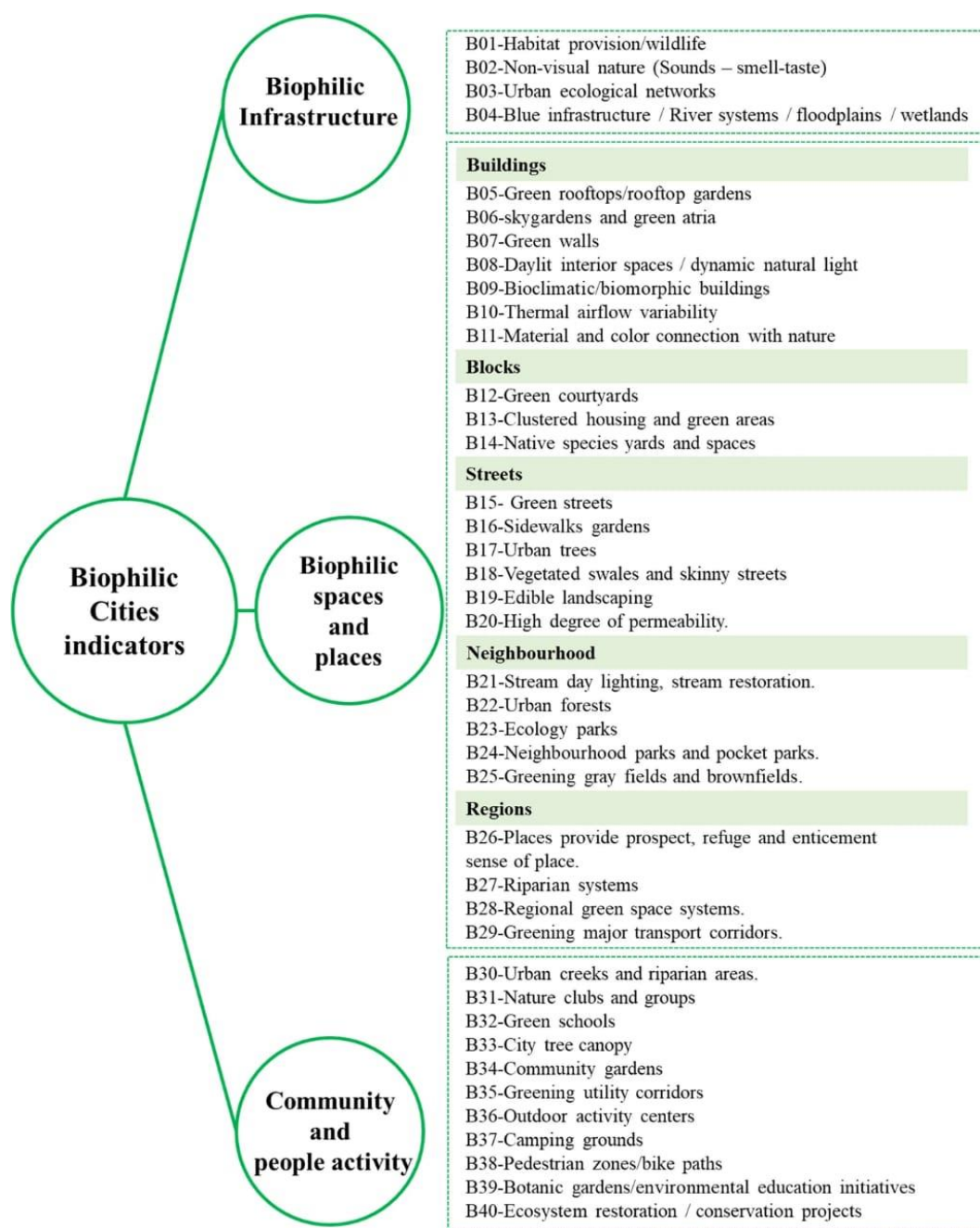


Figure 2. 4 Indicators of biophilic urbanism

Source: (Tarek, 2021)

The indicators are divided into three primary categories: community and human activity, biophilic infrastructure, and biophilic spaces and places (buildings, blocks, streets, neighbourhoods, and regions). It was essential to select indicators that could be measured and utilised with the provided framework since the numerous categories include both physical and non-physical components.

2.1.4 Biophilic design elements

Table 2. 1 Biophilic city design elements

Source: (Beatley, 2013)

Scales	Biophilic design elements
Building	Green rooftops Sky gardens and green atria Rooftop garden Green walls Green courtyards
Block	Clustered housing around green areas Native species yards and Green Urban trees
Street	Low impact development (LID) Vegetated swales and Edible landscaping High degree of permeability Stream day lighting, stream restoration Urban forests
Neighbourhood	Ecology parks Community gardens Neighbourhood parks/pocket parks Greening greyfields and brownfields Urban creeks and riparian areas Urban ecological networks
Community	Green parks City tree canopy Community forest/community orchards Greening utility corridors River systems/floodplains
Region	Regional green space system Greening major transport corridors

2.1.5 Biophilic city dimensions

Biophilic Conditions and Infrastructure

- Percentage of people living close to a park or other open area, such a few hundred feet or metres away
- Ratio of urban land that is covered by trees or other types of vegetation.
- Number of environmentally friendly design elements, such as rain gardens, green walls, and green roofs
- Amount of naturally occurring images, shapes, and forms used in and visible in city architecture
- Dimensions of the city's flora and wildlife (such as its species diversity)
- Biophilic Behaviors, Patterns, Practices, Lifestyles
- The average amount of time spent outside average time spent outside during the day
- The number of people who visit city parks
- The proportion of walking trips
- The size and level of participation in local environmental organisations and groups

Biophilic Attitudes and Knowledge

- Percent of people who say they care about and are concerned about nature
- Percentage of inhabitants who are able to name common types of flora and fauna
- Biophilic Institutions and Governance
- Environmental protection is given top importance by local government; biophilic programmes get a portion of the municipal budget.
- Number and scope of nature education initiatives in neighbourhood schools.
- Number of nature clubs and organisations in the city, ranging from social to advocacy organisations. (Beatley, 2013)

To meet the core of biophilia, biophilic urbanism should keep looking for new solutions. To mirror nature as closely as possible in the place where people live is the core idea behind biophilic urbanism. It makes it possible for individuals to enjoy both the varied advantages that nature offers and its psychological stability. In metropolitan settings, especially in those with a lot of people living there, it might be challenging to dedicate a sizable area to nature only for its role in promoting psychological stability.

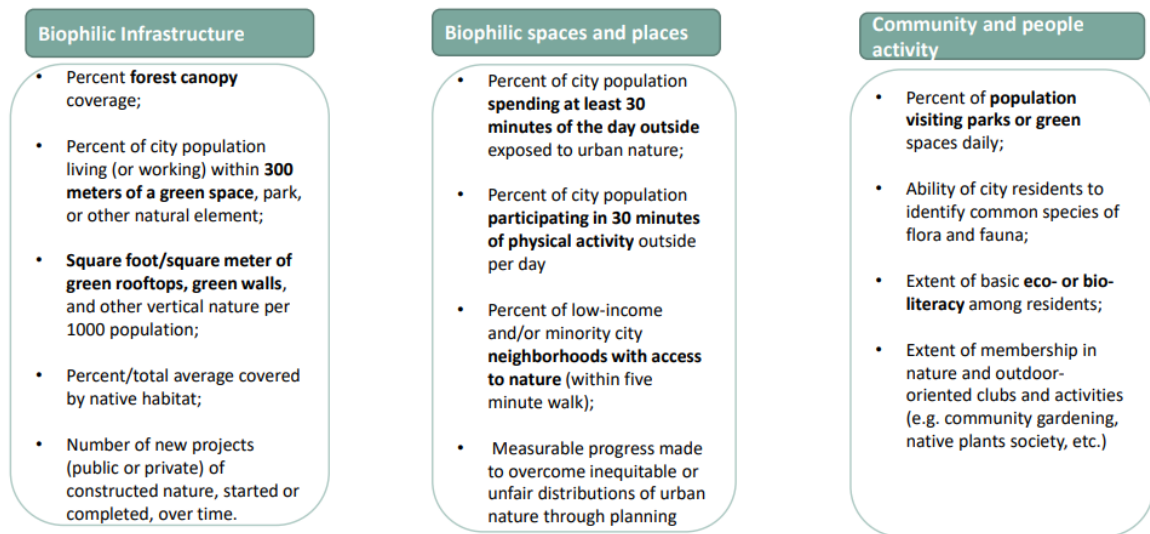


Figure 2. 5 Dimensions of Biophilic urbanism

Source: (Cabanek, 2020)

2.1.6 Scales of biophilic urbanism

Table 2. 2 The scales in Biophilic urbanism

Source: (Lee, 2021)

Macro	Region and city Relatively large and have planar and linear forms.
Meso	Neighbourhood and street Relatively small and appear in partial or pointed forms.
Micro	Small plot areas Individual private areas.

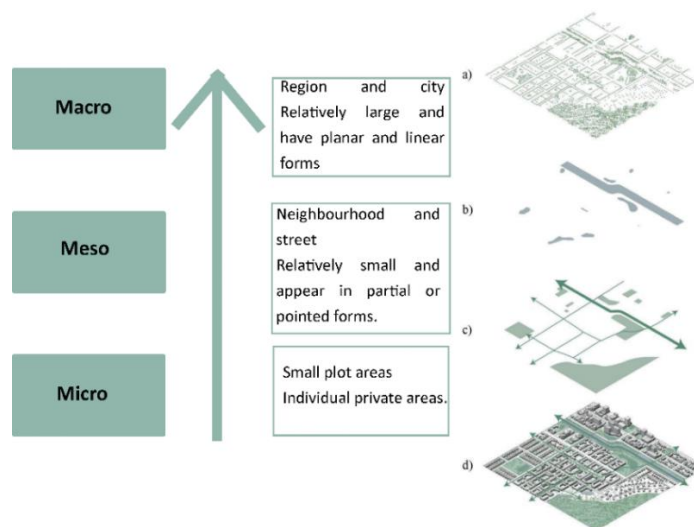


Figure 2. 6 Scales of Biophilic urbanism

Source: (Lee, 2021)

2.1.7 Biophilic urbanism for improving climate change adaptability

According to projections, climate change poses the greatest risk to the stability of the world's economy, society, and environment in recorded history, with mild to severe disruptions affecting populations around the world who have unequal access to resources for adaptation, mitigation, and resilience. Climate change can produce a variety of urban environmental issues (heat waves, urban floods, droughts, etc.) that can reach the level of national catastrophes.

Therefore, it is crucial to develop appropriate climate change solutions, and biophilic urbanism may be a useful strategy for gradually reducing the issues by increasing climate change resilience. In order to create living structures and ecosystems, biophilic design must incorporate sustainability. A development can gain a variety of advantages by including green areas, water features, numerous plants, and natural materials, including lowering its carbon footprint and controlling building temperatures.

Sustainability is viewed as a comprehensive framework for managing urban regeneration and helping cities achieve multiple objectives at once, including lowering their environmental impact and resource demands, raising acceptability and quality of life, and opening up economic opportunities for the underprivileged. The resilience of cities with a dense tree canopy cover is influenced by a variety of ecological benefits, including the reduction of air pollution, the cooling effects of evapo-transpiration and shade, and the avoidance of urban floods and runoff. Urban stream and river conservation and rehabilitation would reduce flood risk, provide major cooling benefits, and help to mitigate the anticipated temperature and precipitation increases brought on by climate change. (Lee, 2021)

2.1.8 Benefits from the perspective of climate change adaptability

- Conservation of biodiversity
- Absorption of greenhouse gas Generation and inflow of fresh and cold air
- Response to heavy rain, flood and drought -Mitigation of urban heat island
- Provision of shading and cool air Reduction of heat stress
- Air quality enhancement and ventilation

- Sustainable stormwater management
- Enhancement of indoor thermal comfort
- Reduction of building energy demand
- Reduction of storm-water runoff
- Mitigation of thermal effects on the surrounding microclimate

2.2 Concepts and definitions of Urban heat island

An **urban heat island (UHI)** is a region that, as a result of human activity, is much warmer than the nearby rural areas. When breezes are light, the temperature differential is frequently greater at night than during the day.

Heat islands are urbanized areas that experience higher temperatures than outlying areas. (EPA, United states environmental protection agency, n.d.).

2.2.1 Evolution of Urban heat island globally

- In the early 1800s, scientists in London made the first discovery of the urban heat island phenomenon.
- The Atlanta Land-use Analysis: Temperature and Air-quality (ATLANTA), study funded by NASA from 1996 to 2000, has been contrasted with the Urban Heat Island Pilot Project (UHIPP). (NASA SCIENCE)
- Reduce urban heat island through the Urban Heat Island initiative of the United States Environmental Protection Agency. (EPA, United states environmental protection agency)

2.2.2 Evolution of urban heat island in Indian Context

- India's Cooling Action Plan by Ministry of Housing and Urban Affairs provide an integrated vision towards cooling across sectors. (Ministry of Environment, Forest and Climate Change, 2019)
- Ensure green covering in cities through stopping deforestation, improving urban design, and boosting planting, according to the Ministry of Health and Family Welfare's National Action Plan for Climate Change and Human Health. (Ministry of Health & Family Welfare, 2018)

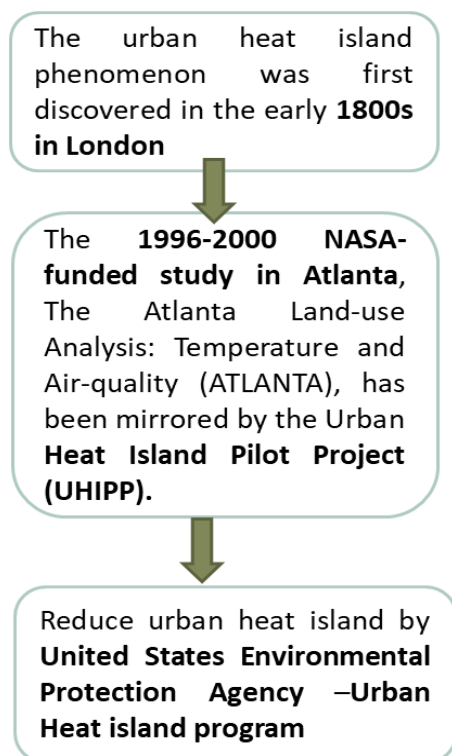


Figure 2. 7 Emergence of urban heat island globally

Source: (Ministry of Health & Family Welfare, 2018)

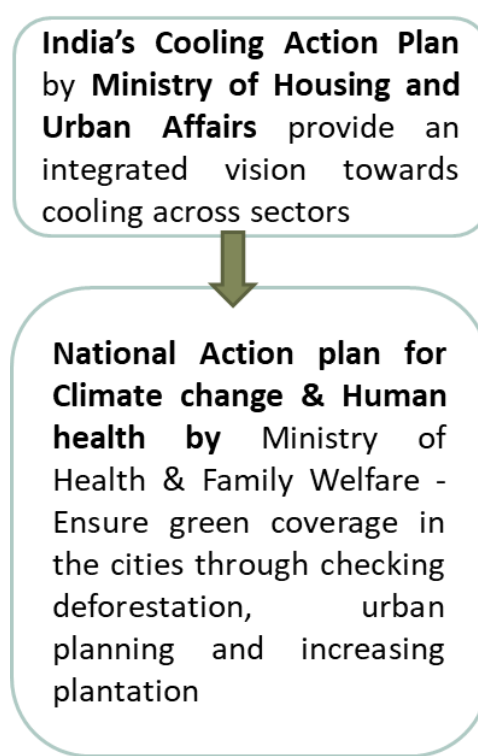


Figure 2. 8 Emergence of urban heat island globally

Source: (Ministry of Health & Family Welfare, 2018)

2.2.3 Urban Heat Island classification

Atmospheric Heat Island (AHI) and Surface Heat Island are the two basic categories of UHI (SHI). SHI is always present. AHI is most prevalent at night and barely detectable during the day. Both permanent weather stations and mobile traverses are used to evaluate the AHI's intensity.

AHI is once again divided into two types: boundary layer heat islands (BLHI), which are found above canopy layer heat islands (CLHI), and canopy layer heat islands (CLHI), which are present in the air between roughness components with an upper boundary below the roof level. (Veena, 2019)

2.2.4 Characteristics of UHI

Typically, the temperature disparity between cities in relation to their environs is used to quantify heat islands. The temperature can vary even within a same city. Due to the uneven placement of heat-absorbing pavements and buildings, some places are hotter

than others, while other areas stay cooler thanks to the presence of trees and other vegetation. Intra-urban heat islands are the term for these temperature changes. Urban ponds, parks, and residential areas are cooler than downtown regions, as the heat island effect graphic shows.

Table 2. 3 Types of UHI effect

Source: (Abraham, 2019)

Feature	Surface UHI	Atmospheric UHI
Temporal Development	Present at all times of the day and night Most intense during the day and in the summer	May be small or non-existent during the day Most intense at night or predawn and in the winter
Peak Intensity	More spatial and temporal variation: Day: 10 to 15°C Night: 5 to 10°C	Less variation: Day: 1 to 3°C Night: 7 to 12°C

2.2.5 Causes of UHI

- Reduced natural scenery in urban areas,
- urban material characteristics,
- urban geometry, and
- heat produced by human activity
- Geography and weather

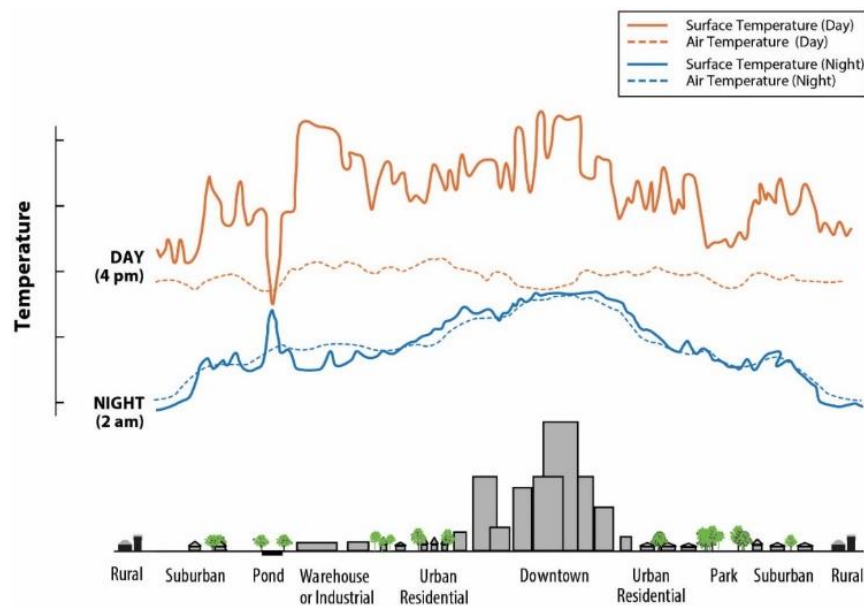


Figure 2. 9 Heat Island effect

Source: (EPA, United states environmental protection agency)

Surface temperatures fluctuate more throughout the day than atmospheric air temperatures, but at night, they are usually equal. Because it does not absorb the sun's energy in the same way as buildings and paved surfaces do, water keeps a relatively consistent temperature throughout the day and night.

This is demonstrated by the dips and spikes in surface temperatures over the pond region. Cooler places may be created within a metropolis via parks, wide open spaces, and bodies of water. Borders between suburban and rural regions often see cooler temperatures than metropolitan centres. The more built-up area will have more heat stress as compared to other open areas. A waterbody can improve the microclimate of an area by releasing hot air up towards the atmosphere. Rural areas are denser with vegetation which causes reduction in heat produced.

2.2.6 Impacts of UHI

- Improved Human Health and Comfort
- Enhanced Emissions of Greenhouse Gases and Air Pollutants
- Deteriorated Water Quality;
- Urban Heat Island and Climate Change

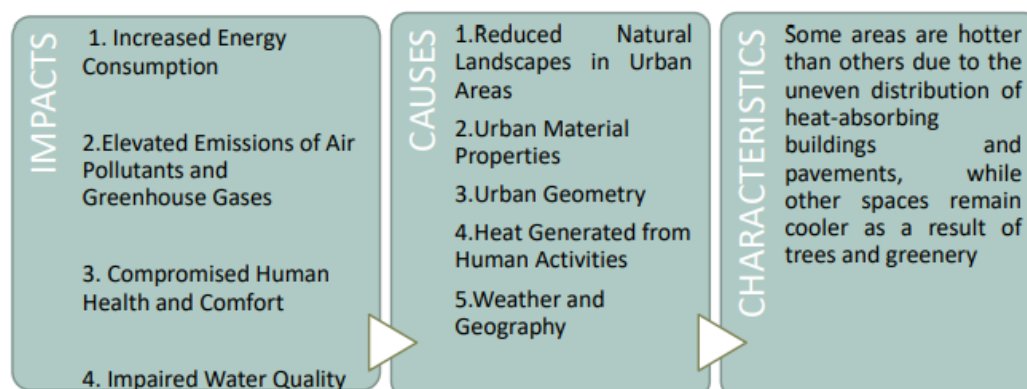


Figure 2. 10 Impacts of UHI

Source: (Mahdavi)

Urban heat island affects climate change in two ways. First, by producing a buildup of heat, the urban heat island effect can exacerbate the consequences of global warming in afflicted urban areas. These places may consequently see more intense heat waves with exceptionally high summer daytime temperatures.

Secondly, the higher power demand for cooling is brought on by the increased heat gains in climate-controlled buildings induced by the heat buildup. Since

conventional energy generation is the primary source of energy for developing nations, an increase in power consumption might result in a spike in the amount of greenhouse gases discharged into the environment. The rising demand for power may also cause economic hardship in developing nations with few natural resources and a growing economy. Therefore, using UHI mitigation measures can help tropical nations reduce climate change.

2.2.7 Increasing Heat Island formation in Indian cities

In a trend study of a series of lowest temperature readings from 1926 to 1994, the heat island effect was found. Additionally, it was discovered that the annual mean temperature was rising by 0.05°C year. In a trend study of a series of lowest temperature readings from 1926 to 1994, the heat island effect was found. Additionally, it was discovered that the annual mean temperature was rising by 0.05°C year.

In Indian cities, urbanisation has become a significant problem because it causes heat pockets, or UHI, which boosts the temperature of the near-surface air, cities grow and the local climate changes as well. Variations in the form of the city and the related sky view factor, as well as air pollution and anthropogenic heat created by human activity, industries, autos, and other factors, all contribute to changes in city climate. The highest UHI intensity ever recorded worldwide is as high as 12 degrees Celsius, while India has the highest measured UHI intensity at 89 degrees Celsius, according to the findings. Due to the formation of heat islands, there is a significant rise in energy and water use, increased emissions of pollutants into the atmosphere that contribute to the greenhouse effect, discomfort from the heat in terms of one's health and quality of life, and deterioration in the water quality of streams, rivers, and other bodies of water. Increased heat is also caused by a lack of public outreach and education. Therefore, measures to balance the microclimate of cities should be developed, and the people should be well informed. (Veena, 2019)

2.2.8 Parameters in UHI phenomenon

- Land cover
- Land cover types
- Population Density

- Average width of streets
- Irregularity of the city
- Clear sky days
- Windless days
- Average max summer temperature
- Average summer thermal excursion

2.2.9 Factors affecting UHI

- Time(day/night)

Day: Urban surfaces are warmed by the absorption of solar radiation.

Night: Surfaces lose heat at night principally by radiation to the comparatively cool sky, and this is blocked by the buildings in an urban area.

- Wind and cloud cover

At Daytime, the change in the temperature difference due to wind speed is very small.

Urban heat islands formed during periods of calm winds and clear skies, because these conditions maximize the amount of solar energy reaching urban surfaces and minimize the amount of heat that can be convected away.

- Climate, Topography and surroundings

Climate and topography, are determined by a city's geographic location and it influence urban heat island formation.

Surroundings-large bodies of water moderate temperatures and can generate winds that convect heat away from cities. Nearby mountain ranges can either block wind from reaching a city or create wind patterns that pass through a city

- Land surface temperature (Type of material)

Land surface temperature (LST) is the radiative skin temperature of the land derived from solar radiation. LST measures the emission of thermal radiance from the land surface where the incoming solar energy interacts with and heats the ground, or the surface of the canopy in vegetated areas.

UHI is a region with high LST than the surrounding areas. Generally, this occurs due to constructions with low albedo material and de-vegetation in urban areas. This causes those areas to have high LST than surrounding areas.

- Ground cover (Landcover, Landuse, Built density)

The change in ground cover results in less shade and moisture to keep urban areas cool. Built up areas evaporate less water which contributes to elevated surface and air temperatures.

2.2.10 Methods of UHI study

In various regions of the world, several approaches for studying UHI have been created. Theoretical/empirical studies have been accessible since the beginning of recognizing the relevance of UHI research. However, observational, experimental, and computational investigations are employed to estimate the existence of UHI in real time and to identify solutions to mitigate its effects. Remote sensing, field measurements, and meteorological weather station data are examples of observational methodologies. (Veena, 2019)

- Satellite data
- For the UHI investigation, the LANDSAT satellite types are primarily employed to acquire photographs of the land surface. The sensors and versions of LANDSAT that are often utilised are MODIS, TERRA, TIRS, TM, ETM, ASTER, AVHRR, etc. Since satellites and the earth are always in motion and it is risky to gather the precise moving air temperature above the ground, remote sensing is employed to measure land surface temperature. Temperature information is provided via satellite thermal sensors at different spatial resolutions.
- Fixed weather station data
- Another way to determine the temperature in urban and rural regions is to use data from meteorological weather stations.
- Field survey

There are two different kinds of field measurements: stationary survey and mobile survey. A permanent location is chosen for a stationary survey, and tools like thermometers are employed to track the temperature variation there. For mobile surveys, a vehicle with temperature measurement equipment already mounted often travels pre-selected routes through various land use categories. Mercury thermometers, infrared thermometers, psychrometers, digital thermometers, RTD probes, automatic temperature recorders, Max tech digital thermometers, etc. are frequently used tools to detect heat intensity. (Veena, 2019)

2.3 Comparative study and analysis

2.3.1 Analysis on Biophilic urbanism elements

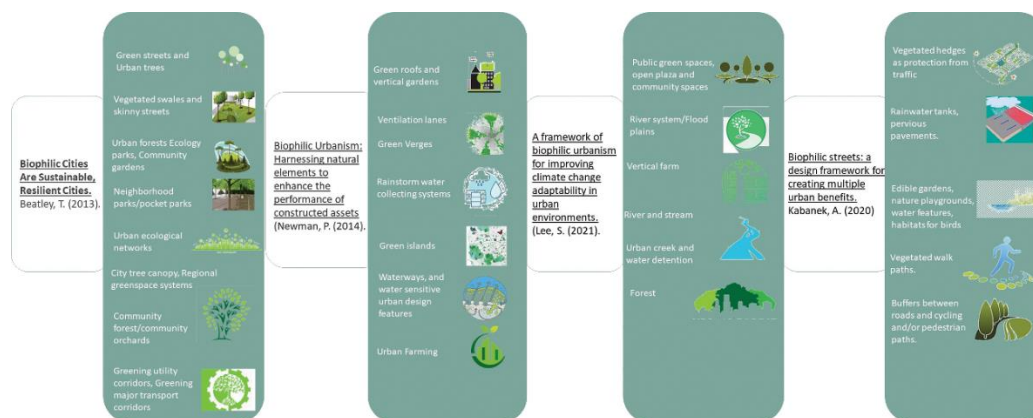


Figure 2. 11 The elements of biophilic urbanism identified

Source: Author generated

Based on the biophilic urbanism and urban heat island mitigation several elements of biophilic urbanism are identified.

By comparing the scales of biophilic urbanism and categorising the key elements in each scale, it was possible to determine which elements were the most prevalent and, maybe, the ones that the literature generally believes will be most effective in delivering excellent quality of life and meet the parameters of urban heat island.

2.3.2 Biophilic urbanism Elements derived w.r.t urban planning level

Table 2. 4 Biophilic urbanism elements identified

Source: (Biophilic cities, 2015)

Streets	Neighbourhood	Regions
Green streets	Stream restoration.	Ecosystem restoration
Sidewalks gardens	Urban forests	Regional green space systems.
Urban trees	Ecology parks	Greening major transport corridors
Vegetated swales and skinny streets	Neighbourhood parks and pocket parks	City tree canopy
Edible landscaping	Greening gray fields and brownfields	Community gardens
High degree of permeability	Low impact development	Pedestrian zones

The biophilic urbanism can be categorised in to different scales as this promotes more efficient planning at urban level. The planning starts from neighbourhood level that is at the micro scale in planning. In planning the scales in urbanism and the elements dealt with it are important elements to consider. The elements are classified in to different categories for the efficient planning strategies.

The comparative analysis between the biophilic urbanism elements and urban heat island parameters creates a strong relationship between the elements that can be integrated with the urban heat island mitigation measures to increase the effect of biophilic urbanism in a high-density built-up area. The biophilic urbanism are taken in to consideration at the planning level. The interconnection between the elements and parameters are considered before planning interventions in to action.

2.3.3 Urban heat island parameters in urban planning

Table 2. 5 Urban heat island parameters identified

Source: Author generated

Key Parameters for Urban Heat Island Assessment in A Mediterranean Context (Agnese Salvati, (2017)	The Urban Heat Island phenomenon modelling and analysis (Kaoutar Ouali, (2017)	Counteracting urban heat island effects in a global climate change scenario (Mahdavi)	Development of a holistic urban heat island evaluation methodology (Sangiorgio, 2020)
The city radius	Air speed	Warm ambient air temperature	Weather and climate conditions
The urban morphology	Cloud cover	Vegetative surfaces	Characteristics of the city
The tree coverage	Sky view factor	Building agglomeration density	Anthropogenic heat, related to population density
The anthropogenic heat from vehicles	Solar radiations and anthropogenic heat sources	Anthropogenic heat production	City canyons whose influence depend on urban layout
		Traffic intensity	
		Presence and extent of green areas and bodies of waterbody	

Parameters Derived-

- Vegetative surfaces
- Weather and climate conditions,
- Presence of Green areas and Waterbodies,
- Air Temperature,
- Tree coverage,
- Cloud cover,
- Air speed.

2.3.4 Comparative analysis for the Framework

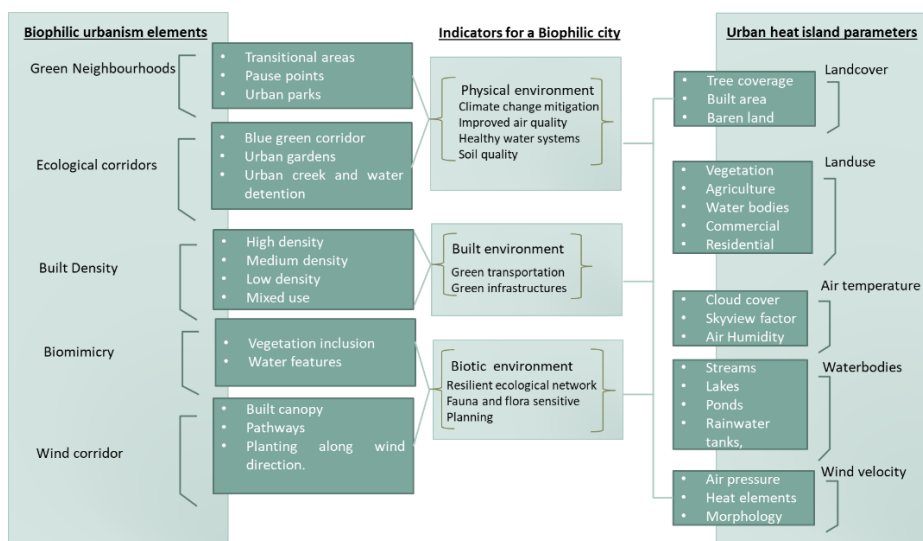


Figure 2. 12 Comparative analysis of BU AND UHI parameters

Source: Author generated

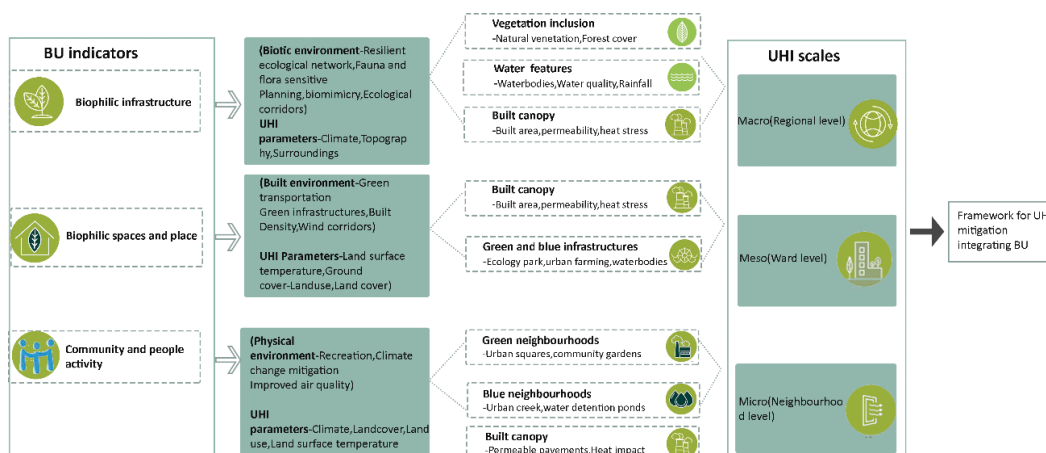


Figure 2. 13 Indicators and elements for Framework

Source: Author generated

The elements identified through the comparative analysis of Biophilic urbanism elements and urban heat island parameters. The comparison shows the relation between them and how they can be interconnected. The indicators formed with respect to the elements and parameters derived, we can arrive at a conclusion of the influence of the above-mentioned elements, sub elements and parameters.

2.4 Biophilic urbanism implemented in uhi zones (case studies)

2.4.1 THE COOL CITY, STUTT GART, GERMANY

2.4.1.1 Background

Stuttgart is particularly vulnerable to poor air quality because of its valley basin position, warm temperature, slow wind speeds, industrial activity, and heavy traffic volume. Air flow through the city has been hampered by development on the valley slopes, which has worsened air quality and increased the urban heat island effect. Of Stuttgart's 207 km² of land, 49 percent is inhabited by towns.

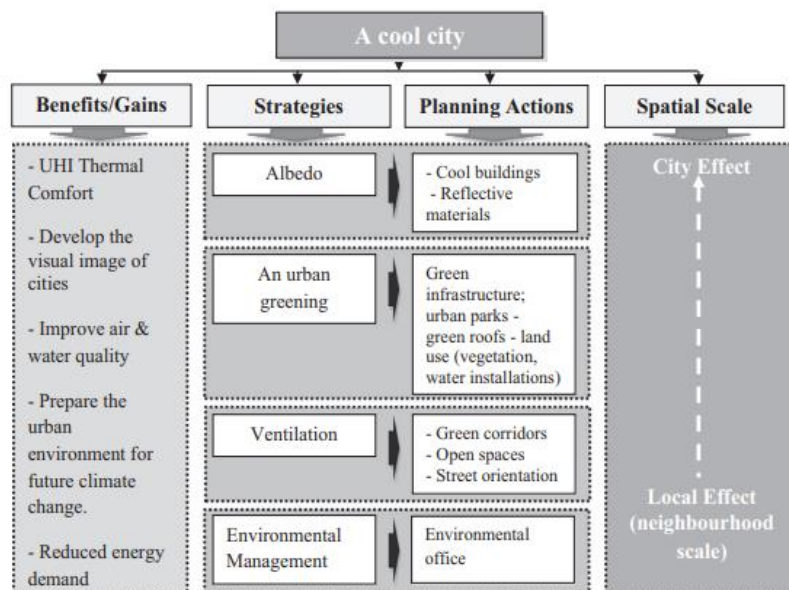


Figure 2. 14 Cool city framework

Source: (Rehan, 2019)

2.4.1.2 Objectives of a cool city

- Support the creation of green infrastructure and green areas to improve air quality and lower greenhouse gas emissions in order to achieve environmental sustainability.

- Helps in cleaning the air, reducing our carbon footprint, and paving the way for a more stable climatic future.
- Reduce energy consumption: Plants and trees that directly shade buildings consume less energy to cool them. By employing tree shade to halt pavement deterioration, less maintenance is required on the pavement. To lower UHI, encourage cooling in urban areas.

2.4.1.3 Concept of Cool city

Encourage the construction of green areas and green infrastructure to improve air quality and lower greenhouse gas emissions in order to achieve environmental sustainability.

Goal: How dense vegetation and natural wind patterns may actively assist the city in reducing its problems with air pollution and overheating.

2.4.1.4 The parameters considered and applied for framework

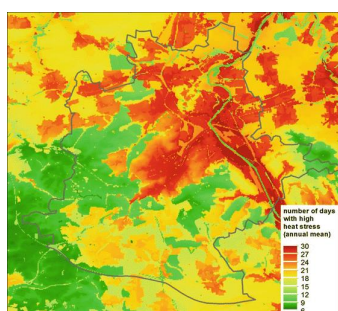


Figure 2. 15 Annual mean temperature in Stuttgart
Source: (Rinke)

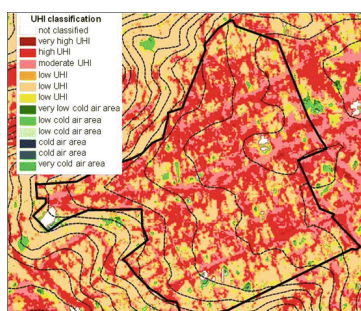


Figure 2. 16 UHI classification as per temperature range
Source: (Rinke)

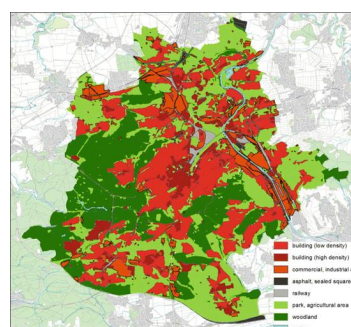


Figure 2. 17 Green cover landuse map
Source: (Rinke)

2.4.1.5 Inference

By reducing the UHI impact, the framework suggests a paradigm to direct urban designers and planners toward building a cool city. Finding chances for **urban greening**, improving the energy efficiency of buildings, and sticking to the idea of the **urban green corridor**—all of which help to improve the quality of the urban environment—are some of the tactics used. The growth of these corridors also improves the city's image, making it more alluring and desirable. If used consistently, each of

these strategies has a good chance of reducing the negative effects connected to the prevalence of UHIs in the built environment.

2.4.2 PORTLAND, OREGON

2.4.1.1 Background

A city in the American Pacific Northwest is Portland, Oregon. It has a generally Mediterranean climate, with mild winters and summers marked by dry, hot weather. Due to its high walkability, significant bicycle population, farm-to-table food, and more than 4,000 hectares of public parks, Portland, the biggest city in Oregon, is frequently listed as one of the world's most environmentally aware towns. A Portland State study reveals how reflecting materials, trees, and plants help lessen excessive heat in urban neighbourhoods. Portland is praised as one of the greenest cities in the world due to its innovative efforts.

2.4.1.2 Cluster Analysis

Using these six land-cover characteristics, groupings of the Portland metropolitan area were created:

- (1) Percentage of canopy,
- (2) Percentage of vegetation,
- (3) Total biomass density
- (4) Building height standard deviation
- (5) mean building height
- (6) overall building volume, and
- (7) building height.

We can evaluate the efficacy of mitigation measures at various landscape characteristics according to the clustering.

- The study used computer modelling to demonstrate the temperature variations that can be produced in different property types, from tree-lined neighbourhoods to extensively paved industrial areas, by using materials on roofs and pavement that reflect heat, growing trees and other plants, creating green roofs, and other similar practices.
- The average city block size in Portland, Oregon, ranges from 80 to 110 m.

Table 2. 6 The type of clusters

Source: (Makido, 2019)

CLUSTERS	TYPE OF CLUSTER
Cluster 1	High-Canopy Neighborhood
Cluster 2	Urban Districts and Corridors
Cluster 3	Medium-Canopy Neighborhood
Cluster 4	Hardscaped Industrial
Cluster 5	Vegetated Urban
Cluster 6	Semi-Rural
Cluster 7	Hillside Forest

Six research sites were finally chosen for microclimate modelling based on the seven cluster types; however, cluster 7 (hillside forest) did not receive a site since it did not meet the criteria.

Here is an illustration of the primary land-use and/or land-cover characteristics for each of the six chosen research locations.

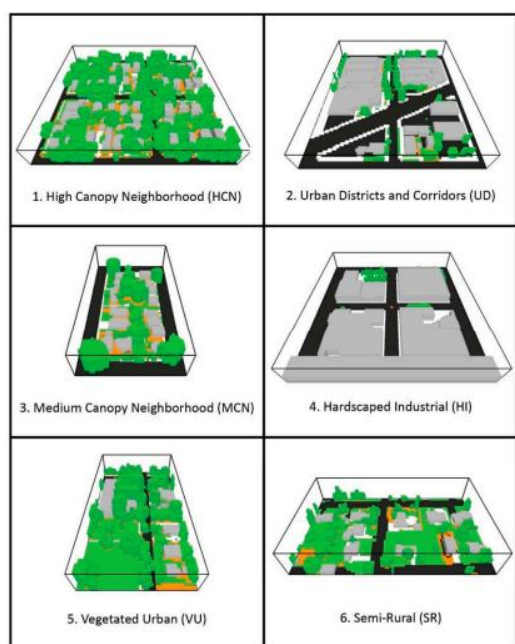


Figure 2. 18 land-use and/or land-cover types

Source: (Makido, 2019)

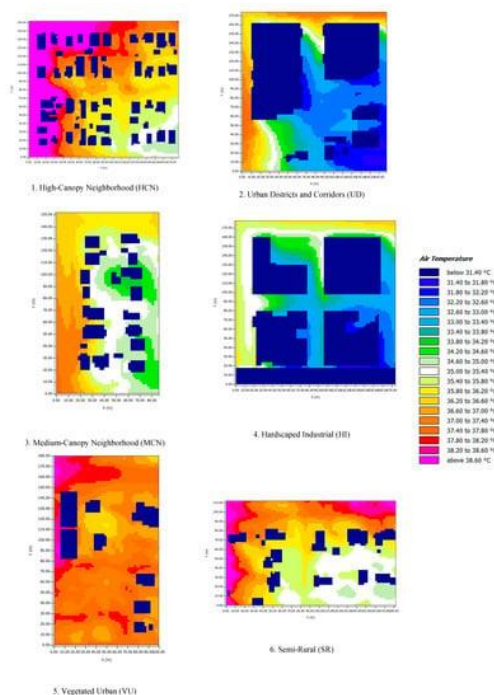


Figure 2. 19 Simulated air temperature

Source: (Makido, 2019)

2.4.1.3 Results

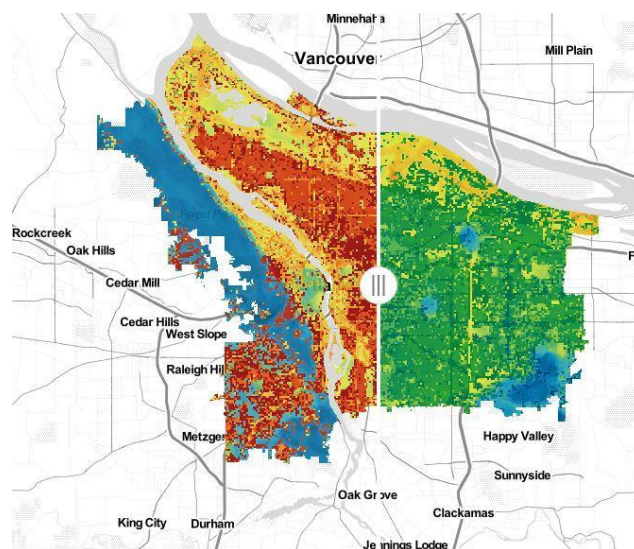


Figure 2. 20 Air temperature (in °C)

Source: (Makido, 2019)

Two different scenarios are depicted on an interactive map showing Portland's temperature changes: one in which cooling measures are put in place, such as increasing vegetation and employing reflecting materials on roofs and pavement, and the other in which they are ignored, resulting in greater temperatures.

2.5 GREEN INITIATIVES PROGRAMMES BY GOVERNMENT OF INDIA

▪ NATIONAL ACTION PLAN ON CLIMATE CHANGE (NAPCC)

To pursue a sustainable development course that meets economic and environmental goals at the same time.

- Green India mission - -The primary aim is to protect, restore and enhance India's diminishing forest cover
- Global Sustainable Environment Plan (under the Ministry of Housing and Urban Affairs)

▪ GREEN SKILL DEVELOPMENT PROGRAMME

Green skills refer to those that contribute to preserve and restore environment and create a sustainable future.

CHAPTER 3 STUDY AREA AND ANALYSIS

Thiruvananthapuram (corporation area)

3.1 Introduction to study area

The capital and largest city of the Indian state of Kerala is Thiruvananthapuram, sometimes referred to as Trivandrum. The population of the city is 957,730, while there are 1.68 million people living in the nearby metropolitan region. As of 2015, 55% of Kerala's software exports came from Thiruvananthapuram, a significant IT centre in India. On India's west coast, not far from the country's southernmost point, is the city of Thiruvananthapuram. The 2192 sq. km. district as a whole is classified as a single revenue division. There are four taluks in this district: Nedumangad, Thiruvananthapuram, Chirayinkeezhu, and Neyyattinkara. As of January 1st, 2006, the district has 12 development blocks and 115 revenue villages. As per census 2001, Thiruvananthapuram district having an area of 2192 sq.km and population of 986578 in 2011.



Figure 3. 1 Location of study area
Source: (Anupriya R S, 2020)

3.2 Issues identified for macro level site area delineation

3.2.1 Population density

Population Density: 1508 person/sqkm as per Census 2011

Total population: 9,86,578 as per Census 2011

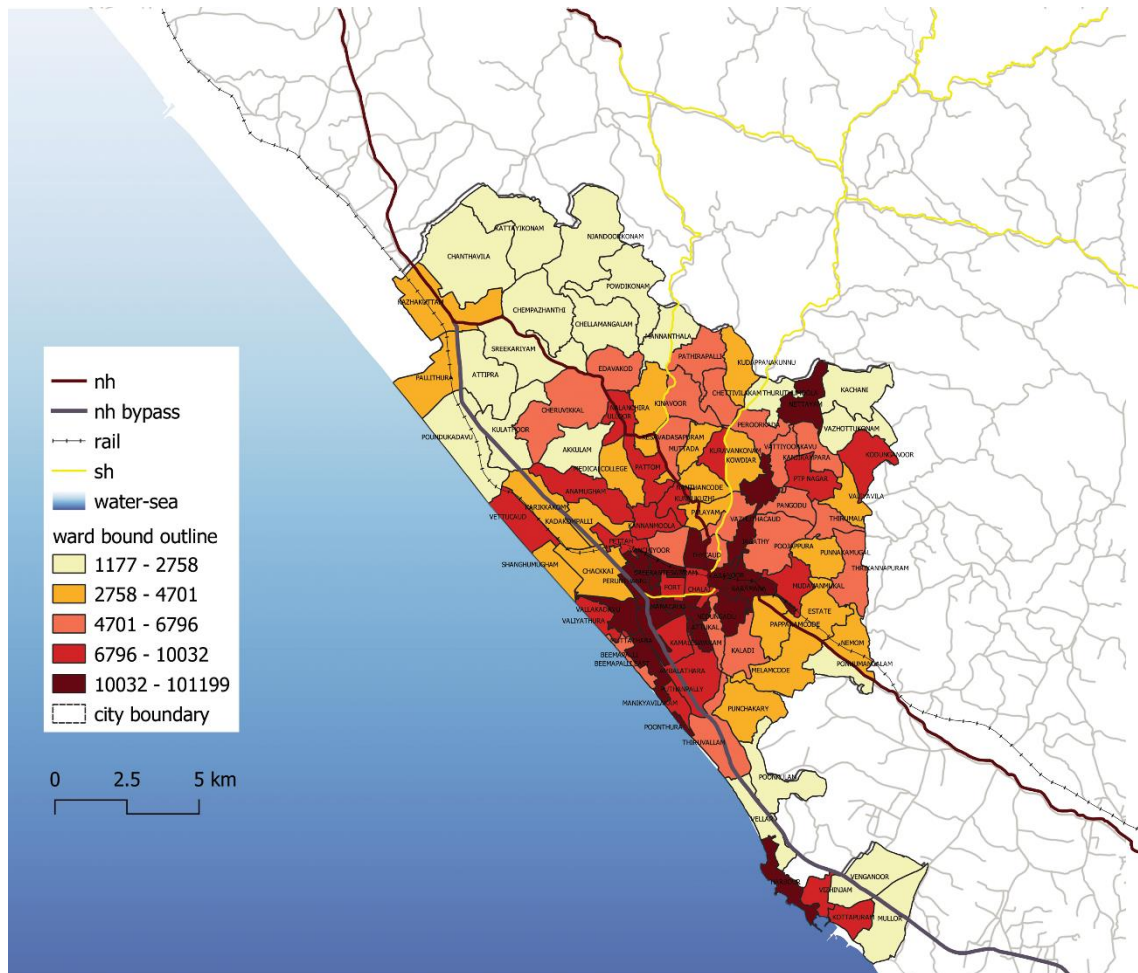


Figure 3. 2 Population density map,2012

Source: Author generated with reference to Regional Town and country planning Department, 2012

Thiruvananthapuram district has fourth rank in the urban content as per the Census classification. Kerala's **“third highest population density”** of 859 people per sq km is an aggregate number and the highest figure is in Thiruvananthapuram - 1508 per sq km. (G Pramod Kumar, 2020) As per data released by Govt. of India for Census 2011, Thiruvananthapuram is an Urban Agglomeration coming under category of Million Plus UA/City.

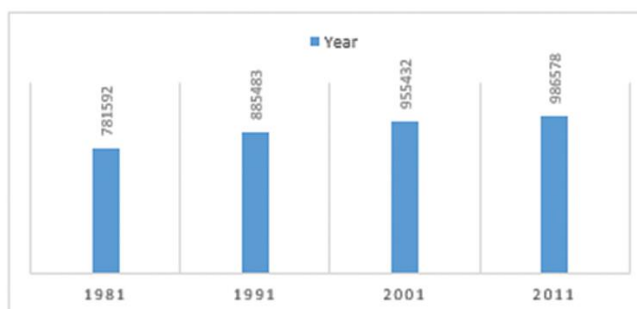


Figure 3. 3 Population growth in different decades
 Source: Author generated with reference to Census handbook 2011

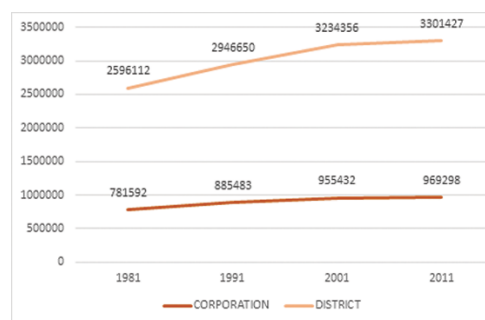


Figure 3. 4 Total population comparison of district and city
 Source: Author generated with reference to Census handbook 2011

Thiruvananthapuram Corporation is taken as first order settlement. The urban population content of the State is 26% and that of Thiruvananthapuram district is 33.8%. The city has an average density of 4444 persons per sq km. Trend of urbanisation is more along the railway and NH corridor.

Inference

- The most populous ward in city is Anamughom with population 20,244 and least populous ward is Manikkavilakom with population 3098 persons per sqkm.
- The most populous wards in the city are: Thampanoor, Sreekanteswaram, Palkulangara, Perunthanni, Vallakadavu, Sreevaraham, Beemapally, Muttathara, Valyasala, Jagathy, Karamana, Nedumangadu, Sasthamangalam

3.2.2 Lack of green spaces

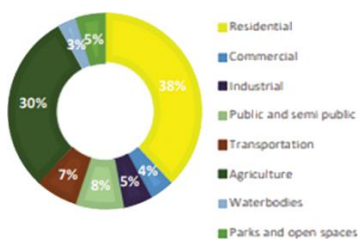


Figure 3. 5 Land use breakup map,2001
 Source: Thiruvananthapuram Masterplan,2012

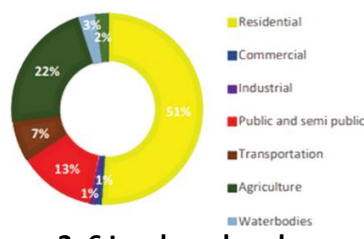


Figure 3. 6 Land use breakup map,2012
 Source: Thiruvananthapuram Masterplan,2012

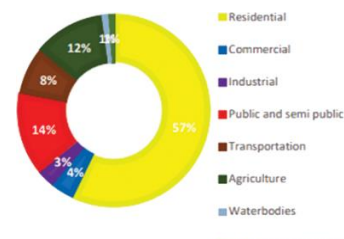


Figure 3. 7 Land use breakup map,2017
 Source: Thiruvananthapuram Masterplan,2012

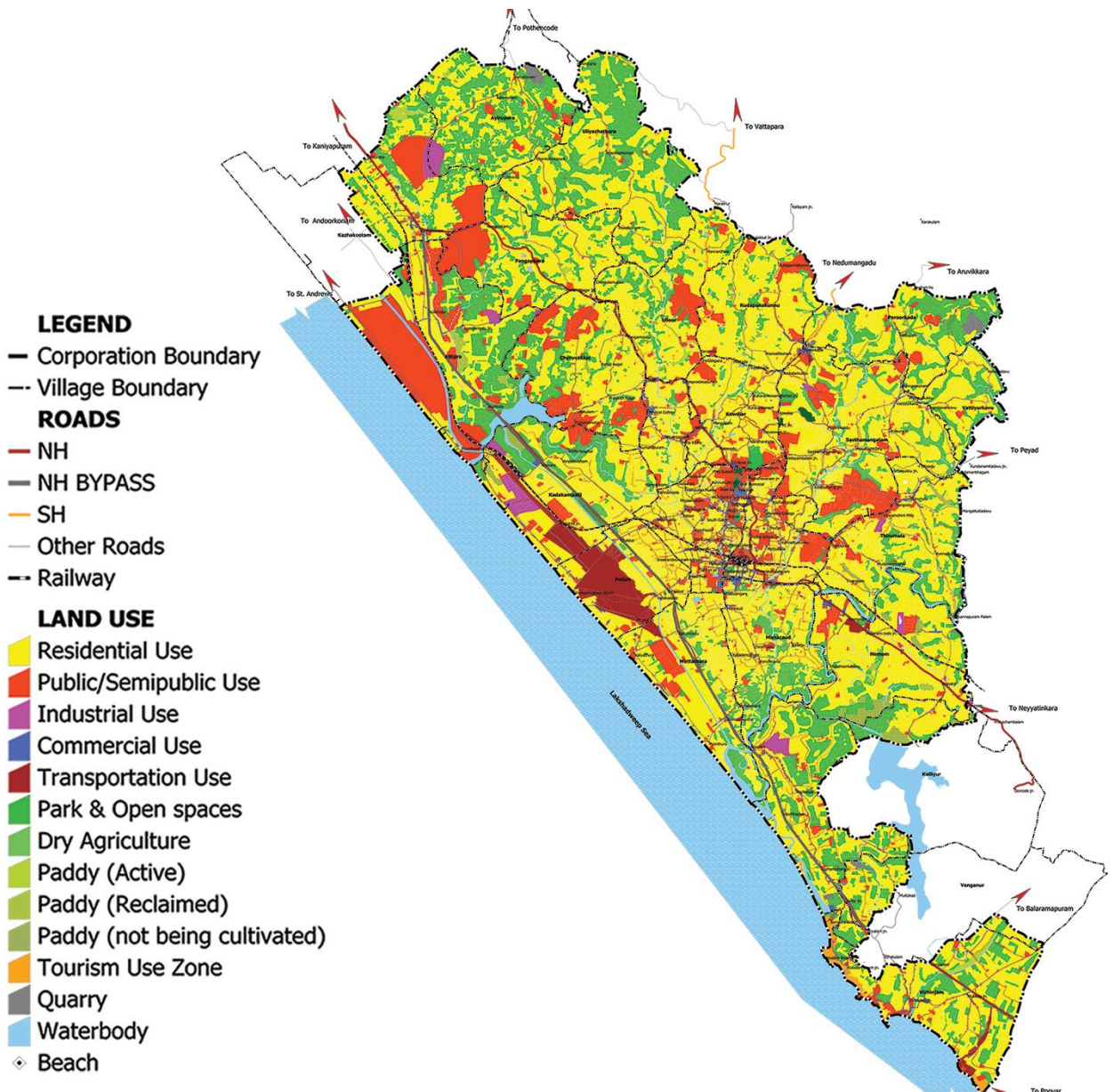


Figure 3. 8 Landuse map,2012
 Source: (Thiruvananthapuram Masterplan, 2012)

Inference

The increasing built up areas such as residential, public and semipublic and a decreasing trend in the green areas over the years is observed in the landuse breakup pie charts. The change over the years is notable that the percentage of waterbodies had a huge shrinkage and also the green cover has affected due to the growth of the city. Most of the areas has been converted to build use where encroachment due to urbanisation occurred over the years.

3.2.3 Highly vulnerable district as per sapcc-2014

Reasons for the climate change are:

1. Urban sprawl and spatial character

Although Thiruvananthapuram acts as a service town, where people are primarily engaged in government and institutional activities, post-1990, there has been tremendous growth in industrial units within the UA. The establishment of Technopark at Kazhakootam in 1990 and KINFRA (Kerala Industrial Infrastructure Development Corporation) in 1993 developed small industries park at Thumba and a film and video park at Kazhakootam.

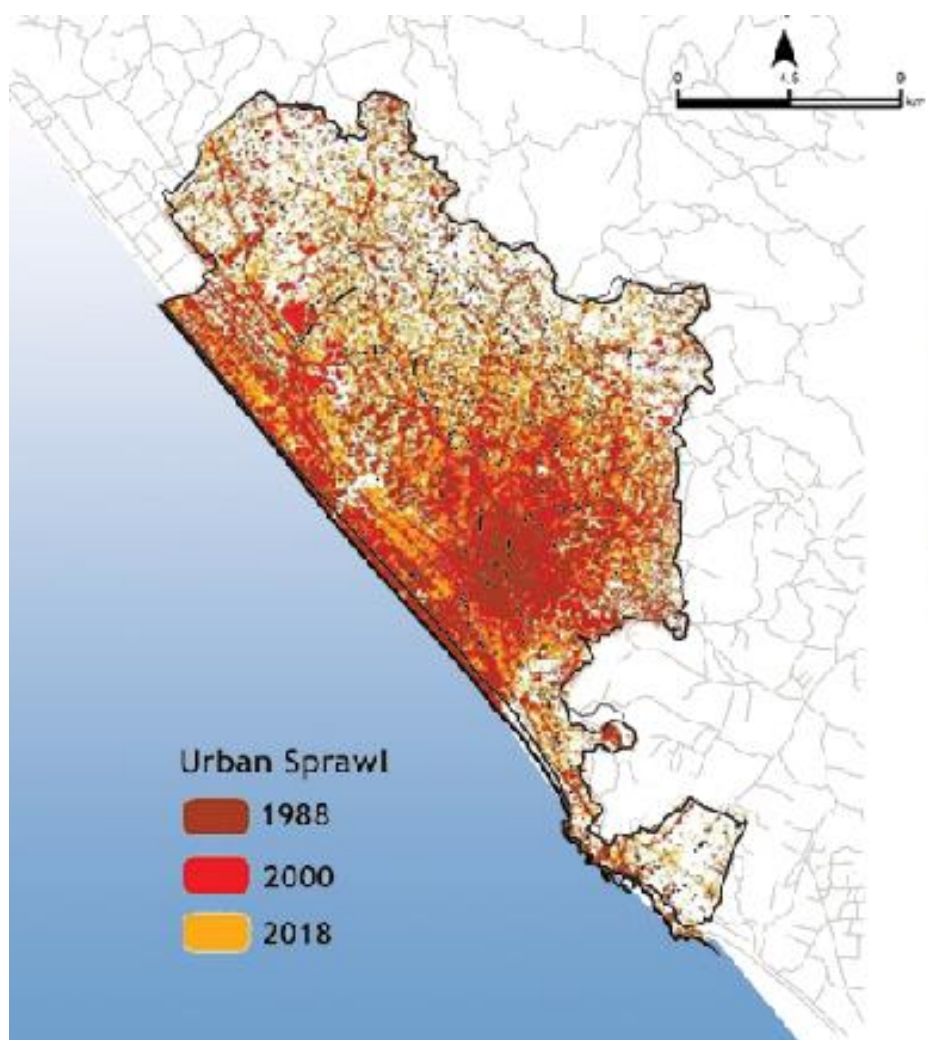


Figure 3. 9 Urban sprawl of various years

Source: Author generated with reference to (Anupriya R S, 2020)

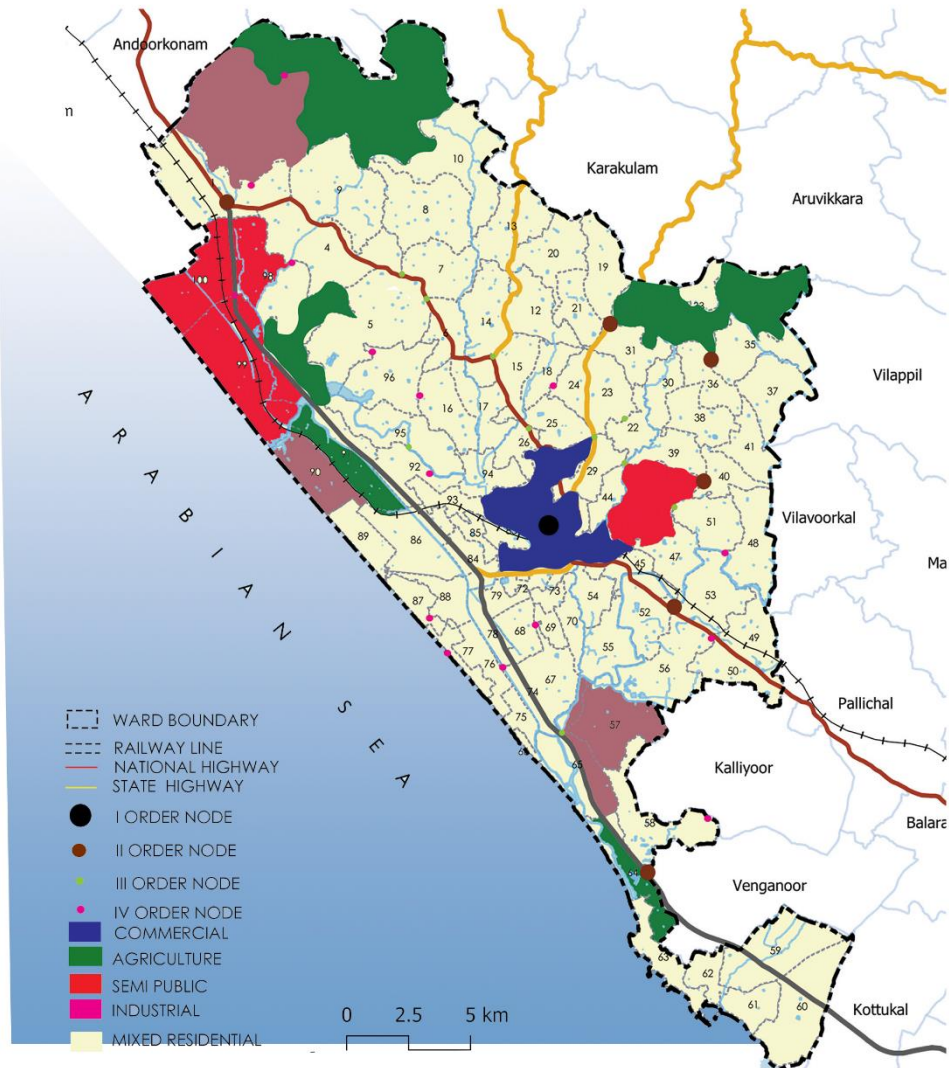


Figure 3. 10 Spatial distribution

Source: Author generated with reference to (Thiruvananthapuram Masterplan, 2012)

Inference

- The highest gain in urban sprawl typologies during 2001–2021 had occurred in scatter development, i.e., 11.91 km².
- Overall scatter development was the dominant urban sprawl typology prevailing in the peri-urban areas of Thiruvananthapuram UA.

2. Heat stress

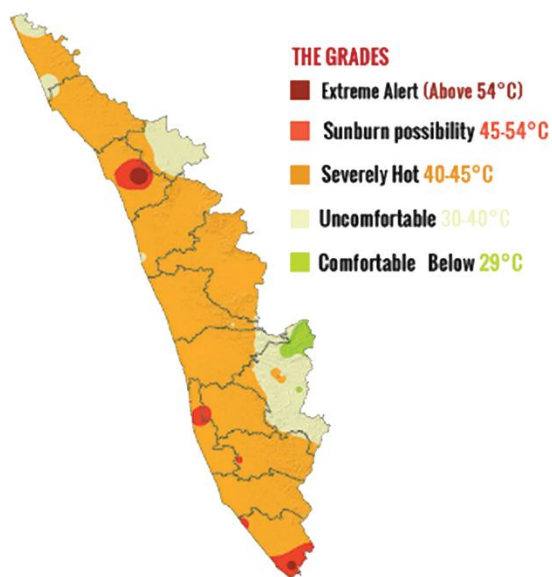


Figure 3. 11 Heat index map

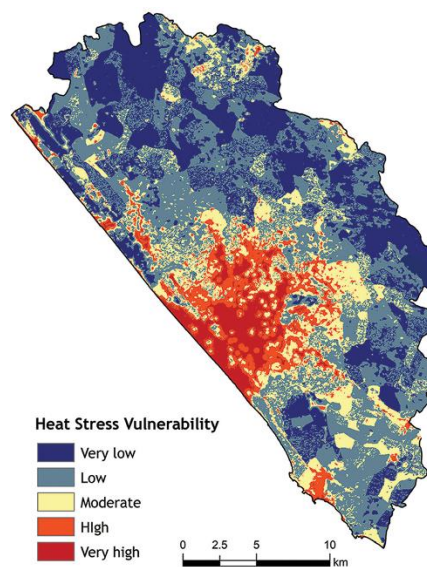


Figure 3. 12 Spatially distributed HSVI

Source: Author generated with reference

to (Anupriya R S, 2020)

3. Rainfall

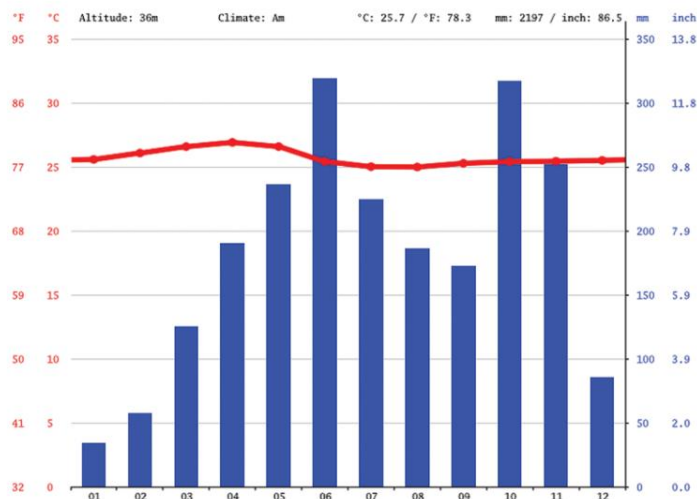


Figure 3. 13 Rainfall data of various months

Source: (Meteorological department, 2021)

Inference

- Thiruvananthapuram is one among the extreme alert of heat stress as per the latest report and the heat stress is high at the city centre
- The driest month is January, with 34 mm ie;1.3 inch of rain. Most of the precipitation here falls in June, averaging 319 mm ie;12.6 inch.

3.2.4 Urban/rural cooling rates in Thiruvananthapuram

Study conducted by Atmospheric Sciences Division, Centre for Earth Science Studies, Thiruvananthapuram it is observed that the UHI intensity in Thiruvananthapuram is comparable to the UHI observed in other cities, especially coastal cities like Kochi, Chennai, etc.

The peak cooling rate recorded at rural area was 3.4 degree C/hr. while highest at the urban site was only 1.5 degree C/hr. It shows medium intensity UHI with maximum value of 2.4 degree C in the city centre.

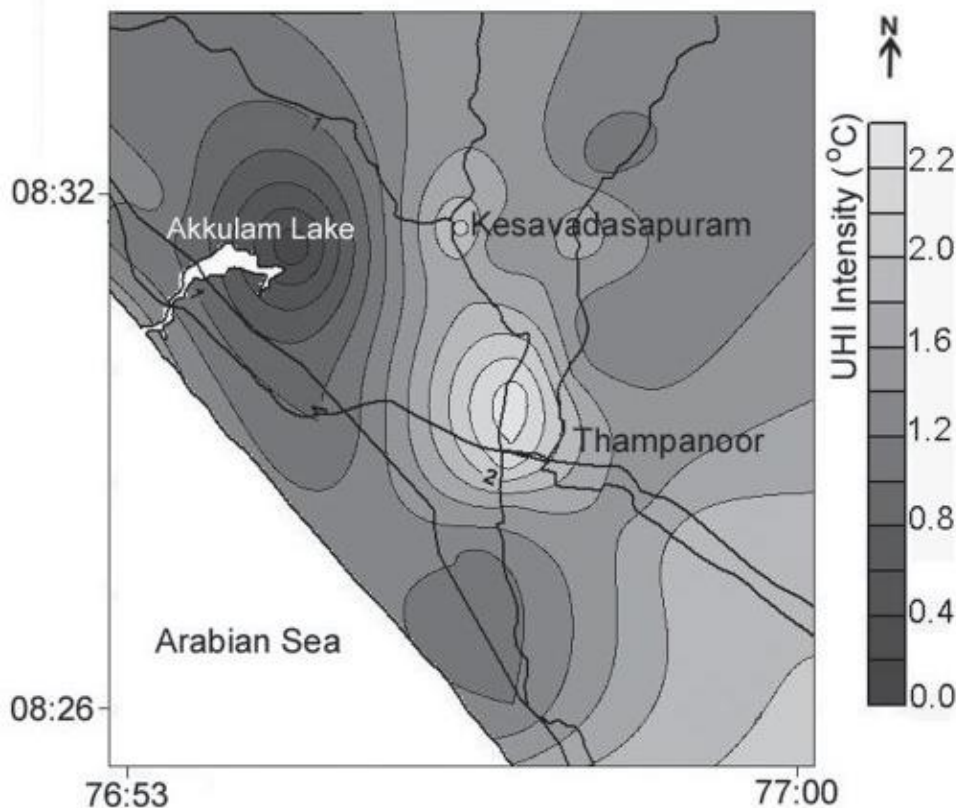


Figure 3. 14 UHI Intensity

Source: (S.Ansar, 2012)

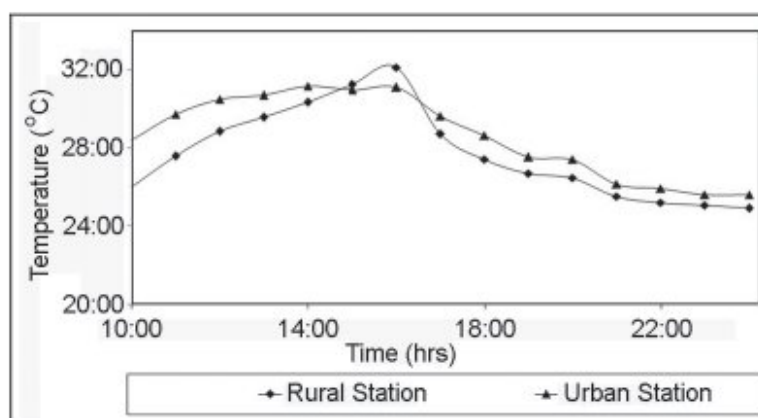


Figure 3. 15 UHI variation in rural and urban areas with temperature

Source: (S.Ansar, 2012)

Inference:

Heating rates show a higher value in the rural area. The dense buildings restrict the sky view factor in cities. Regions showing lower temperature fall under Open set low rise and sparsely built classes.

3.3 Macro level indicator analysis

Indicator 1 -Biophilic infrastructure

BU Indicators: Biotic Environment-Resilient ecological network, Fauna and flora sensitive Planning, biomimicry, Ecological corridors

UHI parameters: Climate, Topography, Land surface temperature

Elements and sub elements:

- Vegetation inclusion
- Water features
- Built Density

3.3.1 Vegetation inclusion: Natural vegetation and forest cover

Amid growing forest cover, shrinking canopy in three districts worries Kerala. As per the latest report of Kerala Forest Department, there is decline forest cover in three districts of kerala in which 23 sq km decline of forest cover in Thiruvananthapuram. (The New Indian Express, 2020)

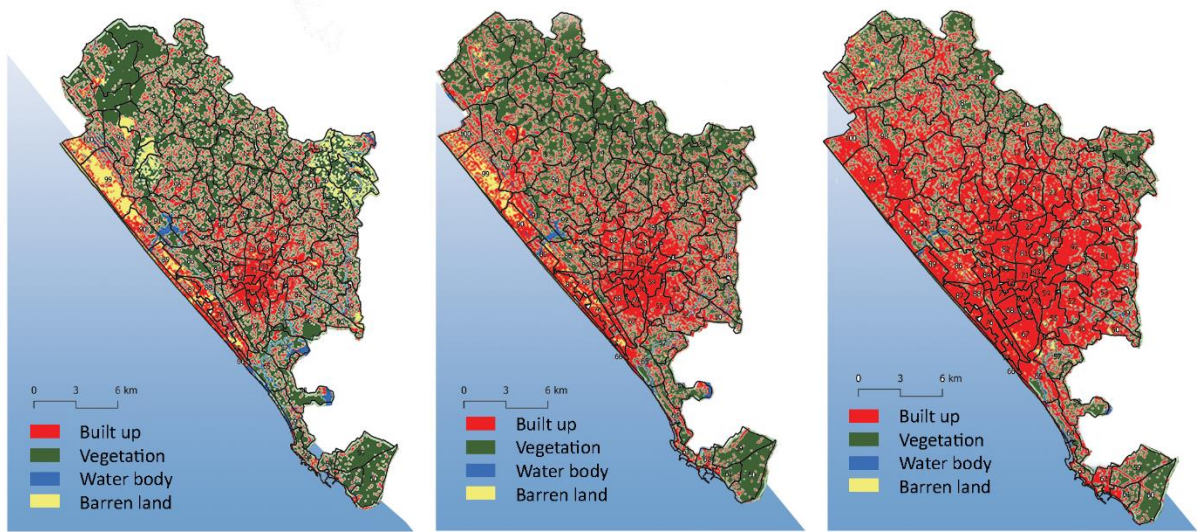


Figure 3. 16 Landcover map (1988,2000,2022)

Source: Author generated using Landsat image,2023

Table 3. 1 LULC change over years

Source: Author generated with reference to (Chethry, 2021)

	1988		2000		2022	
LC	Area(sqkm)	Area(%)	Area(sqkm)	Area(%)	Area(sqkm)	Area(%)
Built	102.08	19.33	141.93	26.89	163.23	42.23
Vegetation	125.65	71.03	98.23	68.76	54.34	25.2
Waterbody	13.88	2.63	10.57	2	7.79	1.48
barren land	36.74	7.01	14.12	2.36	12.38	2.5

Inference:

- As of 2022, the vegetative land cover had decreased from 143.13 km² in 1988 to 54.34 km². Between 1988 and 2022, the built-up area rose from 102.08 km² to 163.23 km².
- The built area increased due to the urbanisation and population growth vegetation reduced immensely due to the increase in built.

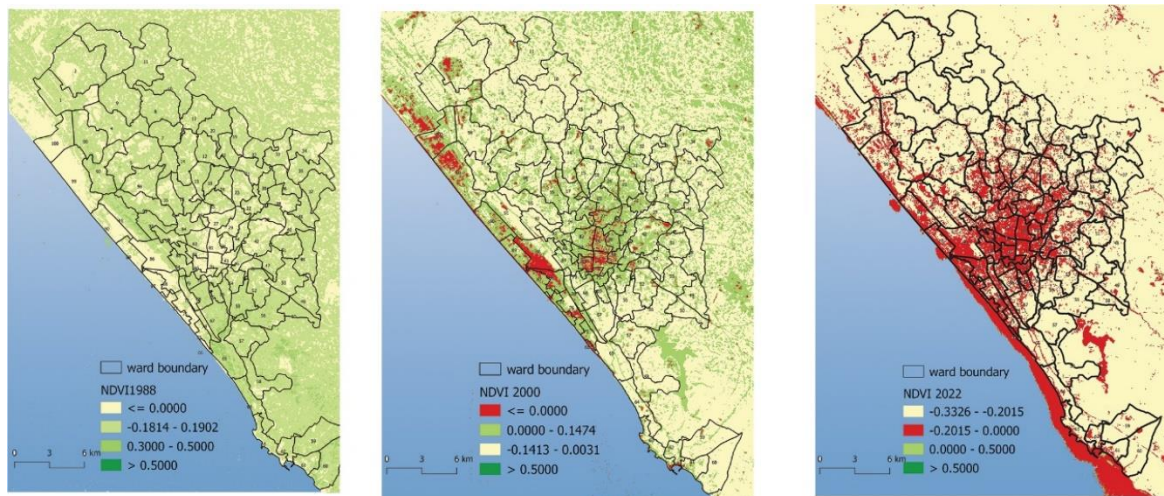


Figure 3. 17 NDVI map (1988,2000,2022)

Source: Author generated using Landsat image,2023

Inference:

NDVI maps of 1988 and 2000 shows a remarkable spatial increase of low NDVI values indicates the increase of impervious surfaces. Similarly, the NDVI value of 2022 also shows decreasing trend.

3.3.2 Water features: Water bodies, Water quality, Rainwater Harvesting

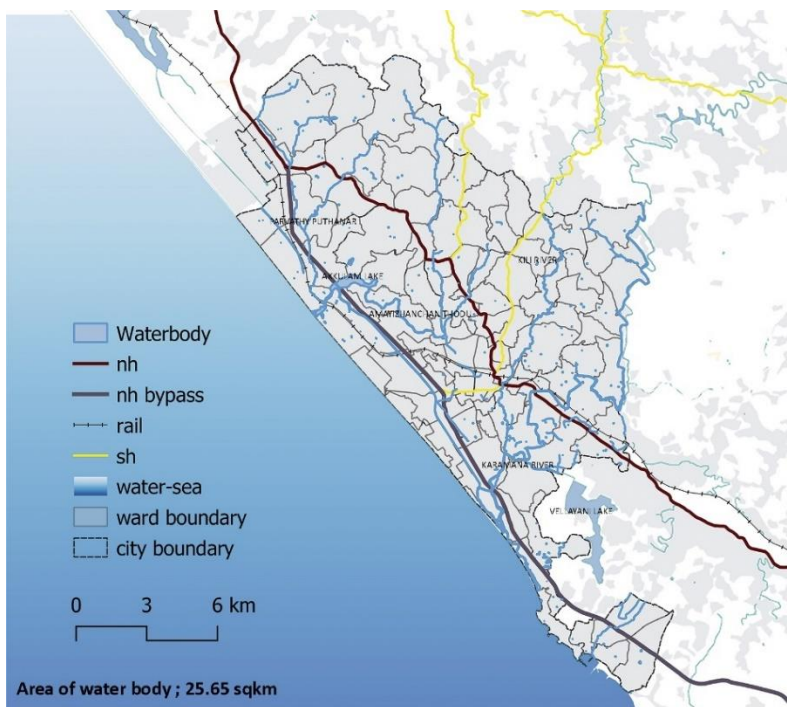


Figure 3. 18 Water bodies in the study area

Source: Author generated using Qgis,2023

The important rivers draining the district are Neyyar, Karamana, Vamanapuram, Mamom and Ayirur, which form three main drainage basins such as Neyyar, Karamana and Vamanapuram basin in which Karamana is in study area. Karamana River with two reservoirs at Peppara and Aruvikkara is the main surface water source for Thiruvananthapuram water supply scheme. The best-known tributary of the Karamana River is Killiyar.

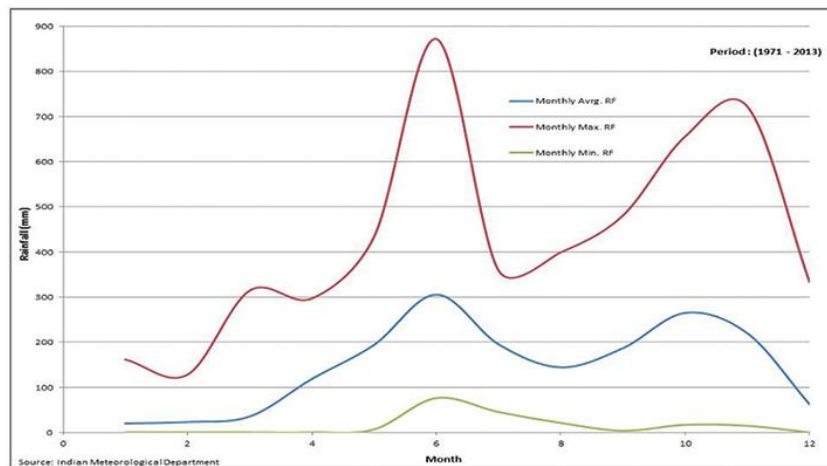


Figure 3. 19 Rainfall changes over years (1972-2013)

Source: (Meteorological department, 2021)

The month with the most rain is June, with an average rainfall of 10.1 inches and the least as 0.7 inch .0.30inch rainfall is considered as heavy rainfall.

Inference

The area of waterbody declined over years as inferred from the landuse map due to the encroachment of built use still the area of water body in the present scenario is 25.65sqkm out of total corporation area which is very less in percentage.

3.3.3 Built canopy: Built up area, permeable pavements, heat stress

Table 3.1: Built, on built growth over years

Source: (Chethry, 2021)

Classes	2001	2007	2014	2021
Built up	77.35	98.41	123.78	174.65
Non built up	465.22	444.16	418.79	367.92

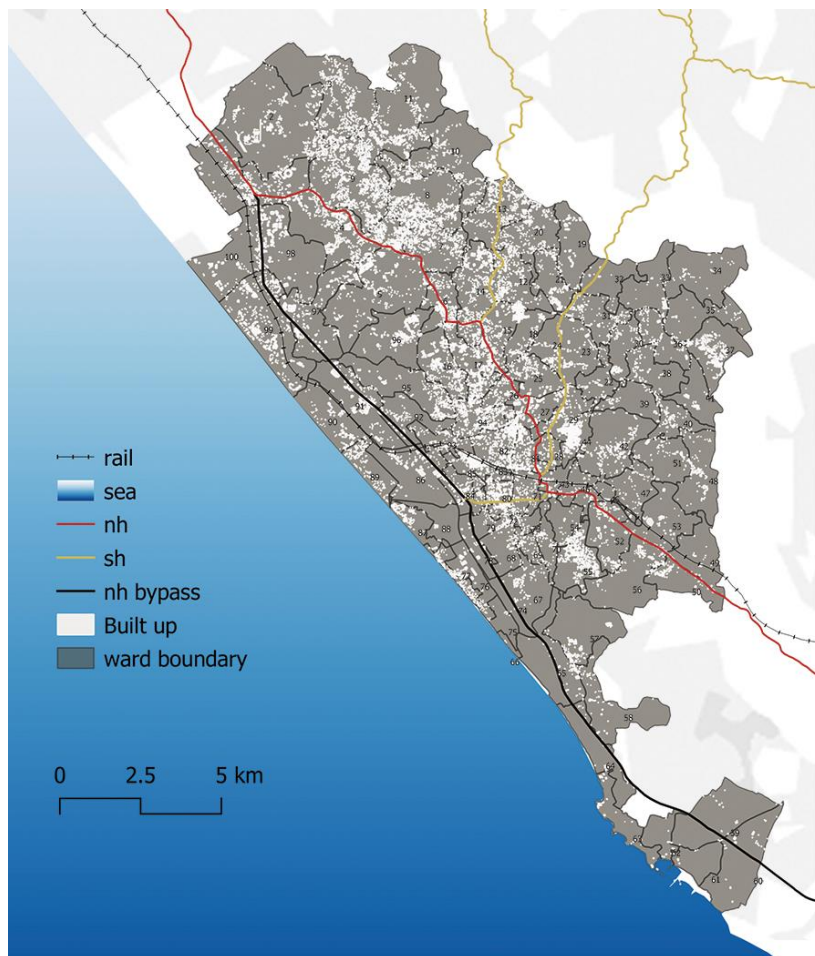


Figure 3. 20 Built Density map

Source: Author generated using Qgis,2023

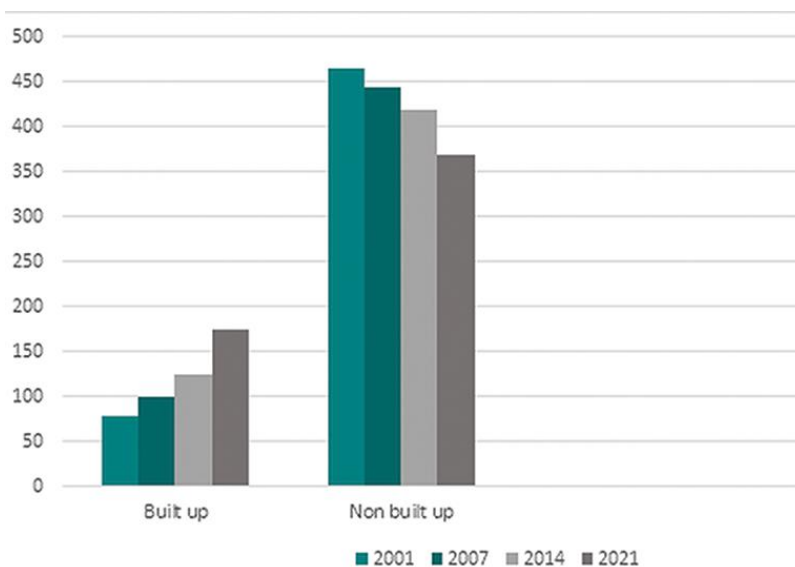


Figure 3. 21 Built and non-built-up change over years

Source: Author generated with reference to (Chethry, 2021)

Inference:

- The built density increased covering the open and green spaces causing reduction in the non-built area.
- The built is more concentrated in the city center due to the spatial structure of the city.

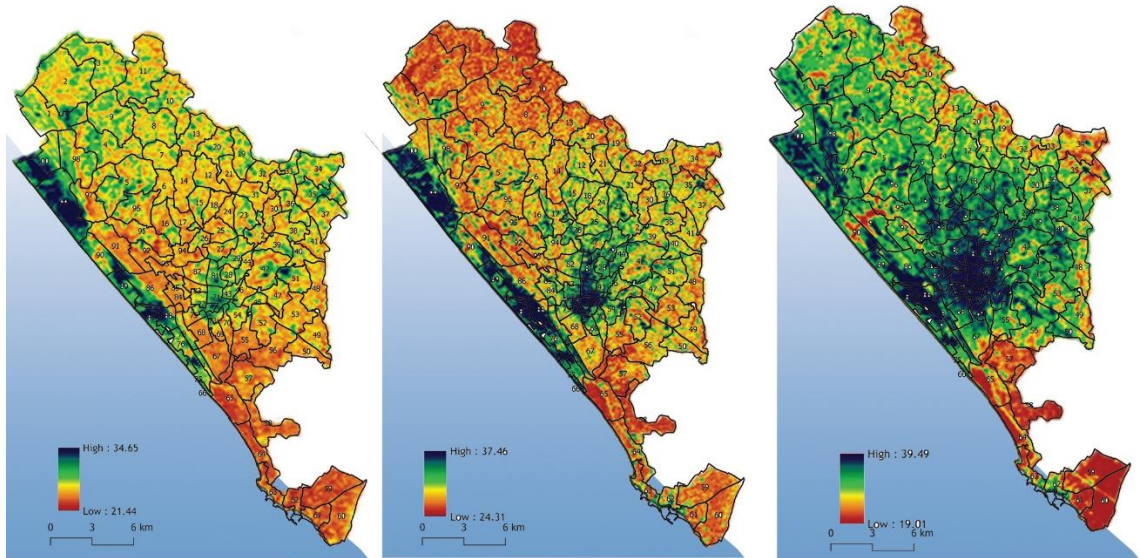


Figure 3. 22 Land surface Temperature change (1988,2000,2022)

Source: Author generated using Landsat image,2023

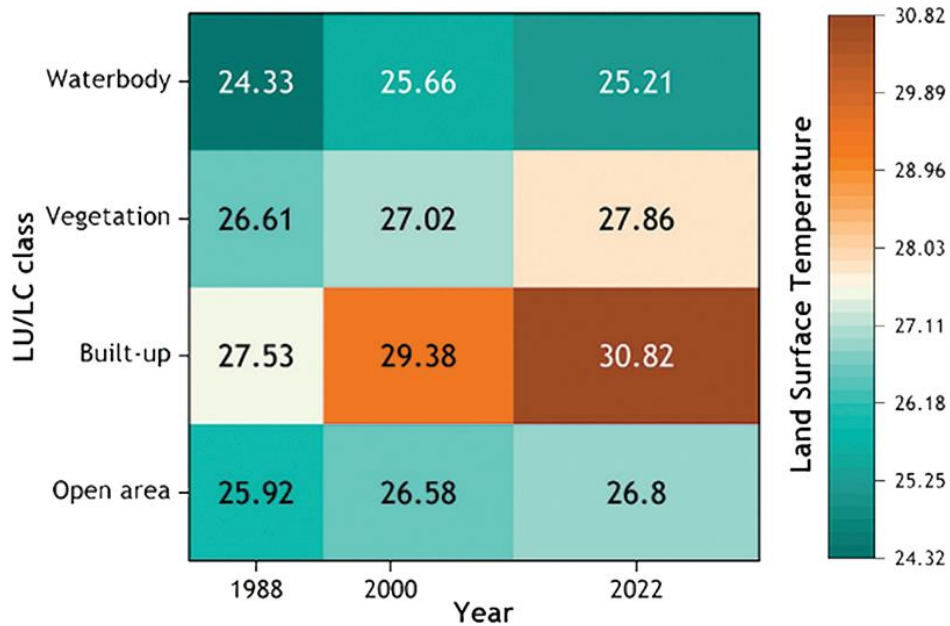


Figure 3. 23 Landcover change effect w.r.t LST

Source: (Anupriya R S, 2020)

It can be observed that the mean temperature of waterbody, vegetation and open area shows more or less constant trend. Whereas the mean LST of built-up area is increased 27.53°C in 1988 to 30.82°C in 2022 which is primarily due to high intensity built-up areas and also attributed to micro climate change. It can be observed that the higher LST values are clustered at central core of the study area. Central region is characterized with the traditional urban growth of the center of the city whereas north-western part represents the recent growth due to IT park implementation.

Inference:

Based on the LU/LC change analysis it can be observed that the substantial share of vegetation cover, open area and waterbodies and wetland units were converted into built-up land and the LST increased respectively.

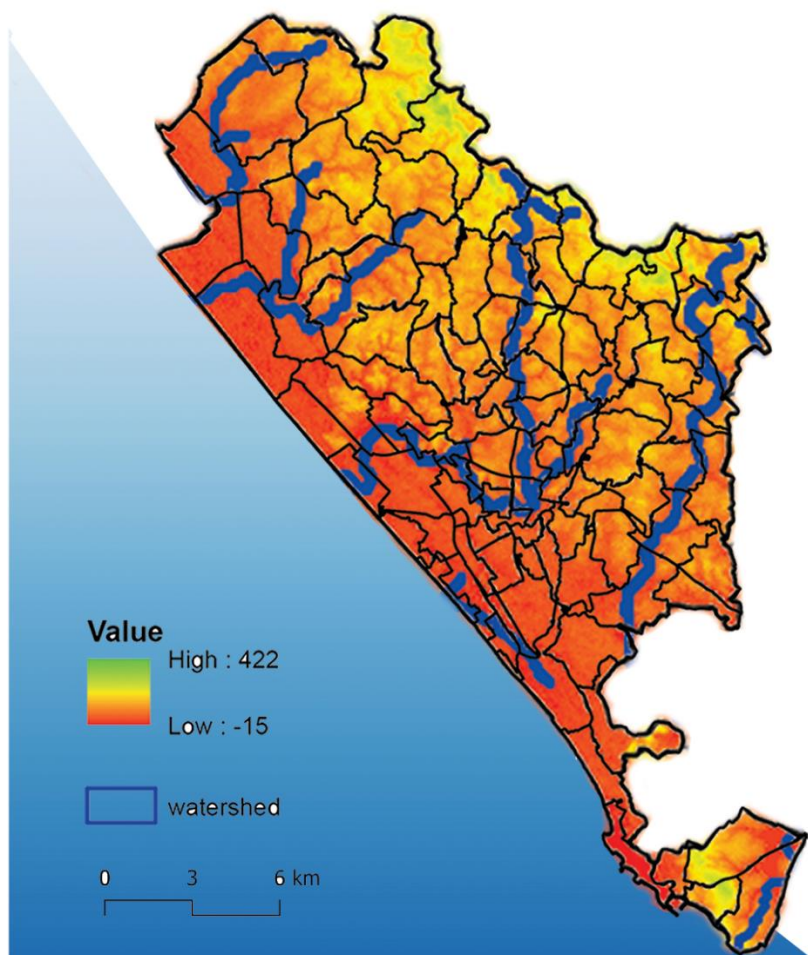


Figure 3. 24 Drainage map

Source: Author generated using Landsat image,2023

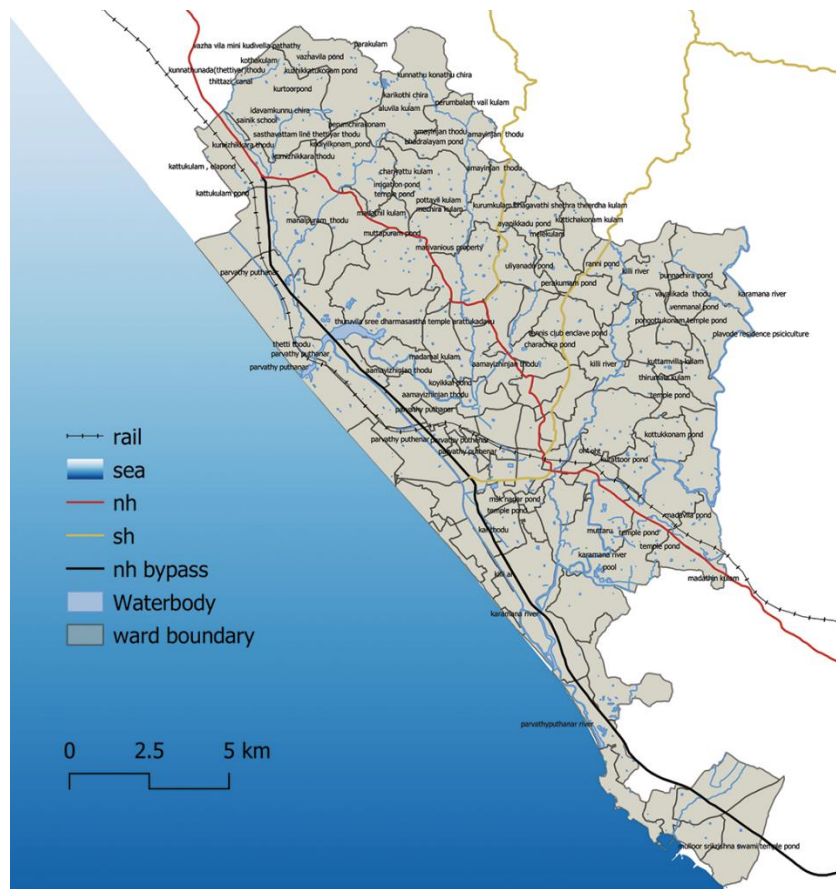


Figure 3. 25 Waterbodies (Natural and artificial)

Source: Author generated using Qgis,2023

Study area is having a gentle slope towards the central city (<25%). The drainage network of the city consists of two rivers, a few canals (thodus), their feeders and lakes. The rivers are Karamana and Killiyar which flow through the city area. Flood plains of Killi river and Karamana river are reclaimed and occupied by residential houses.

Inference:

- Most of the waterbodies and flood plains are having a landuse change due to urbanization.
- The width of the drains and the flow are getting blocked and affected due to the inappropriate constructions and landuse over the years.
- Even if the area has a sufficient number of waterbodies, the impact of climate change from the waterbodies is diminished due to poor management and an increase in the sediments that clog drains.

3.4 Meso level study area delineation

Delineation method:

The meso level study is carried out with the elements and indicators identified from the literature study.

1. Population Density: The wards with the highest population density ranging from 10032 -101199-person persqkm

2.Land surface temperature: The wards that are common in the year 1988,2000 are overlapped in different layers which are having greater value.

3.Landcover: The 1988,2000-year change is overlapped to get the common wards are overlapped together in which built up is given priority.

4.NDVI: The 1988,2000-year change is overlapped to get the common wards are overlapped together in which green cover reduction is given priority.

5.Built Density: The wards with more concentration of building are selected for the delineation.

Finally, all the layers are merged together to identify the wards that meet all the parameters in common.

Inference

- The different parameters considered in the formation of UHI are studied and inferred in the macro level, for the detailed study and conclusions the study area must be more delineated therefore the maps are overlapped accordingly following the years.
- The maps when overlapped gives concentration of different parameters in some of the wards, the area is delineated with respect to the intensity of parameters observed when overlapped.

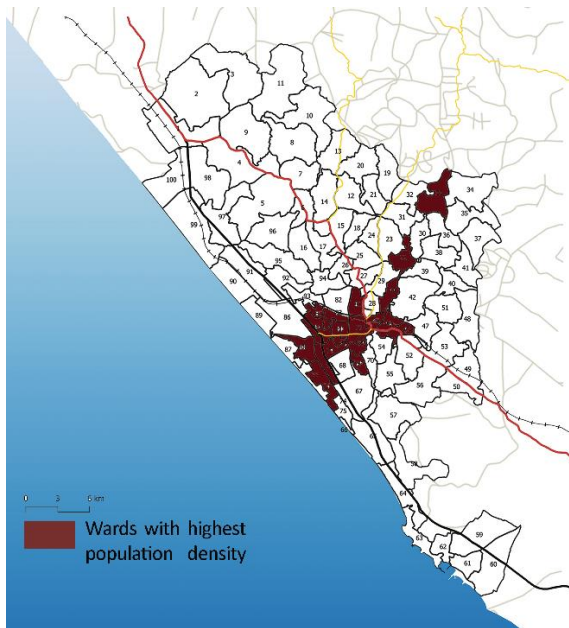


Figure 3. 26 Population density map
Source: Author generated using Qgis,2023

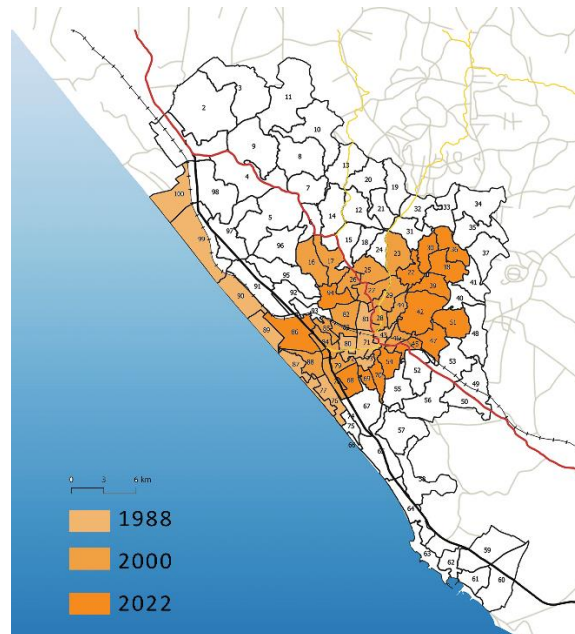


Figure 3. 27 LST map overlapped with three years
Source: Author generated using Qgis,2023

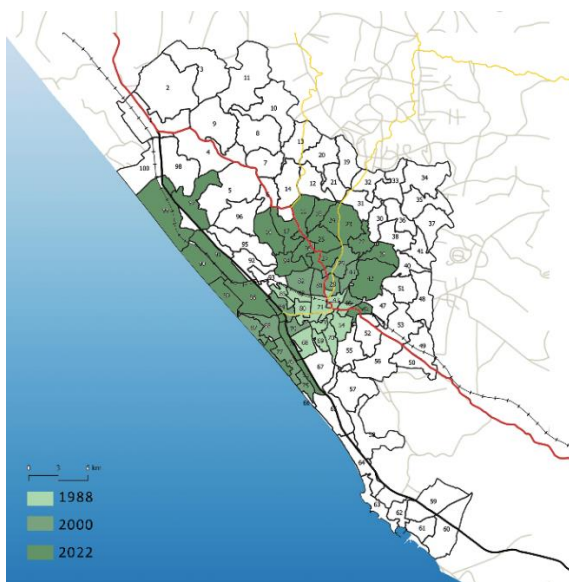


Figure 3. 28 Landcover map overlapped with three years
Source: Author generated using Qgis,2023

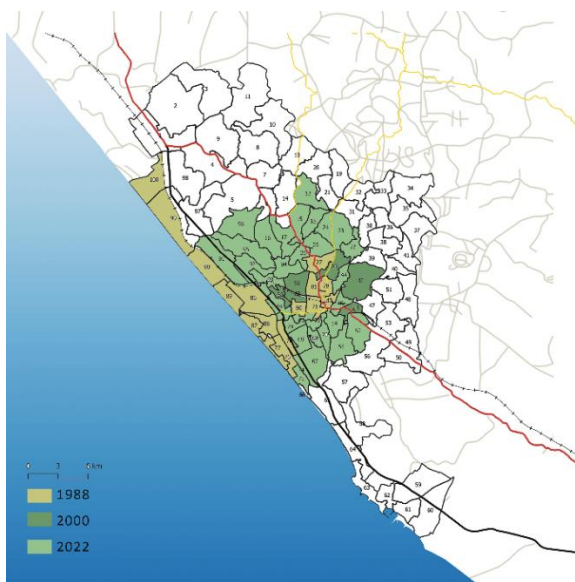


Figure 3. 29 NDVI map overlapped with three years
Source: Author generated using Qgis,2023

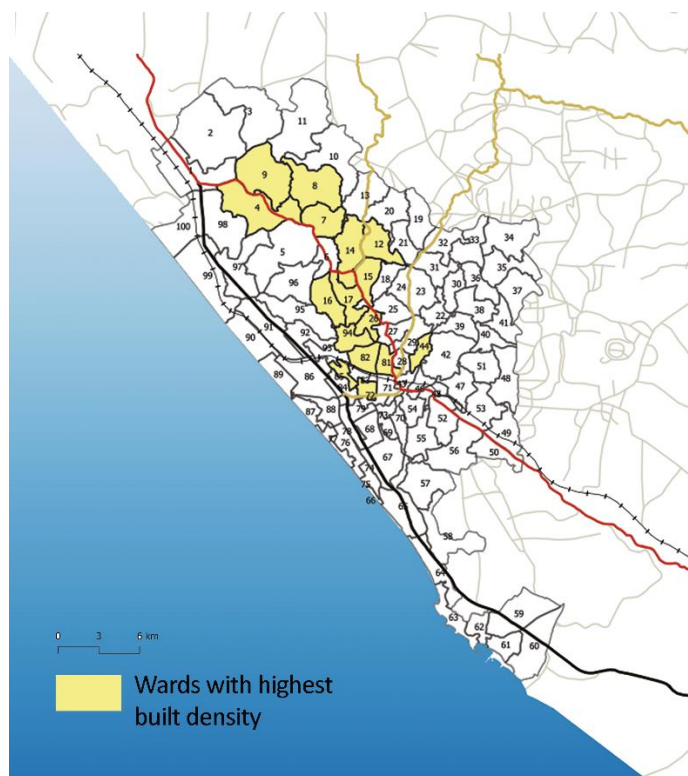


Figure 3. 30 Built density map

Source: Author generated using Qgis,2023

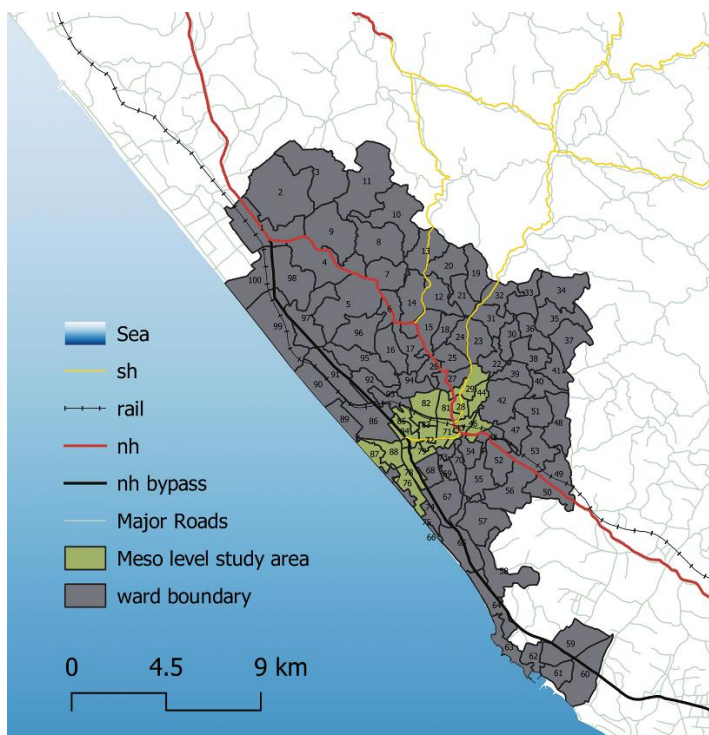


Figure 3. 31 Meso level study area within macro level area

Source: Author generated using Qgis,2023

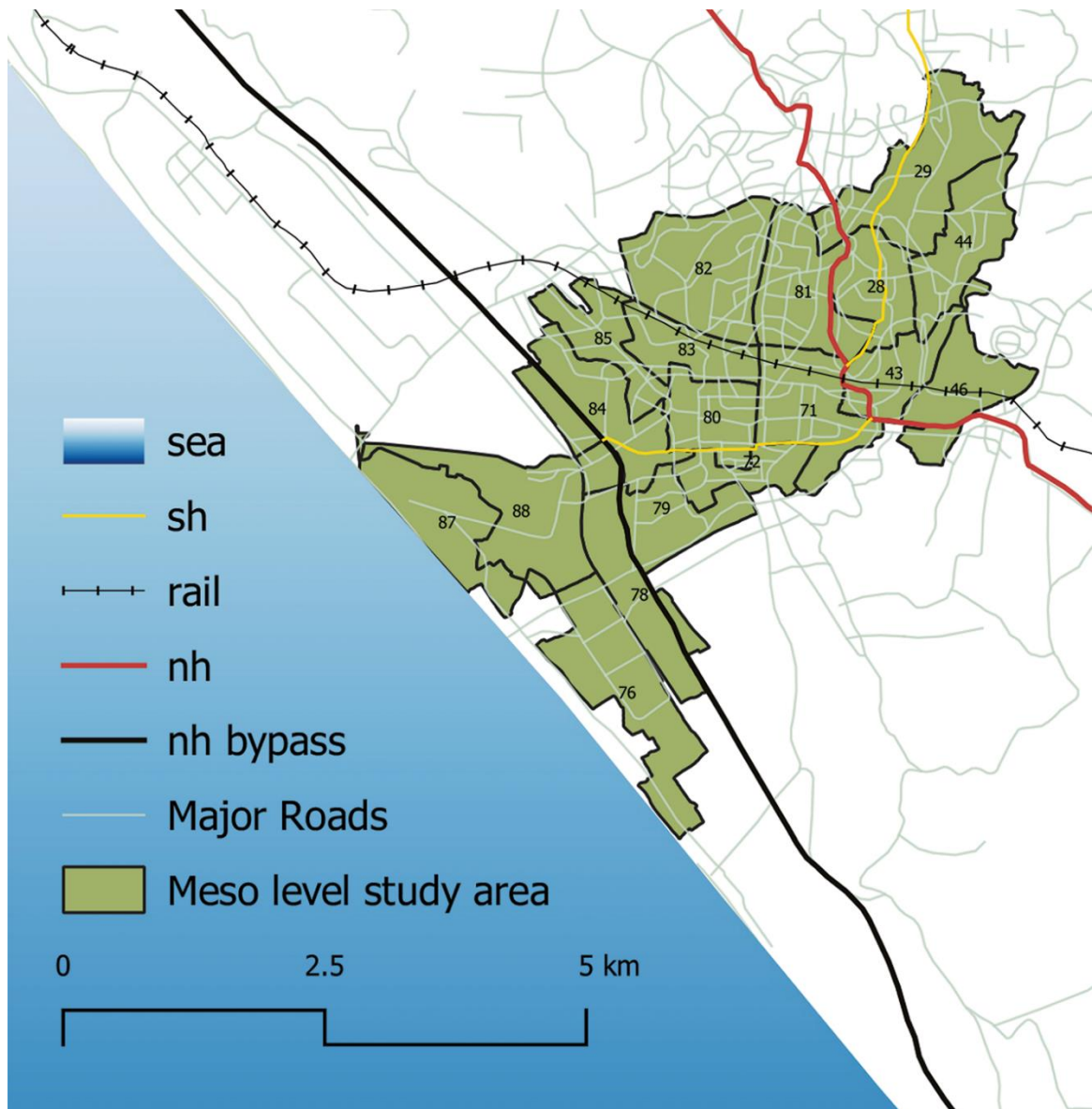


Figure 3. 32 Meso level study area map

Source: Author generated using Qgis,2023

Total area:16.62 sqkm					
No of wards:18					
28.Thycaud	44.Jagathy	72.Manacaud	79.Sreevaraham	82.Vanchiyoor	85.Palkulangara
29.Vazhuthacaud	46.Aranoor	76.Beemapally east	80.Fort	83.Sreekanteswaram	87.Valiyathura
43.Valiyasala	71.Chalai	78.Muttathara	81.Thampanoor	84.Perunthanni	88.Vallakadavu

3.5 Meso level indicator analysis

INDICATOR 2: BIOPHILIC SPACES AND PLACES

BU Indicators: Built environment-green infrastructures, Built Density, Wind corridors

UHI Parameters: Land surface temperature, Ground cover-Landuse, Land cover

Elements and sub elements:

- Built canopy
- Green and blue infrastructure

3.5.1 Built canopy

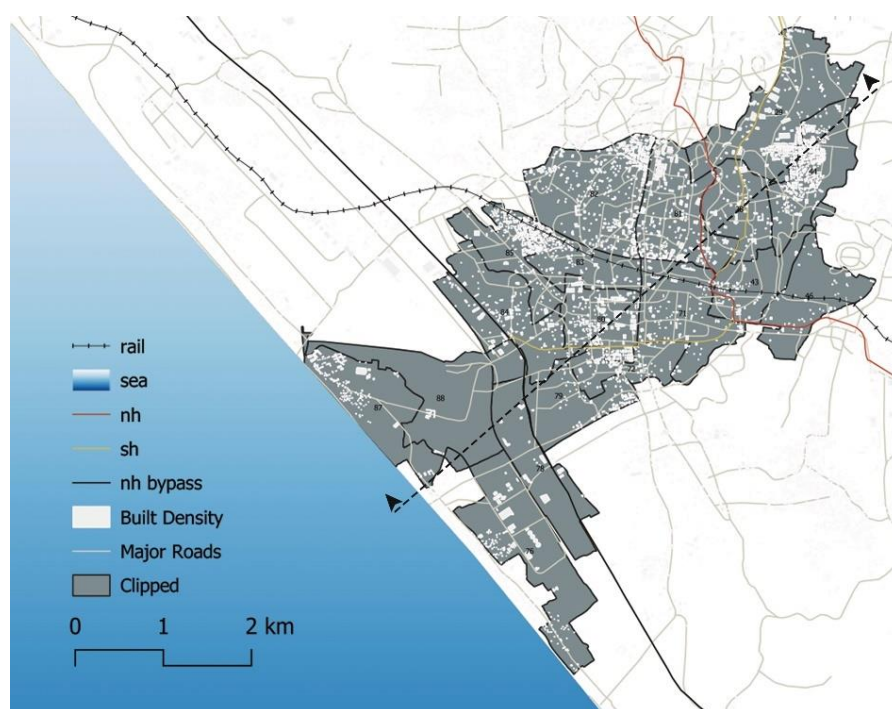


Figure 3. 33 Built Density

Source: Author generated using Qgis,2023

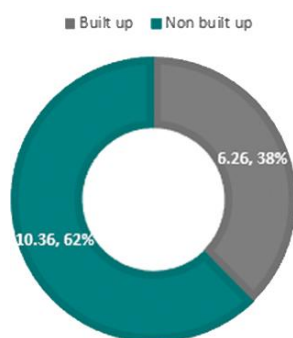


Figure 3. 34 Pie chart showing the Built and non-built percentage

Source: Author generated using Qgis,2023

The rate of built-up increase was 126%, and the rate of non-built-up decrease was -21% from 2001 to 2021.

Inference:

- More built concentrated at the centre of the study area which causes less wind velocity due to build structure.
- Rapid loss of non-built-up land cover poses a significant threat to the urban sustenance of the city.

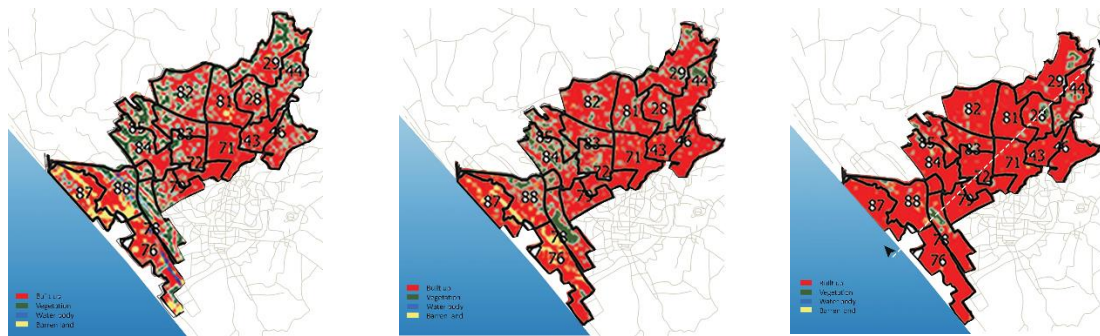


Figure 3. 35 Landcover map (1988,2000,2022)

Source: Author generated using Landsat image,2023

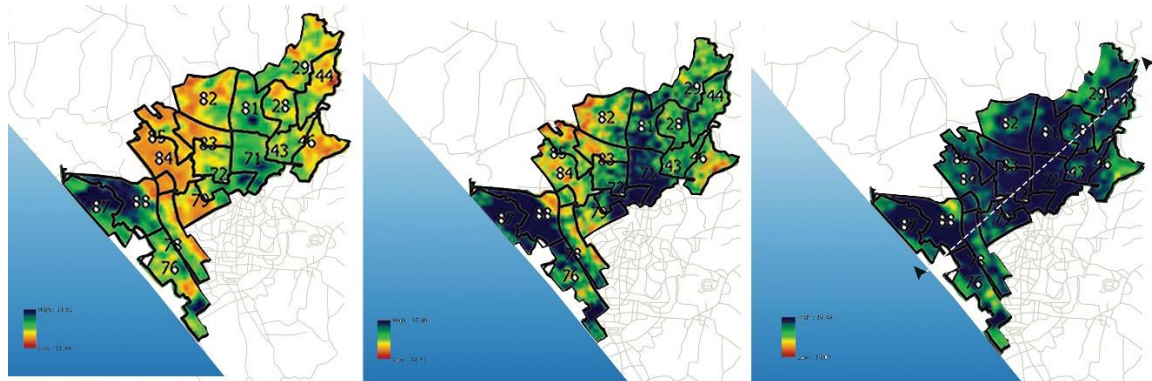


Figure 3. 36 Land surface temperature (1988,2000,2022)

Source: Author generated using Landsat image,2023

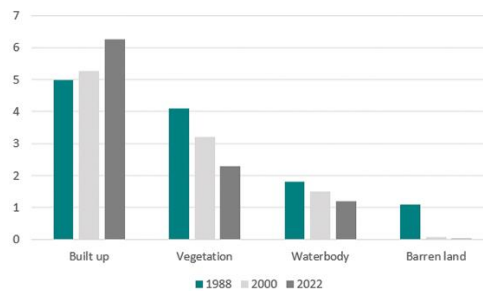


Figure 3. 37 Pie chart showing the landcover change over years

Source: Author generated

Inference:

- The landcover is proportional to the LST as the temperature increases with the absence of the green cover and the open spaces. Less vegetation causes harm to the biodiversity causing the water quality and the ecosystem.
- The high value of LST areas has less vegetation and more built as compared with the maps above.
- LC, LST and Built are proportionate with each other as they directly cause increase in the temperature and heat stress.

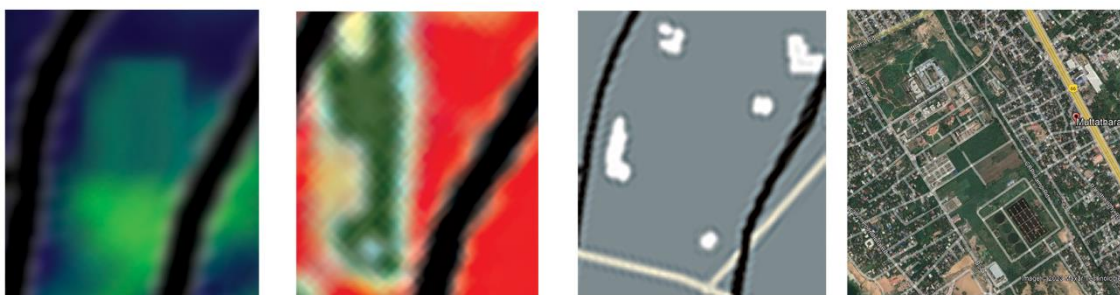
3.5.1.1 Hotspot analysis



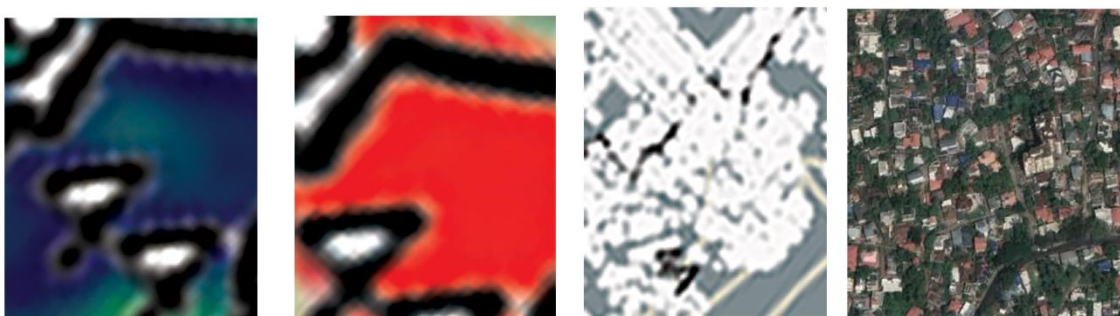
Figure 3. 38 Hot spots identified w.r.t LST, Landcover and Built map

Source: Author generated using Landsat image,2023

- More green and less built area



- More built less green



Source: Author generated

Factors affecting for the formation of hotspots is analysed on the basis of LST, landcover, Built density, Earth images

- Low green cover

- High density-built canopy
- More paved surface
- Residential and semipublic landuse
- Low permeability

Green area: CISF Complex ASG, Muttathara

Built area: C&C College, Jagathy

Inference:

- The hotspots are identified for the primary LST survey for categorising the heat change with respect to materials.
- Denser and built, no vegetation more temperature is observed.

3.5.2 Permeability

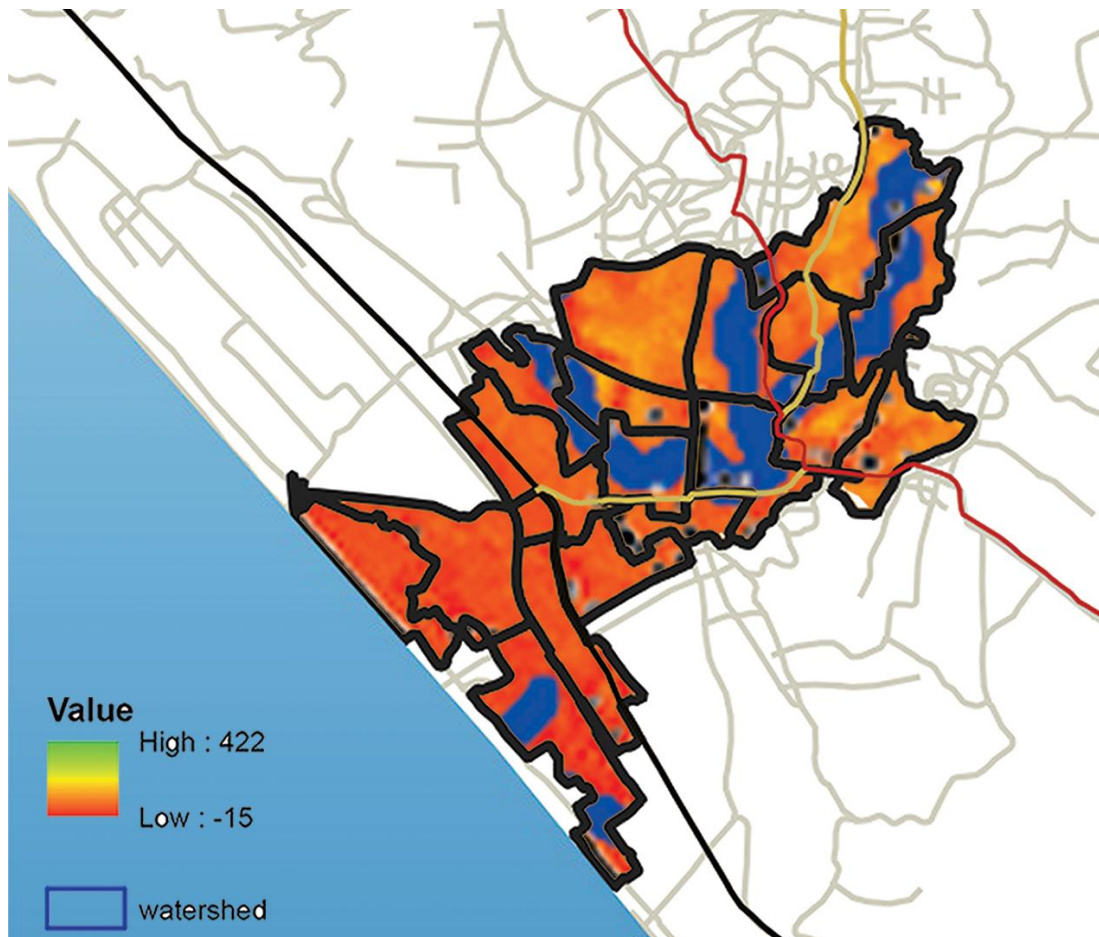


Figure 3. 39 Drainage map

Source: Author generated using Landsat image,2023

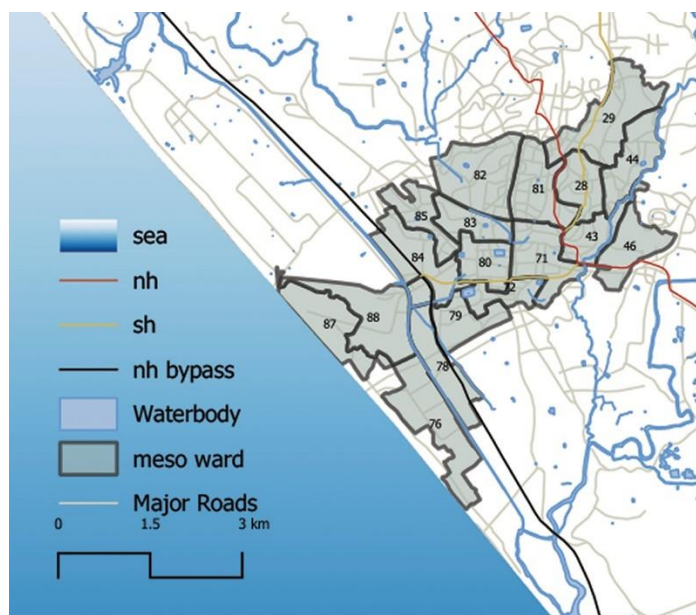


Figure 3. 40 Waterbodies

Source: Author generated using Qgis,2023

Inference:

- The water body is 1.1 sqkm (6%) in area as compared to the ward area 16.62 sqkm.
- The majority of the study area is mid and low land. There for the drainage pattern is towards the study area where more permeability can occur.

3.5.3 Green and blue infrastructure: Ecological parks, Ventilation lanes, urban farming, waterbodies

- Ecological Park /open spaces

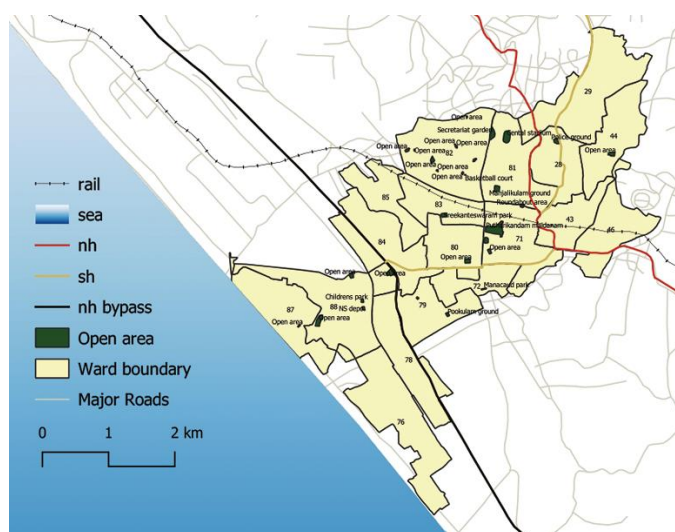


Figure 3. 41 Ecology parks, open area

Source: Author generated using Qgis,2023

Urban farming (Agriculture)

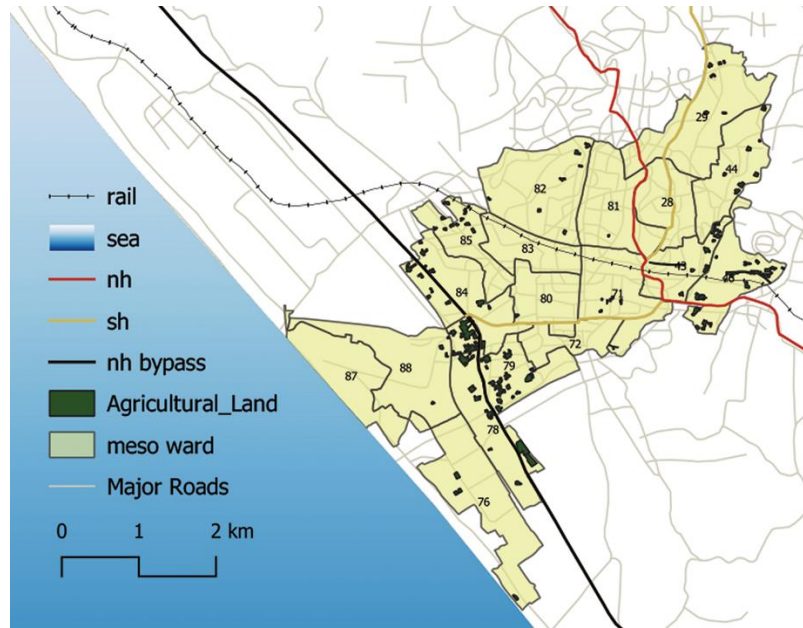


Figure 3. 42 Agricultural area

Source: Author generated using Qgis,2023

Inference:

- The total open space is 0.1sqkm(1,00,000sqm) within the total area of 16.62 sqkm area of the total ward.
- The agricultural land is 0.3sqkm i.e.; only 2% of the total ward area which is very less compared to the total population in the ward which is 1,64,299.

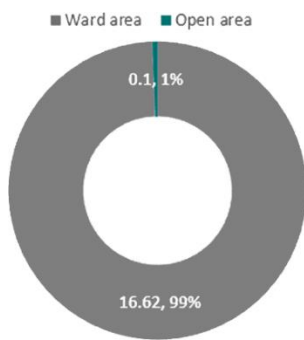


Figure 3. 43 Pie chart with percentage and area(sqkm)of open area

Source: Author generated

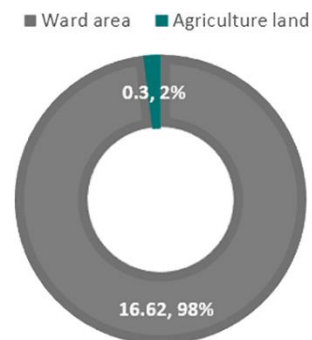


Figure 3. 44 Pie chart with percentage and area(sqkm)of Agriculture land

Source: Author generated

Waterbody (Natural and artificial)

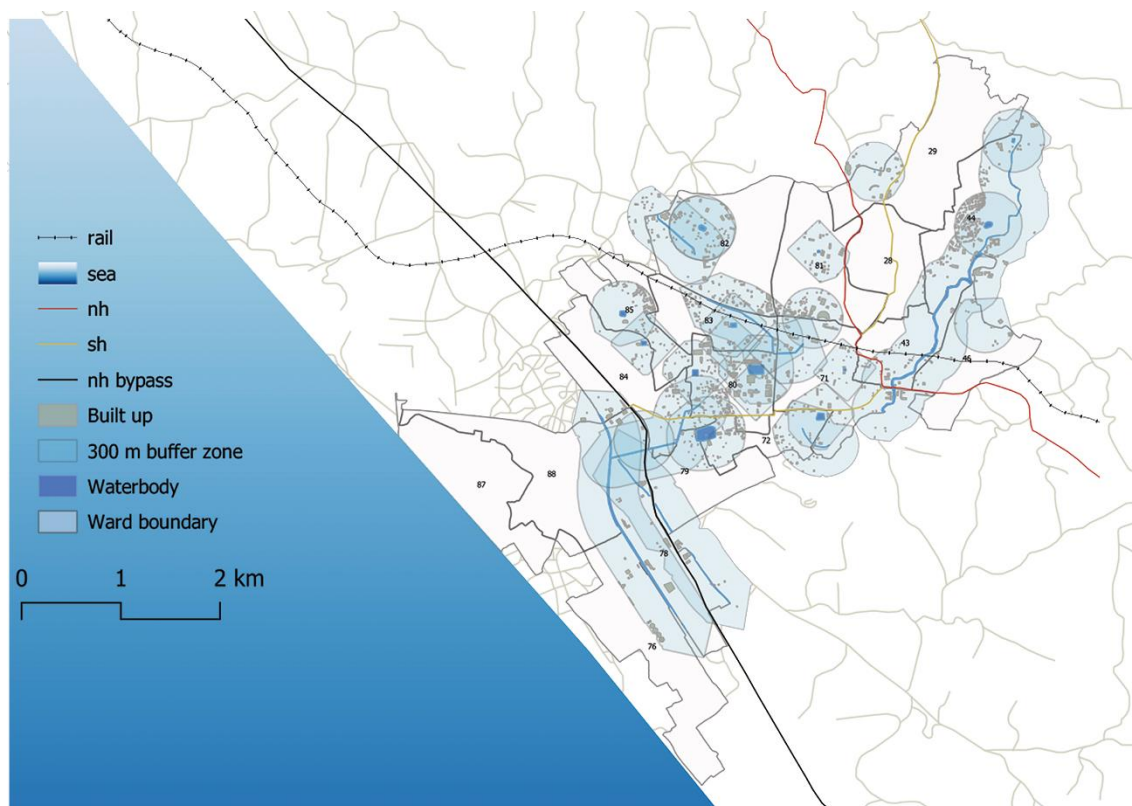


Figure 3. 45 Waterbody in 300m buffer zone

Source: Author generated

■ Built area around water body ■ Total built area

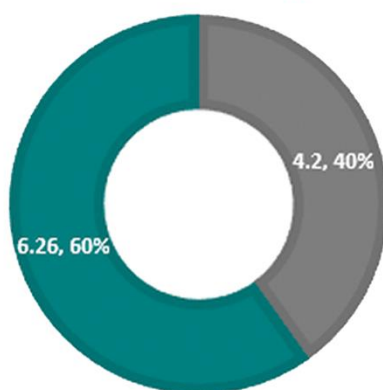


Figure 3. 46 Pie chart with percentage and area(sqkm)of built area in buffer zone

Source: Author generated

Inference:

The majority of the built is around the buffer zone within waterbodies but the available area of surface water is insufficient to meet the increase in temperature as we can observe from the LST and landcover maps.

- 4.2 sqkm of the built area is within the buffer zone of the waterbody which can be considered as a positive impact within built area.

3.6 Micro level study analysis and primary survey

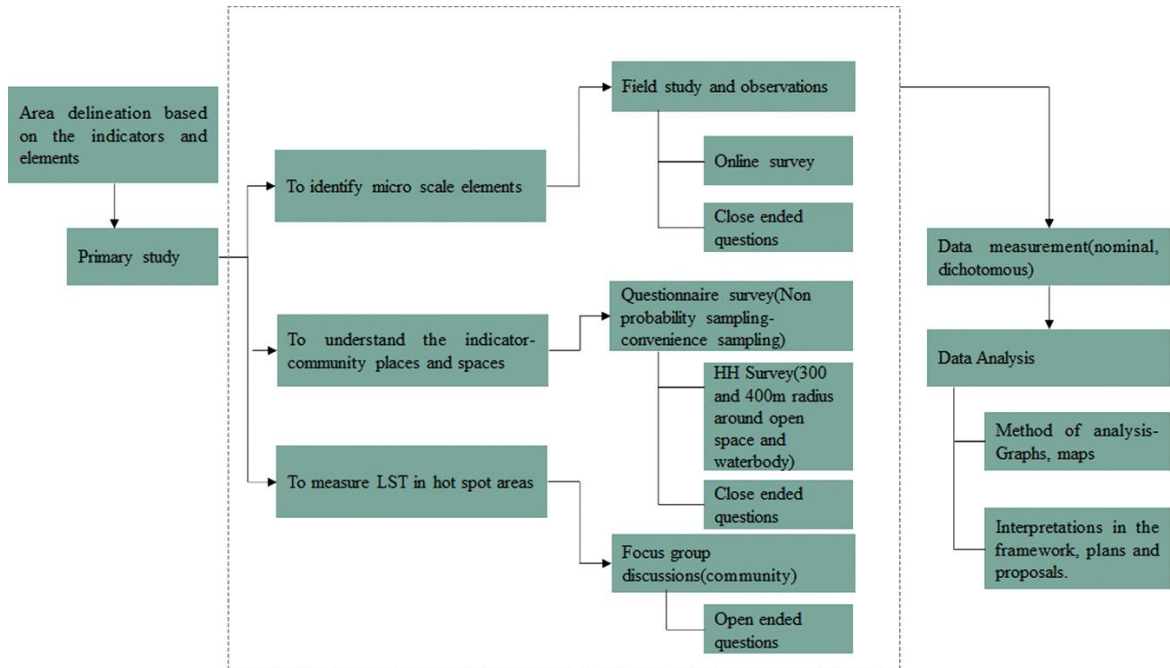


Figure 3. 47 Primary study Methodology

Source: Author generated

INDICATOR 3: Community and people activity

BU indicators: Physical Environment-Recreation, Climate change mitigation

Improved air quality

UHI parameters: Climate, Landcover, Landuse, Land surface temperature

Elements and sub elements

- Built canopy
- Green neighbourhoods
- Blue neighbourhoods

3.6.1 Built canopy: Permeable pavements, Heat stress

- Permeable pavements

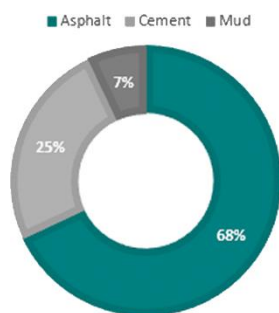


Figure 3. 48 Pie chart showing the type of pavement

Source: Author generated

- Heat stress

Table 3.3: LST measured w.r.t different materials

Time	Asphalt pavement	Cement pavement	Mud pavement	Green area
7.00 am	26.7	25.3	24.1	22.3
9.00 am	38.5	36.3	33.2	29.6
11.00 am	48.9	47.6	37.9	31.7
1:00 PM	61.4	55.3	41.8	36.4
3:00 PM	57.4	51.5	39.7	35.5
4.00pm	52.6	49.3	37.5	32.7
6.00pm	44.3	37.7	34.8	29.2
8.00 pm	35.4	32.6	30.5	23.6

Source: Author generated from primary survey,2023

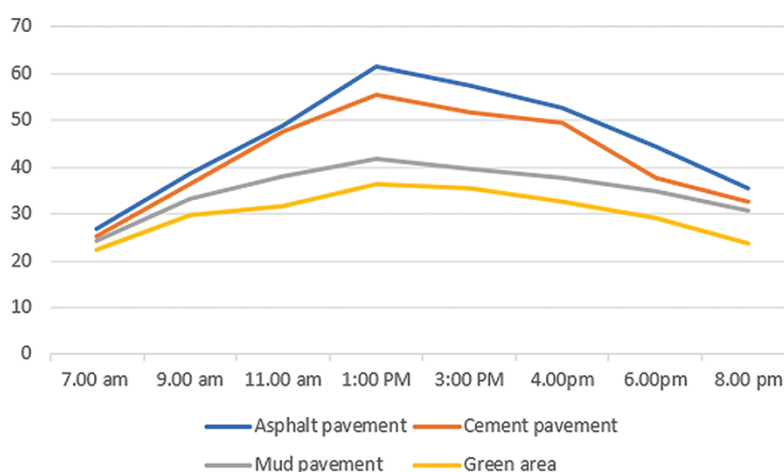


Figure 3. 49 Graph showing the LST change with different material

Source: Author generated from primary survey,2023

Inference:

- The type of pavement mainly in use is Asphalt roads from which we can understand

the impervious nature.

- The LST was measured high during 1.00pm in Asphalt pavement and least at 7.00am.
- The LST difference between area with highly impervious pavements and green area are relatively high

3.6.2 Green neighbourhoods

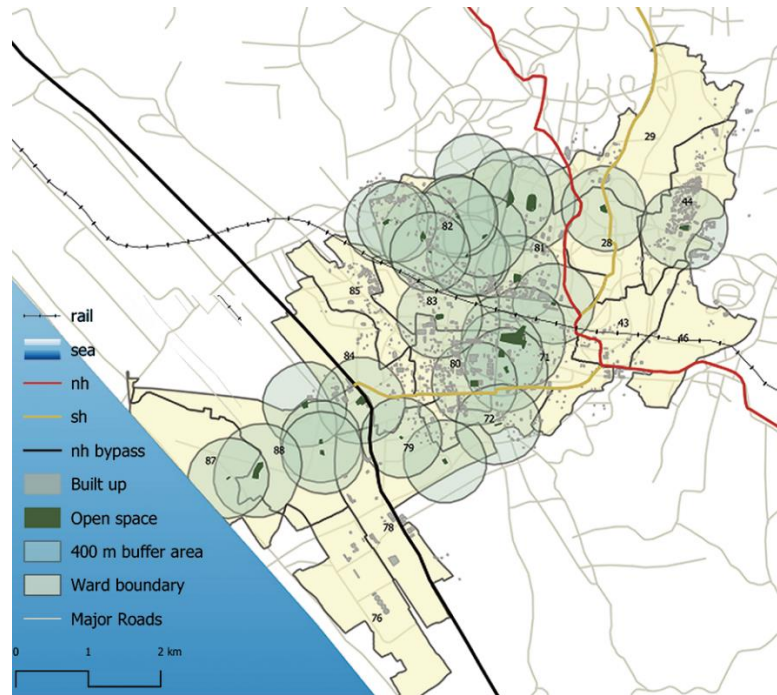


Figure 3. 50 Open area in 400m buffer zone (within 5-minute walk)

Source: Author generated from Qgis,2023

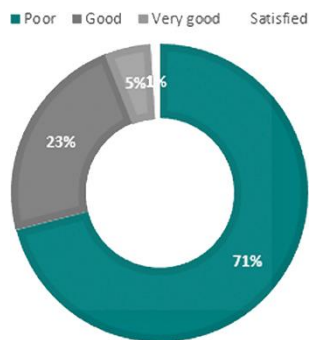


Figure 3. 51 Pie chart showing the satisfaction with open recreational area

Source: Author generated from primary survey,2023

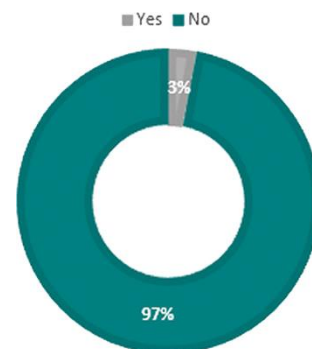


Figure 3. 52 Pie chart showing activities like community garden

Source: Author generated from primary survey,2023

Inference:

- The built area within the green buffer zone is very less from which we can understand the poor interaction of people with the green spaces in their daily life.
- The built within is only 2.8 sqkm in 6.26 sqkm which is very less from which we can conclude the insufficient urban and open squares within the study area and can validate it from the primary survey the involvement of people in community activities.

3.6.3 Blue neighbourhood

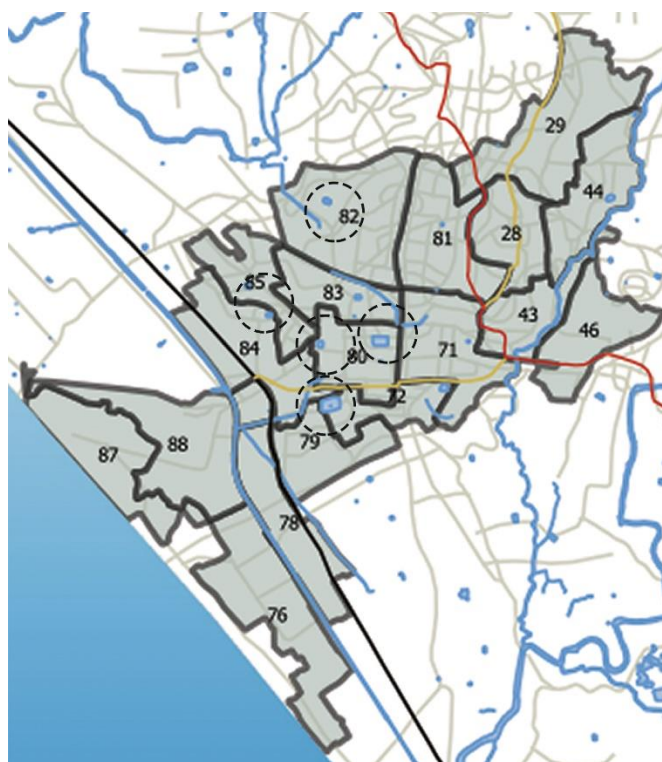


Figure 3. 53 Existing waterbodies

Source: Author generated from Qgis,2023

Inference:

- The existing waterbodies can be transformed to bio retention basins and the small and blocked canals can be developed in to urban creeks between the semipublic areas.
- A sustainable waterfront activity can be promoted by developing the existing ponds (temple, private ponds) etc. with the help of the community.

CHAPTER 4 DEVELOPED FRAMEWORK

The framework is derived in the third phase of the methodology. The second phase leads to the framework where the analysis of the study area is carried out at various scales considering the elements of Biophilic urbanism and parameters of urban heat island.

4.1 Framework for the different scales of Biophilic urbanism

The elements of biophilic urbanism derived from the framework is quantified considering the standards and the issues and the elements that lack in the study are identified through the framework. The elements, sub elements, required standards, assessed values through maps and the maps or data required are tabulated and analysed arriving at an inference from which we can understand the issues of the existing areas and the reason for the formation of urban heat island in the study area.

The framework is based on the three scales as mentioned in the derived framework from the above studies.

- 1.Macro-Vegetation inclusion, Water features, Built density
- 2.Meso-Green and blue infrastructures, Built canopy
- 3.Micro-Built density, green and blue neighbourhoods

Table 4. 1 Framework for the different scales of Biophilic urbanism

Source: Author generated

ELEMENTS AND SUB ELEMENTS	SUB INDICATORS	ASSESSMENT CRITERIA	ASSESSED VALUE	REQUIRED STANDARD	MAP/DATA REQUIRED	INFERENCE
Vegetation inclusion	Natural vegetation	(Total area of natural vegetation / Total area of study area) x 100	(54.34/214.84) x 100 = 25.2%	According to National Forest Policy of India, the ideal percentage of total geographical area under forest should be at least 33% to maintain ecological stability (Kerala Forest Survey of India, 2019)	Landcover map, Landuse map, NDVI	The percentage of vegetation is less as per the required standard which cause disturbance in the ecological stability in the study area
	Forest cover	Very dense forest+Moderate dense forest+Open forest. :- Percentage of Geographical area of study area				
Water features	Waterbodies	(Total area of waterbody + Total study area) x 100	(25.65/214.85) x 100 = 11.93%	Water body area proportion	Surface water map	The percentage of waterbody is less as per the required standard which cause high temperature in the study area
	Water quality	PH: 6.5-8.5 Total coliform organisms (MPN/100 ml) shall be 50 or less Dissolved Oxygen 6 mg/l or more, and Biochemical Oxygen Demand 2 mg/l or less	Monsoon-6 to 6.88 Pre monsoon-6 to 7.72	Air temperature (Degree c) 0.16 34.234 0.35 34.139 0.36 33.234 0.69 35.025 0.64 35.042 0.64 35.042	Central Ground water board	The water quality is at a moderate scale as per the study
Built Density	Rainfall	Annual rainfall(mm) w.r.t to temperature reduction	The month with the most rain is June, with an average rainfall of 10.1 inches and the least as 0.7 inch . 0.30inch rainfall is considered as heavy rainfall	Heavy rainfall may experience a reduction in surface temperature of approximately 0.3 K compared to days with light to moderate rainfall (European geoscience union)	Rainfall data	Rainfall is sufficient as per the reports i.e; there is average rainfall which can reduce the heat
	Built area	(Total built area / Total study area) x 100	(163.23/214.85) x 100 = 75.9%	The temperature difference between a city and its surrounding rural area can be as much as six degrees C (World resource institute)	Built up map, Landcover map	The concentration of buildings are in the central core area as seen in map and the percentage of built occupied is high
Heat stress	Permeability	Percentage of waterbodies / Total area of the ward The drainage pattern of the area to be assessed	(25.65/214.85) x 100 = 11.93% Drainage pattern-mid and low land	The temperature difference between urban areas and surrounding vegetated land due to the presence of impervious surfaces (NASA) A reduction of UHI intensity by 2.3 °C was observed for every 10% increase of the average core water surface ratio (Luang, 2017)	Drainage map, Surface water map	Percentage of water body is very less Permeability is low that the study area has gentle slope which drains away the storm water. Flood plains are reclaimed and occupied by residential houses
	Heat stress	The land surface temperature of the study area	LST is directly proportional to built area	Urban green spaces can help maintain micro-climate conditions and improve thermal comfort by lowering the urban heat island effect (World resource institute)	Land surface temperature map	LST varies with change in LULC. More green cover required.

BIOPHILIC URBANISM AS A TOOL TO MITIGATE URBAN HEAT ISLAND-A CASE OF THIRUVANANTHAPURAM CITY

Green neighbourhoods	Transitional areas (Parks, Totlots, playgrounds)	<p>(2.8sqkm/16.62) x 100 = 16.84%</p> <p>Population visiting the park</p>	<p>0.8 ha per 5000 population Tot lots-0.05 ha per 500 population Childrens park-0.2 ha per 2000 population</p>	<p>Primary survey-Questionnaire survey, identify recreational areas and open areas, focus group discussions</p>	<p>The number of open spaces, park etc are very few and the visitors are also very few due to the absence of these spaces. The available open spaces are not managed properly (community discussion)</p>
	<p>Pause points (Pocket parks, city tree canopy, sidewalk gardens)</p> <p>Urban squares (Outdoor activity, Camping grounds)</p>	<p>A 10,000 square foot building with an Open Space Ratio of 20% would have 2,000 square feet of open space.</p> <p>3-4 local parks and playgrounds (URDPFI Guidelines, 2014)</p>	<p>0.2 ha per 1000 population (town and country planning organization, 2015 URDPFI Guidelines, 2014)</p>	<p>Primary survey-Questionnaire survey, Observation survey</p>	
Green neighbourhoods	Neighbourhood parks	<p>The number of neighbourhood parks less than 1 in most of the wards</p> <p>Household with community garden</p>	<p>10-12sqm per person (Town and country planning organization, 2015 to 7 feet (IC-2012, Guidelines for pedestrian facilities)</p>	<p>10% from the total development area is allocated for open space The preferred minimum width for a nature strip is 5 to 7 feet (IC-2012, Guidelines for pedestrian facilities)</p>	<p>The community gardening programs are not happening and no nature clubs or activities identified.</p>
	<p>Green loop (Community gardens, Vegetated walkpaths)</p> <p>Nature clubs and groups</p> <p>Buffer zones between roads and pedestrians</p> <p>Street trees</p>	<p>Per person requirement of open spaces</p> <p>Squaremeter or squarefoot of the vegetated pathways within 5 Minute walk / Total area of the ward</p> <p>Number of meeting per year and the activities</p> <p>Narrow strips of land bordering creeks, rivers, lakes, or other bodies of water</p> <p>Not satisfied</p> <p>The distance is too long</p>	<p>5-20 m width (United states Environmental protection Agency)</p> <p>Spacing of 10-12m (Urban green guidelines, 2014)</p> <p>Green roof temperatures can be 30-40°F lower than those of conventional roofs and can reduce city-wide ambient temperatures by up to 5°F (United states Environmental protection Agency)</p>	<p>Primary survey-Questionnaire survey, Observation survey</p>	
Blue Infrastructures	Proportion of green wall/rooftops	<p>Area of green roof tops/Green walls identified + Total area of ward/Total houses in ward</p>	<p>Green roof temperatures can be 30-40°F lower than those of conventional roofs and can reduce city-wide ambient temperatures by up to 5°F (United states Environmental protection Agency)</p>	<p>Green roof temperatures can be 30-40°F lower than those of conventional roofs and can reduce city-wide ambient temperatures by up to 5°F (United states Environmental protection Agency)</p>	<p>The existing ponds can be utilised and developed for productive uses.</p>
	Urban creek and bioretention basin	<p>Ponding depth-6 to 12 inches Length-0.3 Min. distance requirement from: Water supply wells: 100 feet Surface water: 30 feet</p>	<p>0.1-2.5 acres Drainage areas to smaller bioretention practices (Urban Bioretention, Residential Rain Gardens) typically range from 0.5 acre to 1.0. (Tennessee Permanent Stormwater Management and Design Guidance Manual)</p>	<p>Primary survey-Identify potential locations for BU elements</p>	

4.2 ANALYSIS

MACRO SCALE: According to the framework's guidelines, the UHI parameters and BU indicators are not at a sufficient level. The absence of every element and sub element in the study area contributes to climate change and leaves the city unfit for its inhabitants to lead healthy lives. The use of BU components to increase climate sustainability at the regional level is challenging since it may be enhanced by starting at the stage of meso level. In order to move on with the procedures, an analysis of a case study demonstrating the use of BU at the regional level is required.

MESO SCALE: The area has been identified to make it convenient to implement mitigation strategies and proposals. As the location with the greatest vulnerability to all the characteristics is chosen, we may observe a larger concentration of buildings, as well as a lack of and inadequate accessibility to green space, permeability, surface water, and other resources. The framework helps to understand the proportion that must be raised, and it also helps to identify the UHI-causing components. As a result, when laying plans and proposals into action, the framework must be taken into account. Additionally, a case study that shows the percentage of area that was increased in order to maintain ecological stability is needed, as well as one that validates the use of spatial analysis to identify UHI reduction.

MICRO SCALE: The primary study provides the answer for the satisfaction level of those in the study area at the micro scale. The micro scale analysis may be used to determine the locations that are suitable for the execution of plans and proposals. According to guidelines, the majority of the population resides beyond the green spaces and waterbodies, which are important factors in increasing UHI and heat stress. By observation surveys and better community activities, it is possible to determine the availability of the existing elements and to improve the nature-based elements. Understanding the present situation and the land surface temperature in relation to the materials used in the study area was aided by the primary survey. The survey demonstrates the correlation between reduced green cover and higher temperatures and the severity of heat stress.

CHAPTER 5 LITERATURE CASE STUDY

5.1 GREEN PLAN, SINGAPORE

5.1.1 Selection criteria

- The Centre for Climate Research Singapore (CCRS) has projected that Singapore's maximum daily temperature could reach 35 to 37 degrees Celsius by year 2100, if carbon emissions continue to rise at the same rate.
- Singapore is already leading the way in efforts to create a greener urban environment following the aftermath of COP26 and demonstrated how high density does not have to mean reduced natural systems.
- The rationale behind Singapore's commitment to greater regional natural systems is to improve biodiversity, reduce the urban heat island effect and improve the thermal comfort of the outdoors.

5.1.2 Location

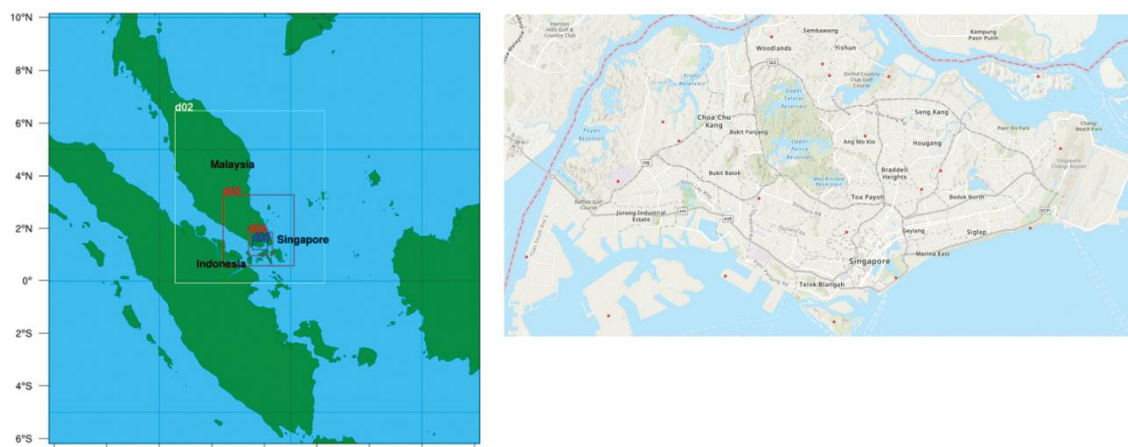


Figure 5. 1 Location map

Source: Natalia Borzino,2020

Located just north of equator, at the southern tip of Peninsula Malaysia. The mean daily temperature minima is in the range of 23–26 °C and mean daily maxima between 31–34 °C.

5.1.3 Background

Since its founding in 1965, Singapore has worked toward the establishment of a "garden city." To inform the people of the need of preserving their city and environment, several campaigns and catchphrases have been utilised. In 1963, then-Prime Minister

Lee Kuan Yew began a tree-planting initiative as part of the "Clean and Green" campaign with the intention of enhancing air quality and introducing the idea of a "garden city." Lee Kuan Yew made National Parks (NParks) a component of the Ministry of National Development, placing them at the centre of the new city-states' political agenda to demonstrate the significance of becoming a garden city model in Asia. Since then, NParks has contributed significantly to innovation in the biophilic city.



Figure 5. 2 Singapore city

Source: (Newman, 2014)

With the expansion of the economy, Singaporeans' demands for a higher standard of living and more attractive recreational spaces have increased. The idea of the "garden city" has also been reexamined in light of the increased recognition of the need of environmental preservation. As a result, the aim shifts from a "garden city" to a "city in a garden," according to the "Singapore Green Plan 2012, beyond clean and green towards environmental sustainability."

"In the next phase, our ambition is to develop a "City in a Garden," to bring green areas and biodiversity to our doorsteps," said Prime Minister Lee Hsien Loong during the 2012 World Cities Summit while describing this idea. This implies that, in addition to the customary requirement to maintain green zones between buildings, buildings, highways, and concrete are all suitable areas for landscaping; it appears to be a particular trait that extends beyond landscape design and planning for parks and reserves.



The Singaporean examples of biophilic urbanism show how Singapore is putting both of its principles into practice: strengthening the natural systems on building facades and extending the natural systems between buildings.

3.2.2 ‘Singapore Green Plan 2012’ (Ministry of the Environment and Water Resources 2012)

A government plan defining Singapore's goal for environmental sustainability, the Singapore Green Plan 2012 (Ministry of Environment and Water Resources 2012), was announced in 2002. One of its core tenets is the preservation of the environment by restoring natural places where development has damaged them, disseminating knowledge about native plants and animals via biodiversity research, establishing new parks, and putting up Park Connectors.

The city also launched the Singapore Biodiversity Index in cooperation with the United Nations Convention on Biological Diversity and built a National Biodiversity Reference Center.



Vision: By shifting the perception of a "garden city" to a "city in a garden," we can bring green spaces and biodiversity right to our front doors.

The biophilic urbanism approach in Singapore is a notable one as it sets goals for the conservation of green areas and integration of green area in to the dense urban area where the biophilia has an immense role. The most heated areas require a cool environment and thus the increase in number of trees and plants can enhance evapotranspiration and reduce the heat in the atmosphere. The presence of native plants and available biodiversity the biophilic urbanism was implemented in Singapore. The enhancement of natural systems in to the heat areas of Singapore.



Figure 5. 3 Implementation of Biophilic urbanism in the city

Source: (Newman, 2014)

5.1.4 Park connectors



Greenery



Conservation



Recreation

A system of linear parks spanning the whole island of Singapore, known as the Park Connector Network (PCN), connects significant green areas and locations, primarily residential districts. By 2015, PCNs want to have developed around 300 kilometers of green linkages over the entire island, using an integrated approach of "greenery, conservation, education, and enjoyment."

The purpose is to make it simple to go about Singapore by walking or cycling through its parks. 200 km of the PCN have been finished as of 2012, according to the Ministry of National Development (2012), and a sizable new north-south connection is planned to be built along the defunct regional rail route. This will link the island city's central business district to the main parks.



Figure 5. 4 West loop park connector, Singapore

Source: (Newman, 2014)

5.1.5 Elements of biophilic urbanism applied

- Green roofs
- Green walls and
- Green balconies
- Park connectors
- Streetscape Greenery Master Plan (SGMP)

5.1.6 The Singapore Green Plan 2030

The Singapore Green Plan 2030, often known as the Green Plan, is a pan-national initiative aimed at advancing Singapore's national objective on sustainable development. Released in February 2021. Global challenges like climate change require strong response, and Singapore is doing its share to create a sustainable future.

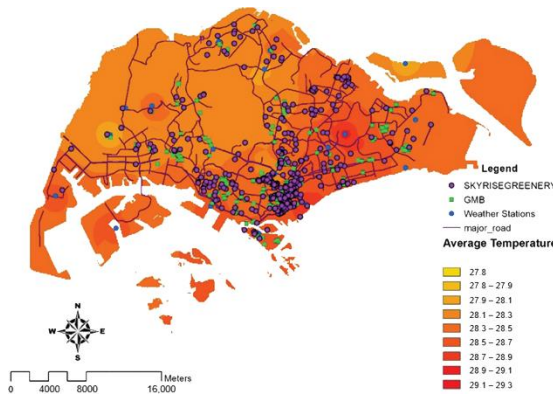


Figure 5. 5 Temperature variation map
Source: (Newman, 2014)

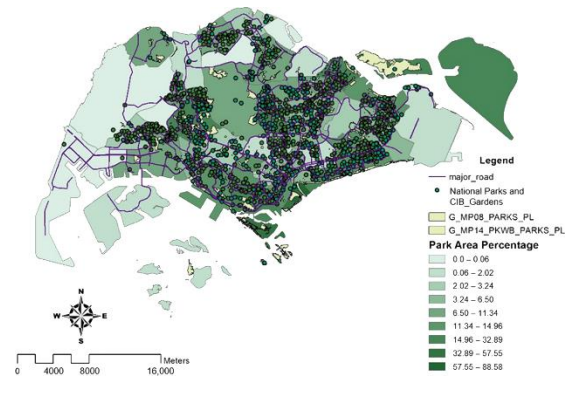


Figure 5. 6 Park areas
Source: (Newman, 2014)

The Green Plan is composed of five pillars that will have an impact on every area of our life.

1. City in the Nature
2. Restore the energy
3. Living Sustainability
4. The Green Economy
5. A Healthy Future

5.1.7 Result and findings of the Singapore Green plan,2012

Green canopy cover has increased by 20%, despite a 70% increase in population

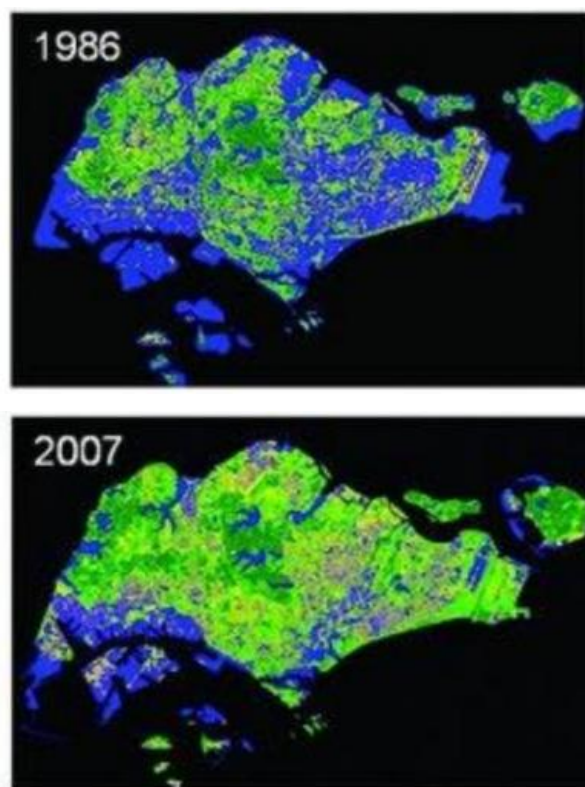


Figure 5. 7 Green canopy cover
 Source: (Newman, 2014)

Table 5. 1 Targets of Green plan
 Source: (Newman, 2014)

Indicator	2013 level	Targets of 2030
Skyrise greenery	61 ha	200 ha
Parks	4040 ha	0.8ha/population
Water bodies	959 ha	1039 ha
Park connectors	216 km	400 km
Waterways	93 km	100 km
Nature ways	21 km	180 km

Table 5. 2 The strategies of Singapore green plan 2020

Source: (Newman, 2014)

City in Nature	Sustainable Living
A Green, Liveable and Sustainable Home for Singaporeans	Green Commutes
Add 1000ha of green spaces and 160km of park connectors	75% of all trips to be on mass public transport by 2030, up from 64% today
Every household will live within a 10-minwalk from a park	Triple cycling path network to 1,320km by2030 from 460km in 2020
Plant 1 million more trees across Singapore by 2030.	Green Citizenry: Less waste and consumption
	Reduce amount of waste to landfill per capita
	Encourage water conservation and water efficient practices for households and industries

5.1.8 Inference

- The Singaporean model is important since many other Asian cities are beginning to follow it, enabling their dense urbanity to be depicted in a more realistic manner.
- They have shown that biophilic urbanism planning policies and strategies can be implemented affordably with strong community support, that proof of concepts can be mainstreamed fastly, so that government incentives and R&D are all crucial parts of enabling innovative change, and that political leadership is what makes it all work.

5.2 THE ACTIVE, BEAUTIFUL, CLEAN WATERS PROGRAMME, SINGAPORE

5.2.1 Selection criteria

- To evaluate the element-water features (waterbodies conservation, Rainwater

harvesting, water quality improvement).

- Singapore has improved its water resilience over time because to smart regulations, planning, and water-related inventions.

5.2.2 Introduction

The National Water Agency (PUB) of Singapore created the Active, Beautiful, Clean (ABC) Waters Programme in 2006 with the goal of transforming rivers and waterbodies into lovely urban assets, integrating these drainage systems with the built environment, and bringing people closer to water. The series highlights the function of water in urban settings and illustrates how water is a key component in the creation of livable cities.



Figure 5. 8 ABC water programme
Source: Singapore’s national water agency

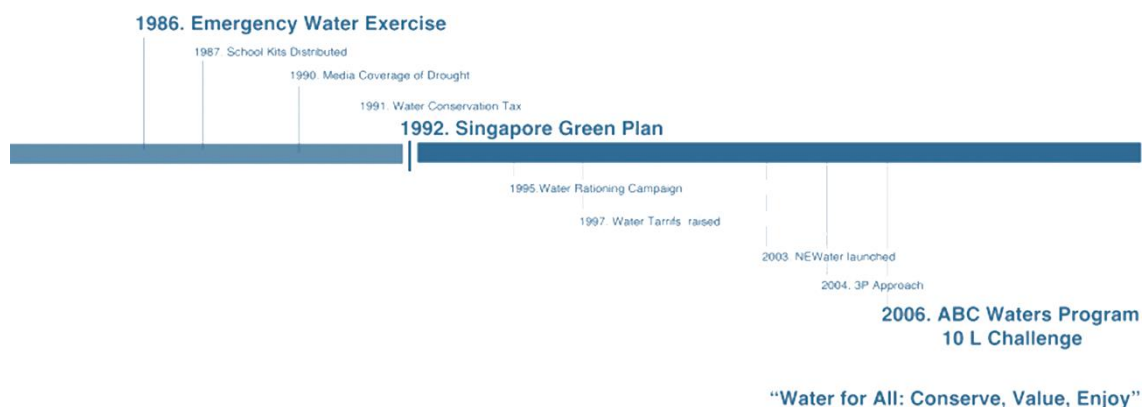


Figure 5. 9 Timeline

Source: Singapore’s national water agency

5.2.3 ABC Water program

Objectives: Improve the water's quality and the area's viability urbanisation that is "blue-green" sensitive and uses low-impact development as a development philosophy.

Aim: To make Singapore's canals, rivers, and reservoirs into lovely public areas where people can enjoy being near water while also protecting it.

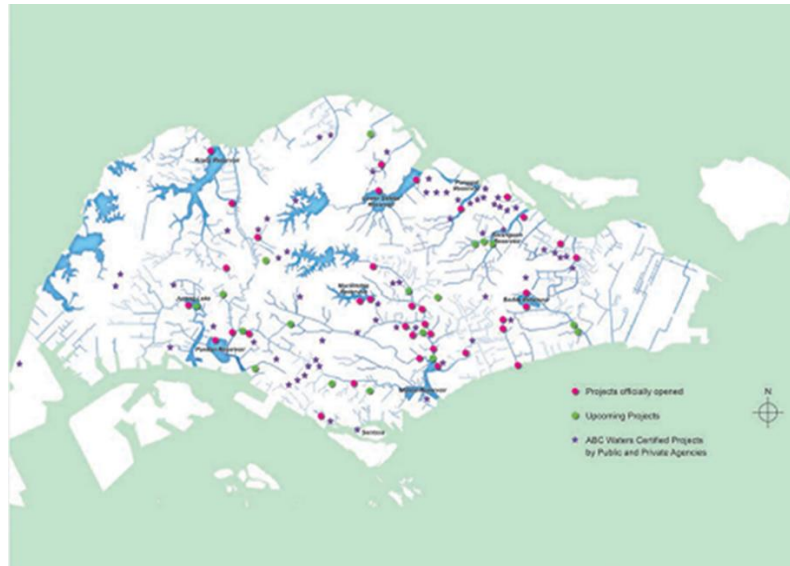


Figure 5. 10 Singapore’s Blue Map with over 8,000 km of waterways and 17 reservoirs

Source: Singapore’s national water agency

ACTIVE	BEAUTIFUL	CLEAN
Creating new recreational and community spaces while bringing people closer to water	Transforming concrete waterways in to vibrant and picturesque waterscapes that are well integrated with the urban environment	Improving water quality through holistic management of our water resources and public education by fostering better people water relationships

Figure 5. 11 ABC programme

Source: Singapore’s national water agency

5.2.4 Central Watershed and Bishan Park-Waterbody conservation and restoration

In the centre of Singapore, there is a project called Central Watershed Bishan Park. Prior to the creation of the projects, the centre watershed was made mainly of undeveloped terrain and the Kallang River, a straightforward concrete channel that transports water from the upstream Lower Peirce Reservoir to the downstream Marina Reservoir. The region was gated off and not intended for human use. This made it the ideal location for high school kids to occupy at night in secrecy. Flooding made the region exceedingly perilous because the water was moving so quickly.

The new Bishan Park was developed as a novel approach to the Central Watershed's water management problems and as a place for people to enjoy and engage with water. Activities/Facilities: Parking lot, restrooms, event grass, playground for kids, foot reflexology pathway, fitness stations, equipment, and exercise station, food and beverage area, restaurant, or café, and dog run corner.



Figure 5.12 Bishan Park restoration

Source: Singapore's national water agency

The plan called for demolishing the existing canal and building a naturalized river with parkland on each side and bioengineered riverbanks in its place.

5.2.5 Rain water harvesting

Singapore's 710 km² territory and expanding metropolitan areas don't provide for enough space to catch and store all of the rain that falls there. Rain that falls on two-thirds of Singapore's land area is diverted to our 17 reservoirs by a system of rivers,

canals, and drains.

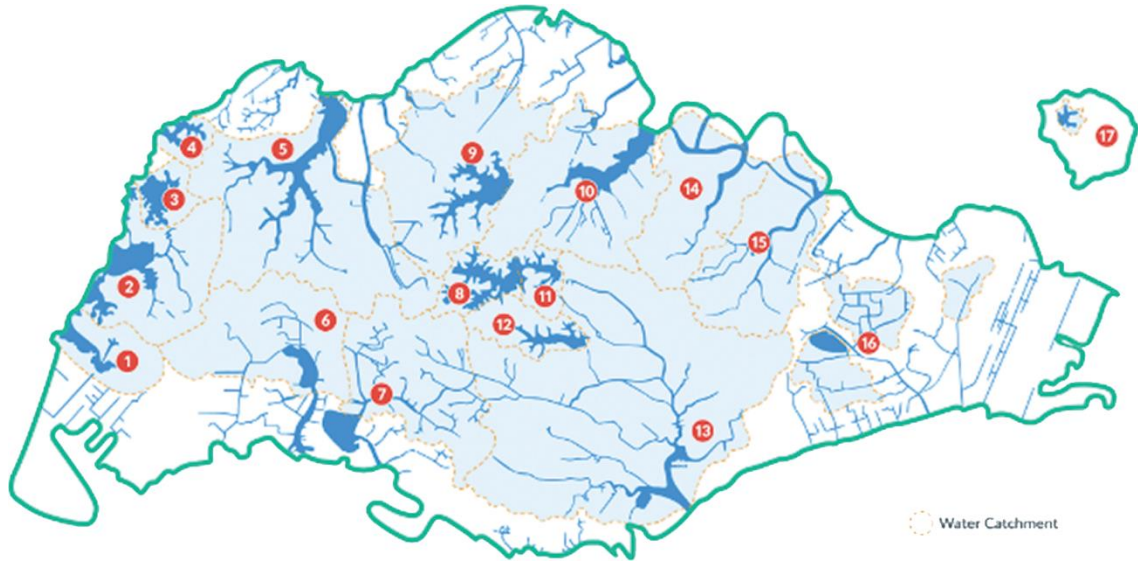


Figure 5. 13 Water catchment area

Source: Singapore's national water agency

In Singapore, used water and rainfall are collected by two different methods.

1. Before being processed for drinking water, rainwater is collected through a vast network of drains, canals, and rivers and sent to the reservoirs.
2. A system of subterranean sewers collects used water and transports it to a water reclamation facility. The cleanness of the rivers is ensured by separate systems.

5.2.6 Catchment area



Figure 5. 14 Water catchment areas protected and unprotected

Source: Singapore's national water agency

5.2.7 Result

With the construction of the Marina, Punggol, and Serangoon Reservoirs since 2011, Singapore's land area's water catchment area has expanded from half to two-thirds. As a result, Singapore is one of the few nations in the world that collect urban stormwater in substantial quantities for potable use.

5.3 TORONTO, CANADA

5.3.1 Selection criteria

To understand the green roof and green street strategies for analysing the element-built canopy in micro and meso scale.

5.3.2 Toronto's Green Roof Policy

The City Council's adoption of a Green Roof Strategy in 2006 marked the beginning of Toronto's leadership in green roof policy. This strategy promoted the installation of green roofs on publicly and privately owned buildings by offering incentives, educating the public, and streamlining the development approval procedure. In 2009, the City's Green Roof Bylaw and the Eco-Roof Incentive Programme were enacted as a result.

A progressive green roof requirement is outlined in the Green Roof Bylaw for new projects with a gross floor area more than 2,000 m². The required percentage of a building's usable roof area is between 20 and 60 percent. The bylaw gives developers the choice to apply for approval to pay \$200/m² in cash-in-lieu rather than erecting the necessary green roof.



Figure 5. 15 Key events in the development of Toronto's green roof policy and bylaw

Source: Toronto's Green Roof Policy, 2015

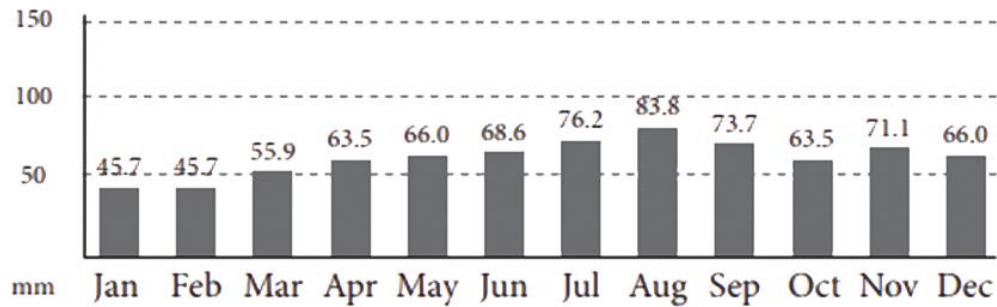


Figure 5. 16 Average Monthly Precipitation in Toronto

Source: Toronto's Green Roof Policy, 2015

Table 5. 3 The benefits of green roof

Source: Toronto's Green Roof Policy, 2015

Public Benefits	Private Benefits
Reduces the urban heat island effect	Aesthetic improvement
Improves air quality	Increases energy efficiency
Reduces greenhouse gas emissions	Improves solar panel efficiency
Improves stormwater management – quality and quantity	Extends life of conventional roofs (Increases roof membrane durability)
Facilitates new recreational opportunities	Increases property value
Improves community health and well-being	Food production
Increases urban habitat and biodiversity	Noise reduction
Increases tax revenue	Improves marketability
Decreases municipal infrastructure costs	Energy savings

Gross floor area (size of building)	Coverage of available roof space (size of green roof)
2000-4000 m ²	20%
5000-9999 m ²	30%
10,000-14,999 m ²	40%
15,00-19,999 m ²	50%
20,000 m ² or greater	60%

Figure 5. 17 Green roof coverage requirements for Toronto's green roof bylaw

Source: City of Toronto, 2010

The required coverage was calculated using a graded scale that ranged from 20% to 60% of the available roof area.

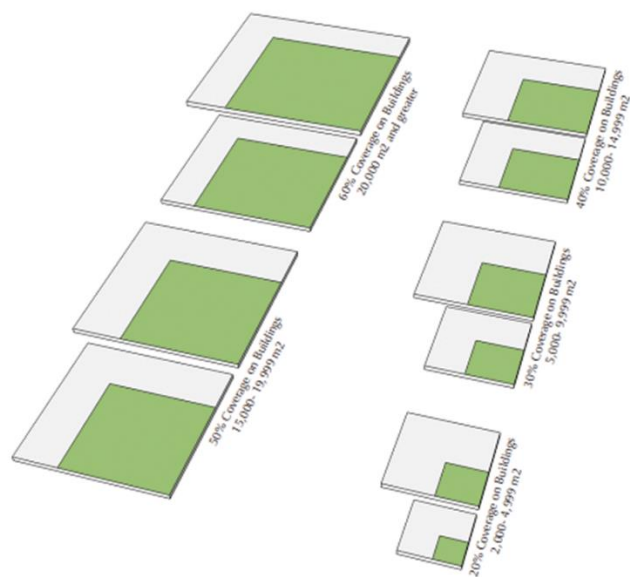


Figure 5. 18 Illustration of Toronto’s Green Roof Policy sliding coverage scale
Policy sliding coverage scale

Source: City of Toronto, 2010

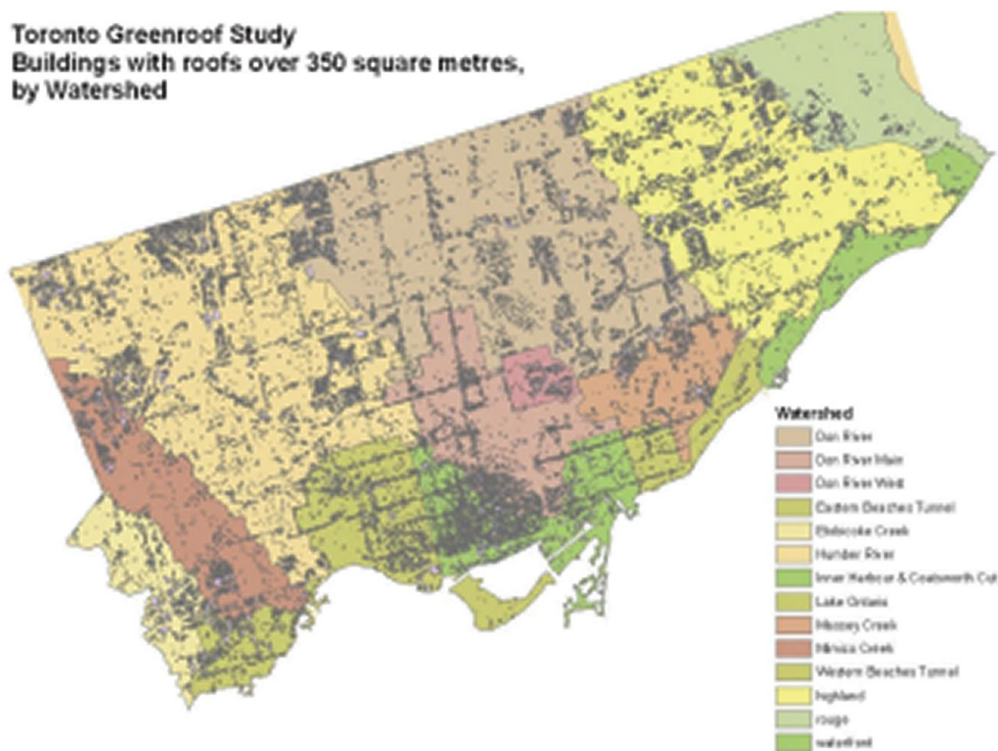


Figure 5. 19 Buildings in Toronto with roofs over 350 square metres s of 2005

Source: Toronto’s Green Roof Policy, 2015

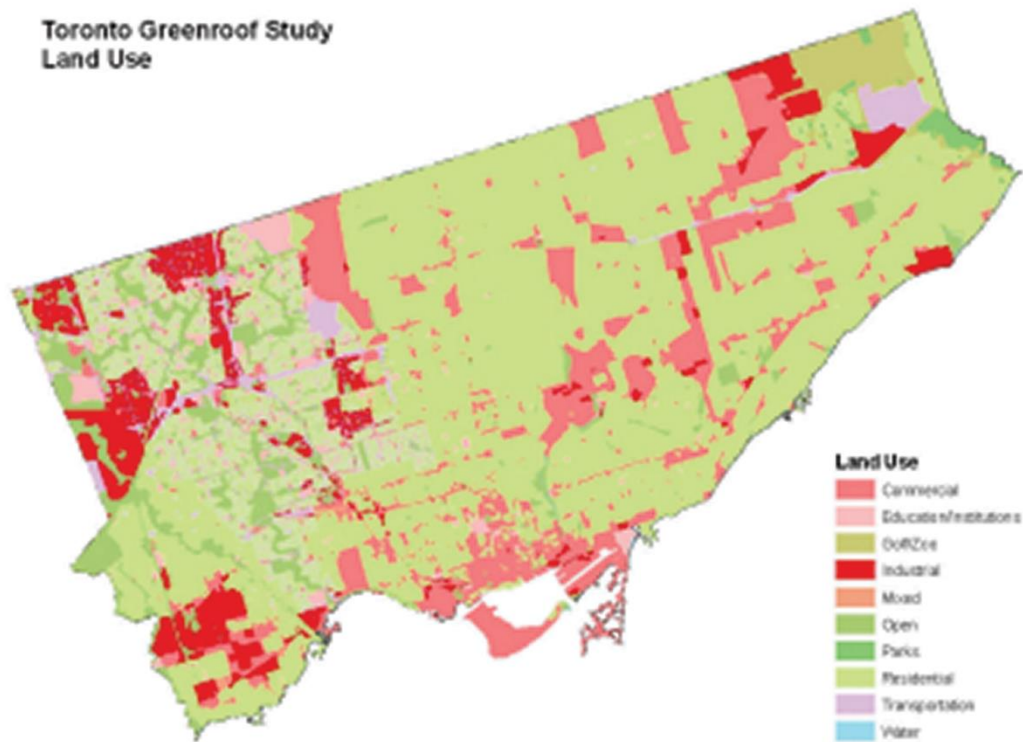


Figure 5. 20 Landuse of Toronto

Source: Toronto's Green Roof Policy, 2015

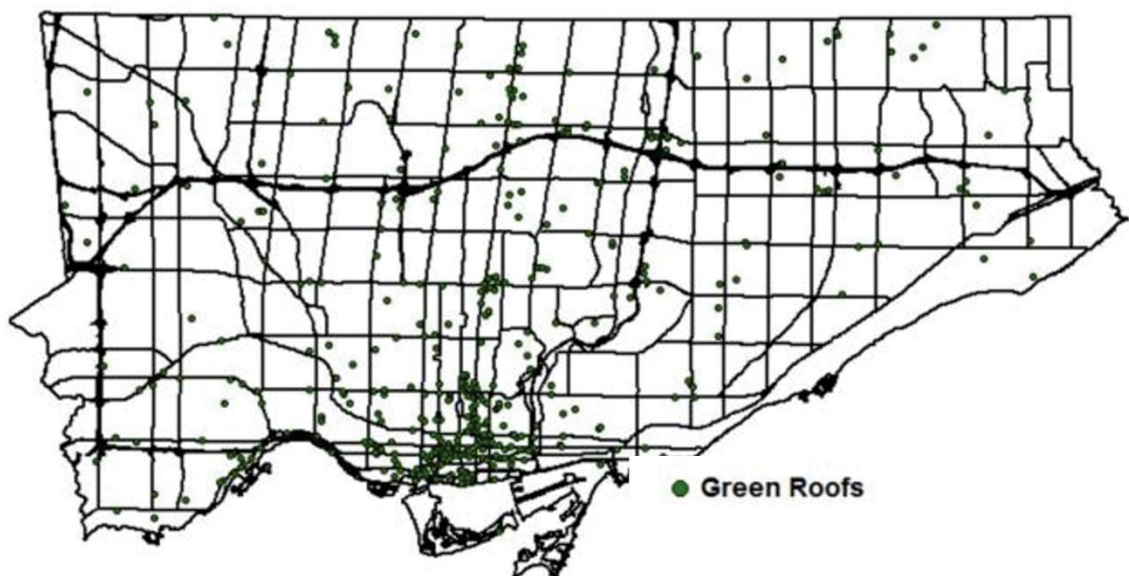


Figure 5. 21 Green roofs after the program

Source: Toronto's Green Roof Policy, 2015

5.3.3 Results

- Approximately 420 green roof permits totaling 450,000 square metres were awarded in Toronto between 2010 and 2017. Since 2009, the Eco-Roof Incentive Programme has financed 336 eco-roof projects out of more than 500 submissions.
- With a direct cooling impact of 4-5°C on the roof surface, widespread use of green roofs can lower local ambient air temperature by 1.5 to 2°C. Green roofs will contribute to creating more green space in urban areas, which may improve biodiversity Green Streets Project

Green Streets are thoroughfares with natural and man-made green infrastructure that collect rainfall and channel it to trees and plants, functioning as a natural filter to purify the water before it enters nearby waterways. It has positive effects on society, the economy, and the environment and is a resilient, cost-effective way to controlling the effects of rainy weather events. In Toronto, "green streets" are replacing "traditional streets," which were built to swiftly channel precipitation into storm sewer systems (such as gutters, drains, or pipelines), which then discharge directly into our waterways while frequently carrying pollutants (such as filth, oil, and grease) with them.

5.4.1 Street selection criteria at macro and meso level

The State of Good Repair (SoGR) Programme, which is the foundation of the City of Toronto's Green Streets programme, is used to guide its implementation. Three parts make up the selection process, with the resources needed for each phase serving as a loose guide.

- The first step is GIS analysis, the second is desktop analysis, and the third is stakeholder consultation. A Geographic Information System (GIS)-based Priority model is used in Phase 1 (GIS Analysis) to rank projects according to the co-benefits that may be attained through green infrastructure. Phase 2 (Desktop Analysis) begins by assessing the viability and appropriateness of GI implementation at the local level. To determine scope, budget, and coordinate further actions, Phase 3 (Stakeholder Coordination) makes use of the experience of the Green Streets Working Group and other implementation agents. other implementation agents.

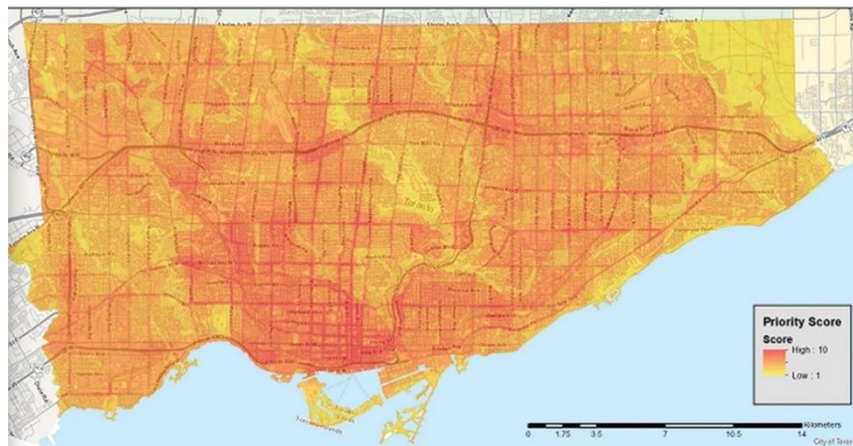


Figure 5.22 Green streets priority map

Source: City of Toronto's Green Streets Project, 2021

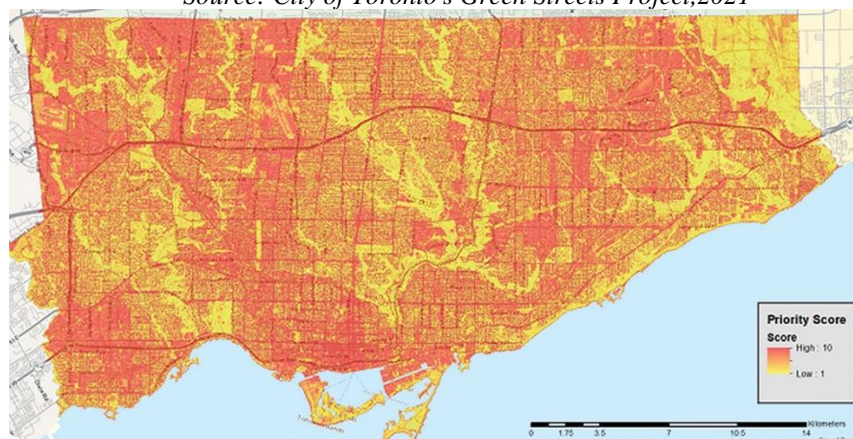


Figure 5.23 Tree canopy cover

Source: City of Toronto's Green Streets Project, 2021

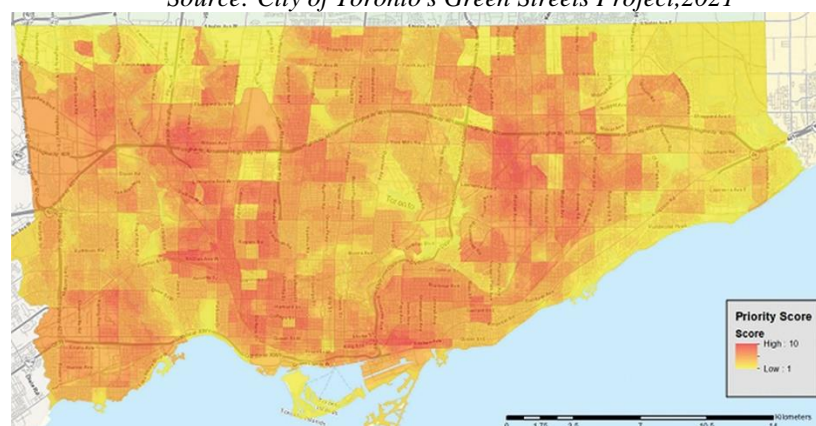


Figure 5.24 Climate resilience map

Source: City of Toronto's Green Streets Project, 2021

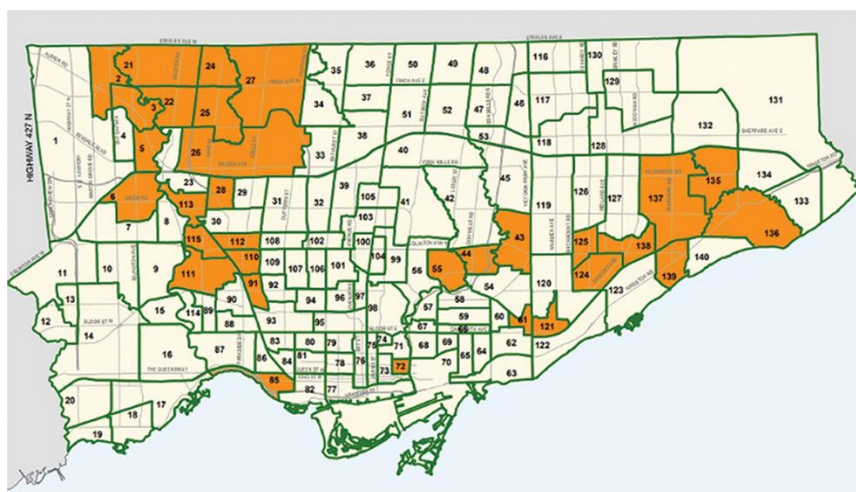


Figure 5. 25 Neighbourhood mapping
Source: City of Toronto's Green Streets Project,2021



Figure 5. 26 Air quality map
Source: City of Toronto's Green Streets Project,2021

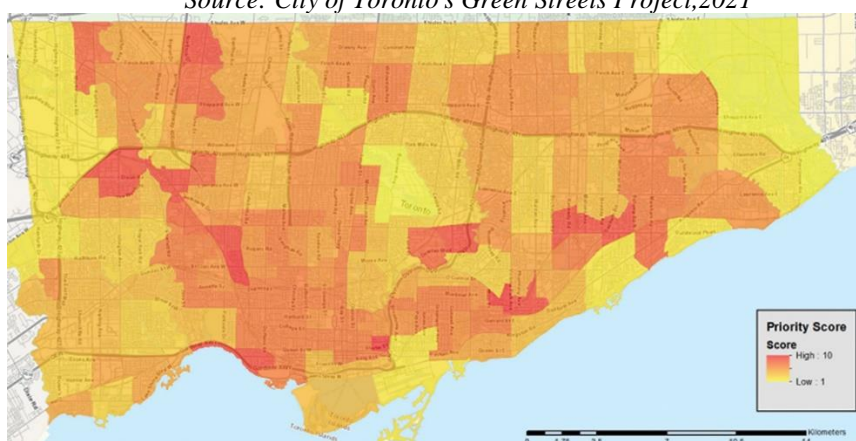


Figure 5. 27 Neighbourhood social wellness map
Source: City of Toronto's Green Streets Project,2021

5.4.2 Street detailing at micro level scale in high density area

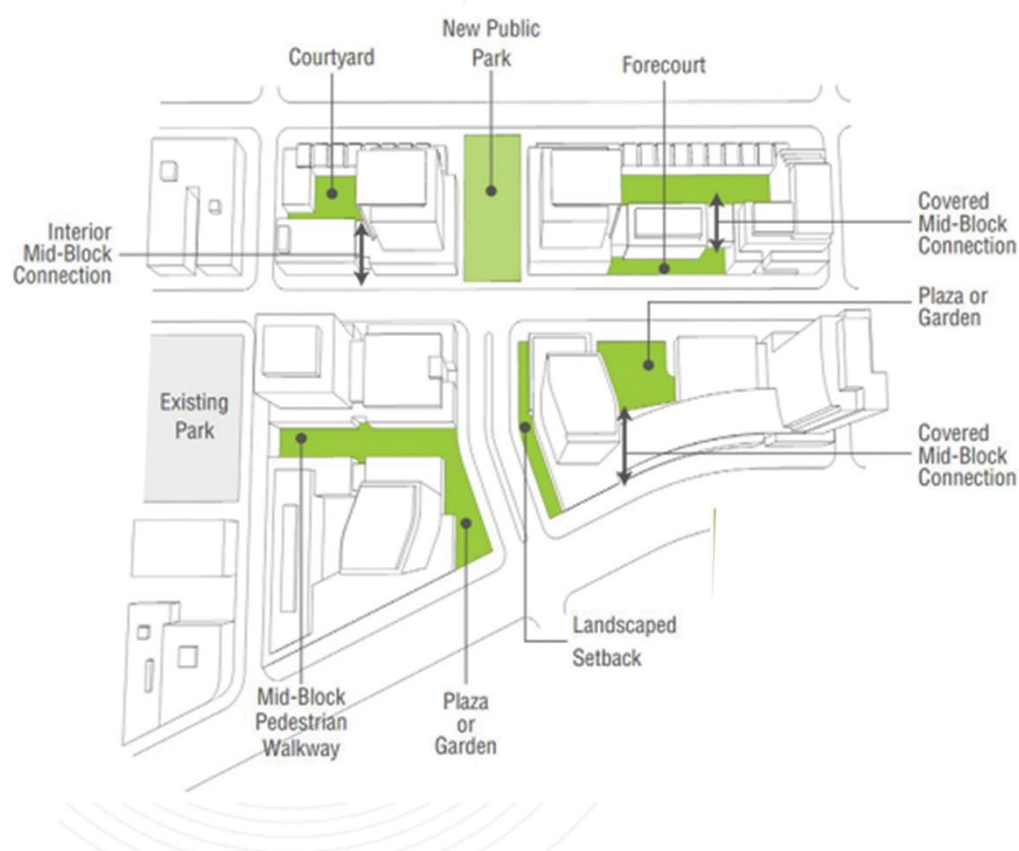


Figure 5. 28 Street level planning

Source: City of Toronto's Green Streets Project,2021

The following are some of the environmental advantages of Green Streets:

- Improving conditions for urban tree development to increase the size and longevity of the urban forest
- Reducing the impact of urban heat islands
- Managing stormwater runoff to improve the quality of the water Improve the city's resistance to severe storms by providing retention to prevent erosion in receiving water bodies.
- Improving air quality
- Offering chances to increase biodiversity -Promoting infiltration to support shallow groundwater systems



Figure 5.29 Street level detailing

Source: City of Toronto's Green Streets Project,2021



Figure 5.30 Street level detailing

Source: City of Toronto's Green Streets Project,2021

5.5 GREEN HYDERABAD PROGRAMME, HYDERABAD

5.5.1 Selection criteria

To evaluate the different elements (open space, Street trees, urban parks, Green buffer zones) specific to indian context and to understand the applications of it in the study area and the changes that occurred due to the program.

5.5.2 Factors affecting UHI in Hyderabad

- Change in Land Use
- Shrinkage of Water bodies
- Population size and density
- Urban geometry
- Built-up

The city has won the 2022 World Green Cities Award from the International Association of Horticulture Producers (AIPH) in the category Living Green for Economic Recovery and Inclusive Growth.

It has an average annual rainfall of 73.55 cms, with lowest and highest temperatures of 11.6 and 40.5 degrees Celsius, respectively. The city is positioned in the middle of Mumbai, Chennai, and Bangalore, three other major cities. Hyderabad, the seat of Telangana's government.

A total of 650 square kilometers of the city are under the management of the Greater Hyderabad Municipal Corporation (GHMC), while a further 7257 km are under the management of the Hyderabad Metropolitan Development Authority (HMDA).5.5.3 Telangana Ku Haritha Haram (TKHH)

Telangana Ku Haritha Haram (TKHH), meaning 'Green necklace to the State of Telangana' is a flagship program which is a large-scale tree-planting program implemented by the Government of Telangana since 2015-16.

In Hyderabad city massive plantations were taken up under various components like

- Avenue Plantation
- Multi-layered Avenue plantations
- Barren Hill Afforestation
- Institutional plantations
- Homestead plantations
- Canal Bank
- Industrial parks
- Greenery under flyovers
- vertical gardens
- Planting in Urban Residential Colonies involving all stakeholders.

Rainfall totals each year (mm) from January 6, 2021, through March 31, 2022 Central Median plantations (190 km), multi-layer avenue plantations (85 km), where there were wider margins along the roads, and also single row street plantations were taken up along the roads in the core city area, which help in mitigating the effects of pollution. Actual: 6958.7; Normal: 5255.6

Table 5. 4 The projects under TKHH

Source: International Association of Horticultural Producers,2022

Roadside Multi Layered Avenue plantations	length 881.5 Km, 37,27,805 No's.
Greenery on Road Central Median	length 406.50 Km, 47,03,241 No's.
Tank bund plantation No. of. Lakes	24, No. of. Plants 32,00,000 No's.
Urban Parks 1087 No's.	
Urban Forest area Block Plantations	5928.38Ha
No. of. Plants 30,00,000No's.	
Colony/Street Plantations	56,25,857 No's.
Institutional Plantations	No. of. Plants 155,00,000No's.
Vertical Garden	12 No's.
Block Plantations	250Ha along ORR
Landscape Gardens	12.5 Ha.



Avenue plants with many layers contributed to better air quality. In addition to providing shade and decent air quality, the 111 urban lung spaces and 24 lake bunds that were constructed with avenue and shrub plantations also have medicinal value. They evolved into recreation areas and environmental education facilities. (International Association of Horticultural Producers, 2022)

5.5.4 Elements and Interfaces of Biophilic urbanism

- Vertical greening hardscaping
- Pervious paving
- Bioretention,
- Rain gardens
- Rain water harvesting, and
- Grey water harvesting



Figure 5. 31 Elements of BU applied

Source: Author generated

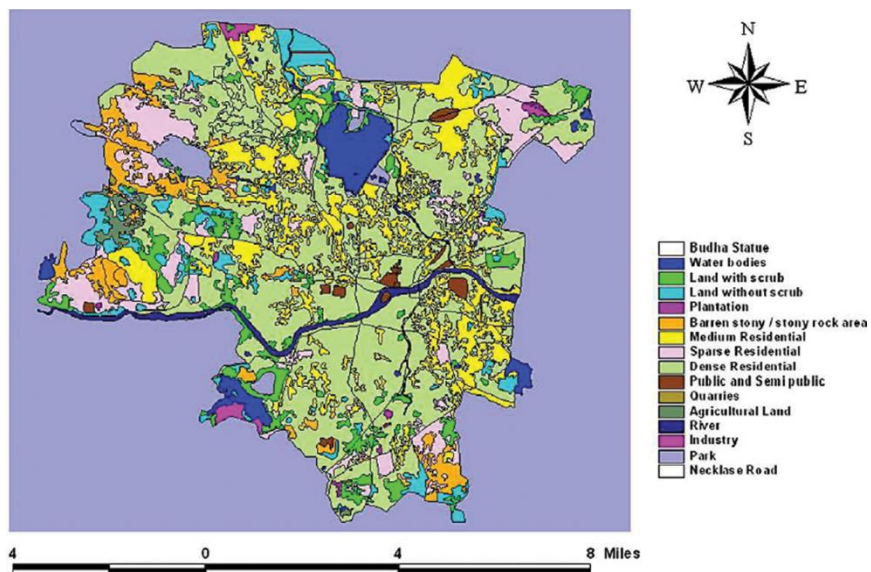


Figure 5. 32 LULC map of Hyderabad,2022

Source: Centre for Environment, J.N.T UNIVERSITY, Hyderabad

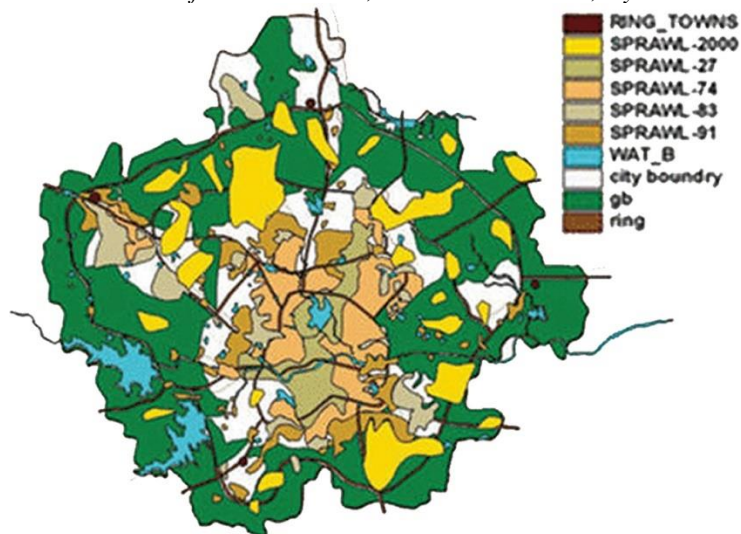


Figure 5. 33 Land use transformations-Hyderabad city

Source: HUDA Hyderabad, 2003

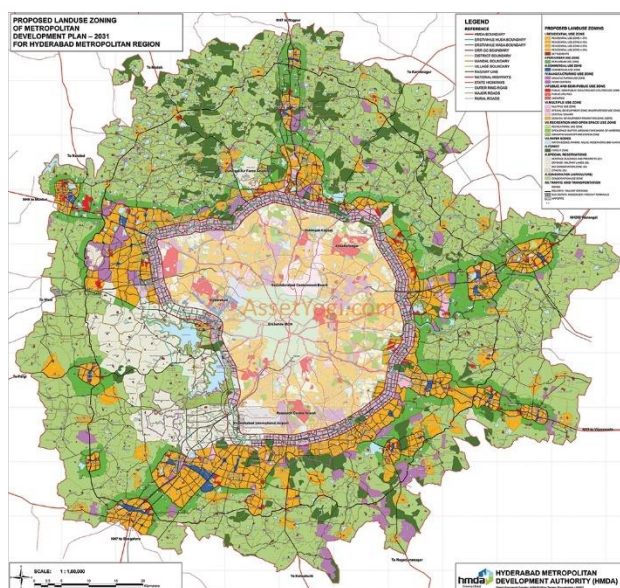


Figure 5. 34 Masterplan,2031

Source: HMDA Hyderabad, 2022

5.5.5 Results

- Area covered by parks and gardens in GHMC rose by more than twice that amount in 2011 and then stabilized.
- The ecology of Hyderabad city has significantly improved as a result of the extensive plantations grown there during the past six years. The state of the groundwater has improved, and noise and air pollution have decreased.
- The 760 colony parks throughout the city have been adopted and maintained by citizen groups who have grown plantations at their homesteads and colonies. FSI research indicates a remarkable rise in the green cover of 48.66 square kilometers, or from 33.15 square kilometers in 2011 to 81.81 square kilometers in 2021. It is crucial that the younger generation have the proper attitude towards trees and the environment.

5.6 COMPARATIVE ANALYSIS

Table 5. 5 Case study comparative analysis

Source: Author generated

CRITERIAS	GREEN PLAN,SINGAPORE	THE ACTIVE, BEAUTIFUL,CLEAN WATERS PROGRAMME,SINGAPORE	TORONTO,CANADA	GREEN HYDERABAD PROGRAMME,INDIA
Programs implemented/Description	Singapore Green Plan 2012 The Singapore Green Plan 2030 by - Ministry of National Development. - Ministry of Sustainability and the Environment.	The programme showcases the role of water in urban spaces , and demonstrates how water is a vital ingredient in the development of liveable cities	<ul style="list-style-type: none"> Toronto's Green Roof Policy Green streets project-Demonstrates the spatial analysis of identifying neighbourhood improvements required. 	Green honor for Hyderabad: Only city in India to get 'Tree City' tag. Telangana Ku Harita Haram(TKHH)
Aim of the program	To Shifts the vision from a 'garden city' to a ' city in a garden ' to bring green spaces and biodiversity to our doorsteps	To transform Singapore's canals, rivers and reservoirs into beautiful recreational spaces where people can be close to water and protect them.	To implement Green roof for new developments that are greater than 2,000 m² in gross floor area. To capture rainwater and direct it to plants and trees, acting as a natural filter that cleans the water before it makes its way into local waterways.	The program envisages increasing the tree cover of the State from 24% to 33% of the total geographical area of the State.
Analysed elements	Vegetation inclusion -Natural vegetation Different scales of implementation- Macro,Meso,micro	Water features (waterbodies conservation, Rainwater harvesting, water quality improvement).	Built canopy -green roof and green street strategies in meso and micro level(high density)	Green infrastructures -Open space, Street trees, urban parks, Green buffer zones in meso level
Findings/Result	Green canopy cover has increased by 20% , despite a 70% increase in population. The total land area covered by greenery rose from 36 percent in 1986 to 47 percent in 2007	Waterbody conservation and restoration. Since 2011, the water catchment area has increased from half to two-thirds of Singapore's land surface. Improved rainwater reservoirs.	Between 2010 and 2017, approximately 420 green roof permits were issued in Toronto , totalling 450,000 square meters of green roof space. green roofs can reduce local ambient air temperature 1.5 to 2°C. The results of the installation include a significant reduction of annual runoff volume—a 91 per cent reduction	Area under parks and gardens in GHMC it increased more than twice in 2011 Remarkable increase in the green cover noticed as per FSI report by 48.66 Sq. Kms. i.e., from 33.15 Sq. Kms in 2011 to 81.81 Sq. Kms in 2021.
Mitigation measures/Elements of BU	<ul style="list-style-type: none"> Green roofs Green walls and Green balconies Park connectors Streetscape Greenery Master Plan 	<ul style="list-style-type: none"> Rainwater harvester Water Recreational areas Urban creek 	<ul style="list-style-type: none"> Parks Permeable pavements Sidewalks Street trees Bioretention Rain gardens 	<ul style="list-style-type: none"> Avenue Plantation Multi-layered Avenue plantations Institutional plantations Homestead plantations vertical gardens Canal Bank

5.6.1 Inference

The regions with BU application that results in the UHI reduction is studied. The drop in temperature with the increase in green cover can also be analysed. The changes that caused by the green areas, open spaces are depicted here and the cooling effect it can provide to reduce the UHI effect is visible from the table. From this we can analyse the amount of heat that can be reduced by increasing the percentage of tree cover and open space.

CHAPTER 6 PROPOSAL

This chapter explains the area level proposals that can be derived from the above studies. It shows the different strategies and proposals that can be used to mitigate urban heat island using biophilic urbanism elements. The goals, strategies and proposals at various scales are mentioned.

6.1 Aim

The strategies and proposals are applied in distinct areas of urban heat island to reduce the heat stress using biophilic urbanism indicators such as Biophilic infrastructure, Biophilic spaces and places and community and people activity.

6.2 Goals



GREEN COVER: Increasing the vegetation inclusion by incorporating, maintaining and restoring green infrastructures within the neighbourhood areas to maintain the ecological stability required to reduce UHI.



WATERBODIES: Increasing and restoring the existing water features by identifying appropriate lands within the area through artificial ponds, urban creeks, bio retentions to attain minimum percentage required to reduce UHI.



HEAT STRESS: Reducing the UHI effect with maximum inclusion of open areas, parks, ecological zones, increasing the tree cover, promoting the community programmes, following the required standards of green zones to reduce climatic impacts.



COMMUNITY ENGAGEMENT: Enhancing the community engagement in improving the BU elements and the networks that can be created within walkable distance of neighbourhoods to maintain the air and water quality.

6.3 Proposal 1

6.3.1 Indicator 1 -Biophilic infrastructure (macro level)



Vegetation inclusion: In 2010, Thiruvananthapuram's natural forest covered 124 kha, or 62% of its total area. Due to urbanisation, forest fires, and changing agriculture, it lost 528 hectares of natural forest in 2021, which is equivalent to 303 kt of CO2 emissions. The framework only allows for 25%, which is a relatively low number compared to the criterion for preserving ecological stability of 33%.



Establishing afforestation and plantation strategies: The less percentage of NDVI and natural vegetation depicts the need for afforestation programme and conservation programs of the existing flora. The programs that can be adopted are:1.Tree planting programmes-medicinal trees and plants, flowering fruit trees, creepers and bushes2.Restricting expansions of built density in to existing green areas with green belt as a remedy.3.Exploring different types of flora and improving the planting strategies

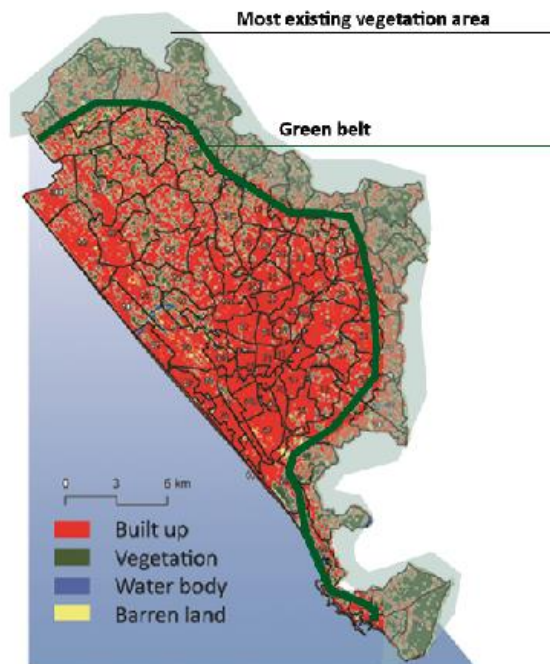


Figure 6. 1 Existing Vegetation area

Source: Author generated using Qgis

Five cents on the Kanakakunnu Palace premises where the Miyawaki method of afforestation has been replicated has transformed into a luxurious mini-forest in just 16 months. This project is a short-term program under the state tourism department.

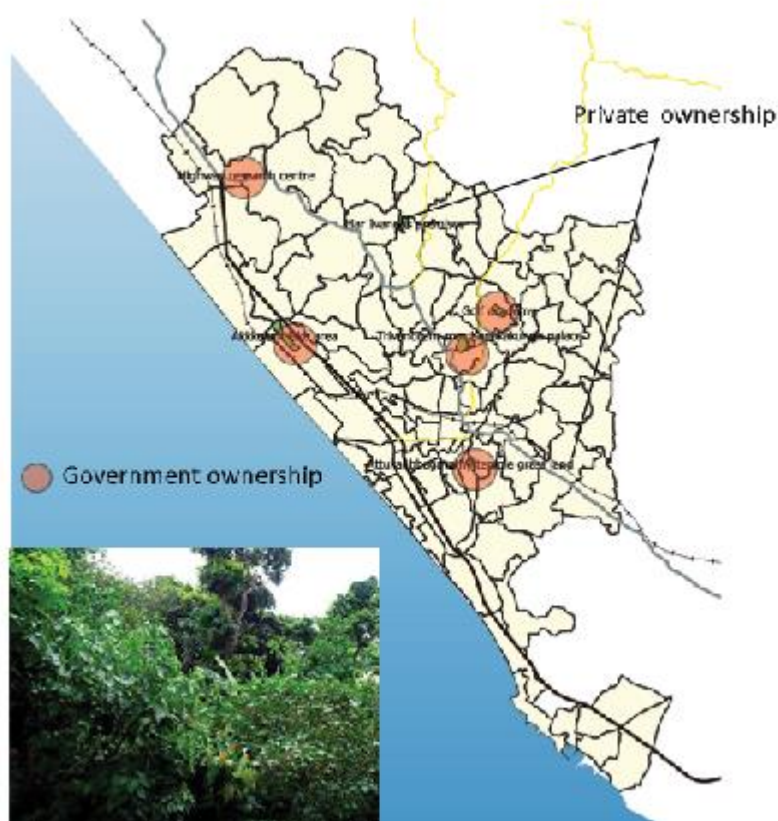


Figure 6. 2 Identified locations for vegetation inclusion

Source: Author generated using Qgis

The areas where afforestation program can be implemented where already exists the green areas but not specific to any flora or a period of time. The Miyawaki program can be extended to several parts of Kanakakunnu and zoo.



Figure 6. 3 Akkulam tourist village

Source: Author generated using Qgis



Figure 6. 4 Golf club
Source: Google earth

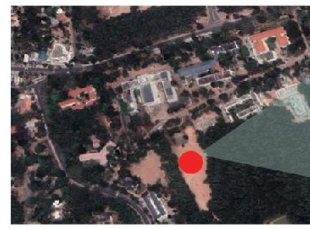


Figure 6. 5 National highway research institute
Source: Google earth



Conservation and reclamation programme in vegetated lands

Conserving the agricultural land by the application of transferable development rights and building byelaws.

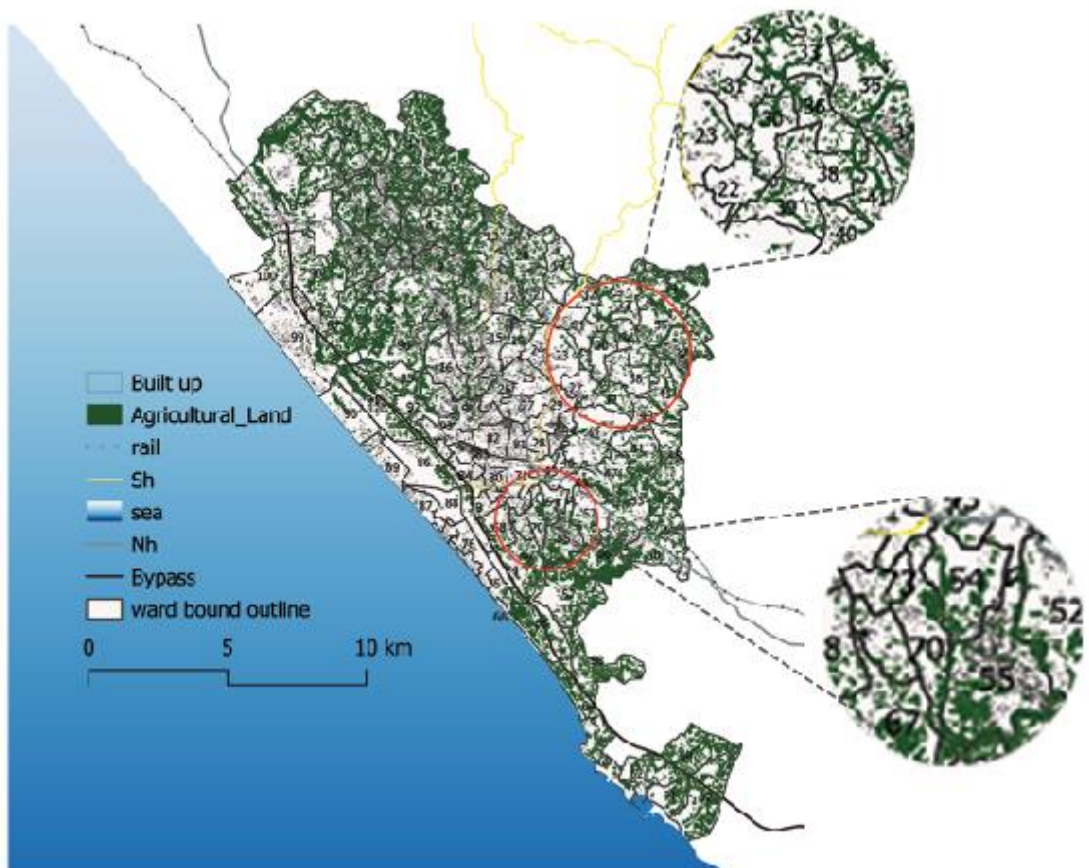


Figure 6. 6 Agricultural land
Source: Author generated using Qgis

The wards that are denser with built area compared to other wards with agricultural land can be observed here. Therefore, diminishing of agriculture lands in the respective wards can increase the heat stress. So, the existing land needs to be conserved.



Green infrastructure on agricultural properties can support farming production and provide additional ecological goods and services.

Buffers and hedgerows protect agricultural lands from wind erosion, provide connections to the natural heritage system and vital habitat for wildlife, including pollinators



Water features-The percentage of waterbody is low as compared to the required standards. The Karamana river, Parvathy puthanar, Amayizhanjan Thodu, Killi river which flows through Thiruvananthapuram is now so polluted that it is close to residents.



Revival of waterbodies and conservation

The existing waterbodies, both artificial and natural identified has the potential to be restored and need to be conserved. Motto for the year 2021 was ecosystem restoration in the Budget presentation on June 4. The Water Conservation Mission envisions to renovate the existing water surfaces ensuring pure and clean water in the local areas and to introduce a new culture for water consumption.

The polluted Killi river and the drainage overflowing through the river causing harmful conditions for the residential people in and around the river premises.

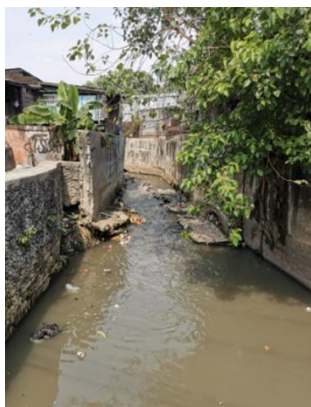


Figure 6. 7 Killi river
Source: Primary survey,2023



Figure 6. 8 Waste dumped in Killi river
Source: Primary survey,2023



Figure 6. 9 Killi river flowing in between residential area
Source: Google earth

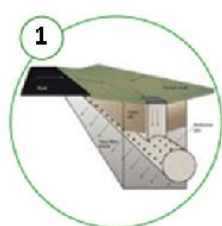
The plant has a capacity of 90 tonnes, but the garbage being accumulated in the plant is about 203 tonnes per day, which continues to pollute the river.



Figure 6. 10 Waste disposed in Parvathy puthanar
Source: Google earth



Figure 6. 11 Waste disposed in Karamana river
Source: Google earth



Perforated pipe



Rain garden and bio retention

The city corporation has started invoking provisions under Kerala Municipality Act pertaining to pollution of water bodies as part of implementing a campaign to clean Karamana River.

KWIL has made use of the most advanced machinery like silt pusher, shredder machine and amphibious harvester to deal with different kinds of waste that had to be cleared from the canal.

Solutions:

A waste plant with more capacity can be provided within the existing one to accumulate more garbage.

Sewers should not be opened to the waterbodies from residential and commercial areas

The tree planting along the edges of waterbody can create a natural filter preventing waste and unwanted substances flowing to the river (hedges, bushes etc.), community must be involved in those activities to promote clean water.



Transforming waterbodies to beautification assets

The waterbodies (canals, lakes) that has the potential for a development and promoting recreational activities to be identified and transformed. The successful pursuit of river rejuvenation entails forging linkages and sharing of responsibilities among different stake holders including people.

The waterfront development can be achieved in this location (Travancore Island resort) as the area is focused on tourism through the development the polluting factors can be avoided.



Figure 6.12 Karamana river flowing through Tourism resort in Thiruvallam ward (Waterfront development proposal)

Source: Google earth



Figure 6.13 Parvathy puthanar flowing through KIMS hospital area (Waterfront development proposal)

Source: Google earth

Existing condition: waterbody is polluted with silting and weeds and not maintained properly. A public semipublic space in the city centre (KIMS hospital) has the potential to extend the development by providing a waterfront for the visitors.



Rainwater harvesting/catchment area

The drainage pattern is mainly in the mid to low lying land with very low water permeability in which the provision of catchment area is important to hold water within the area.



Figure 6. 14 Water logging areas

Source: Author generated

The catchment areas can be provided in Sreekanteswaram park, Ponnara Sreedhar park (Thampanoor round about), temple pond in Sree Sakthi temple near chenkalchoola colony.



Figure 6. 15 Water catchment areas (a)Ponnara Sreedhar park (b)Sreekanteswaram park (c)Sree Sakthi temple

Source: Primary survey,2023

6.4 Proposal 2

6.4.1 Indicator 2 -Biophilic spaces and places (meso level)



Green and blue infrastructures



Ecological corridors/park connectors

Linear parks or adjacent open areas can be connected together to form an island of green space or can create corridors with green and open spaces.

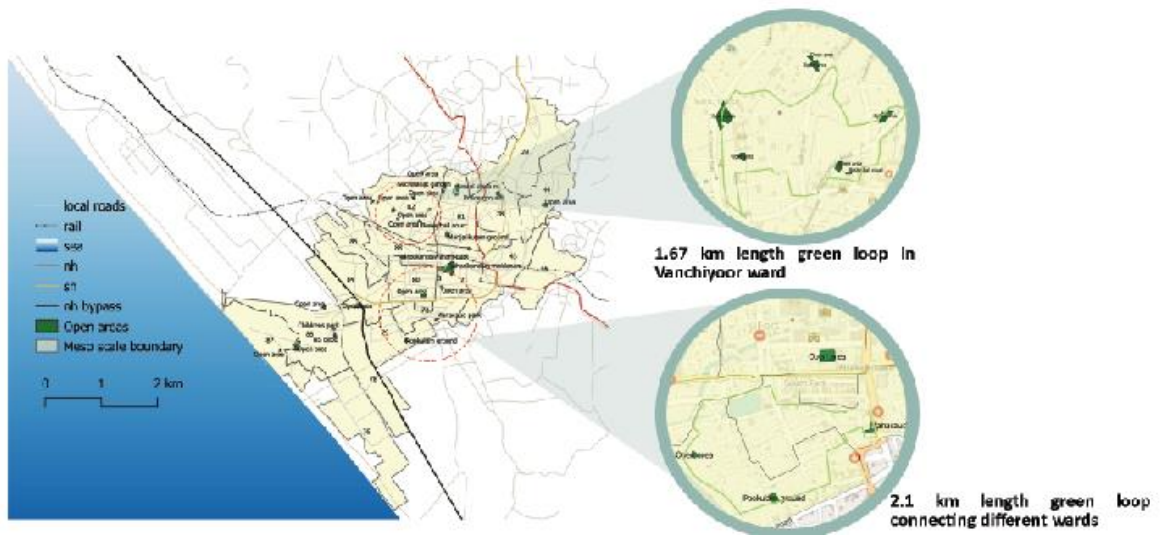


Figure 6. 16 Open spaces within the area

Source: Author generated using Qgis



Figure 6. 17 Pookalam ground

Source: Primary survey,2023



Figure 6. 18 Manacaud park

Source: Primary survey,2023

TRIDA has handed over about seven acres to Smart City Thiruvananthapuram Ltd (SCTL). The government has approved the proposal for an urban park at Palayam. The project would cost about Rs 4.5 crore.

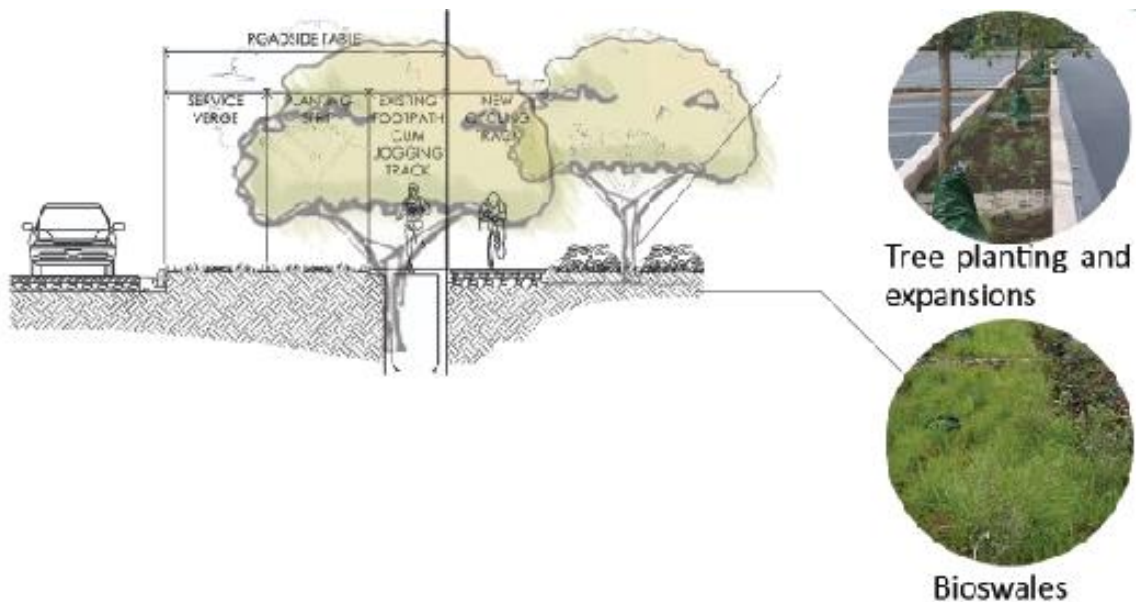


Figure 6.19 Section showing BU elements

Source: Author generated



Figure 6.20 Perspective view of showing BU elements

Type of trees-Neem, golden shower tree, Asoka tree. Planting bioswales to retain storm water runoff while removing debris and pollution.



Protecting the existing waterbodies, ponds

In 2019, E.F.I in association with Thiruvananthapuram Corporation and the IndusInd bank took on the restoration of Karimadom colony pond.

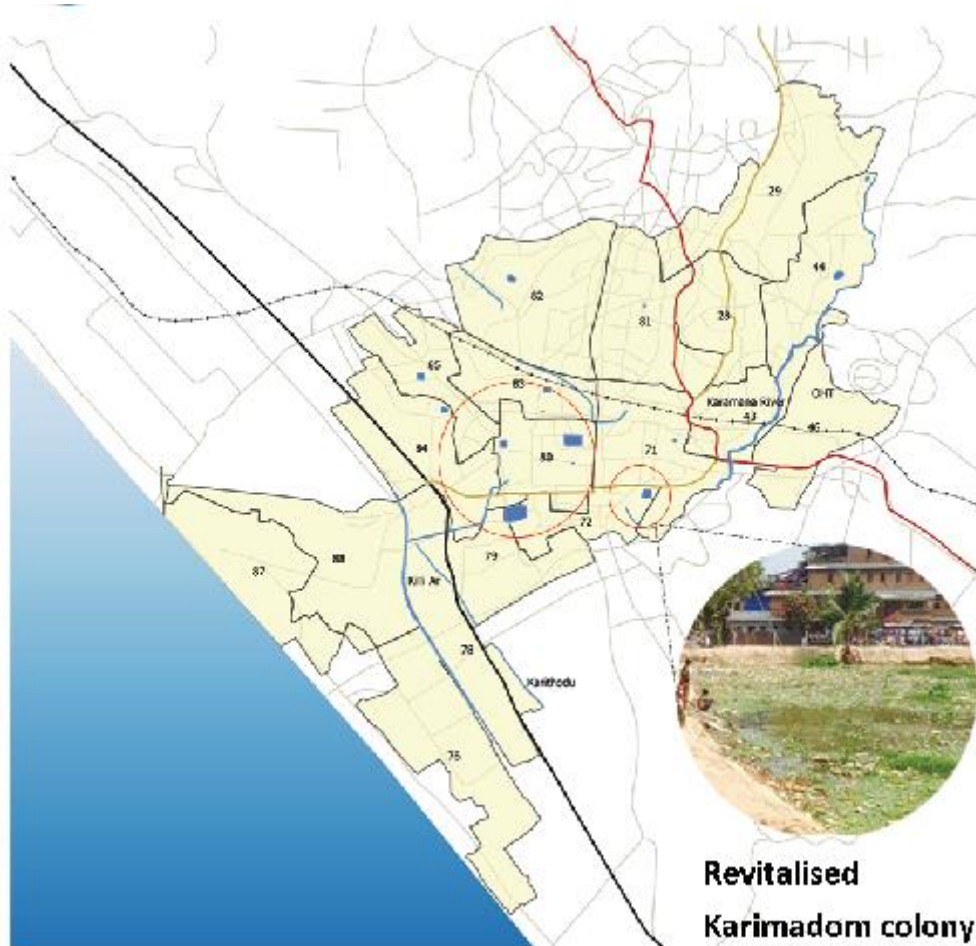


Figure 6. 21 Existing natural and artificial waterbodies

Source: Author generated



Figure 6. 22 Existing natural and artificial waterbodies

1. Do Not Litter near a water body such as a lake, river or sea.
2. Plant trees in catchment areas of rivers and also on banks.
3. Increase Pond volume.
4. Reduce watershed erosion.

5. Build sedimentation ponds.
6. Plant windbreaks.
7. Increase watershed area.
8. Regulate water level in the pond.

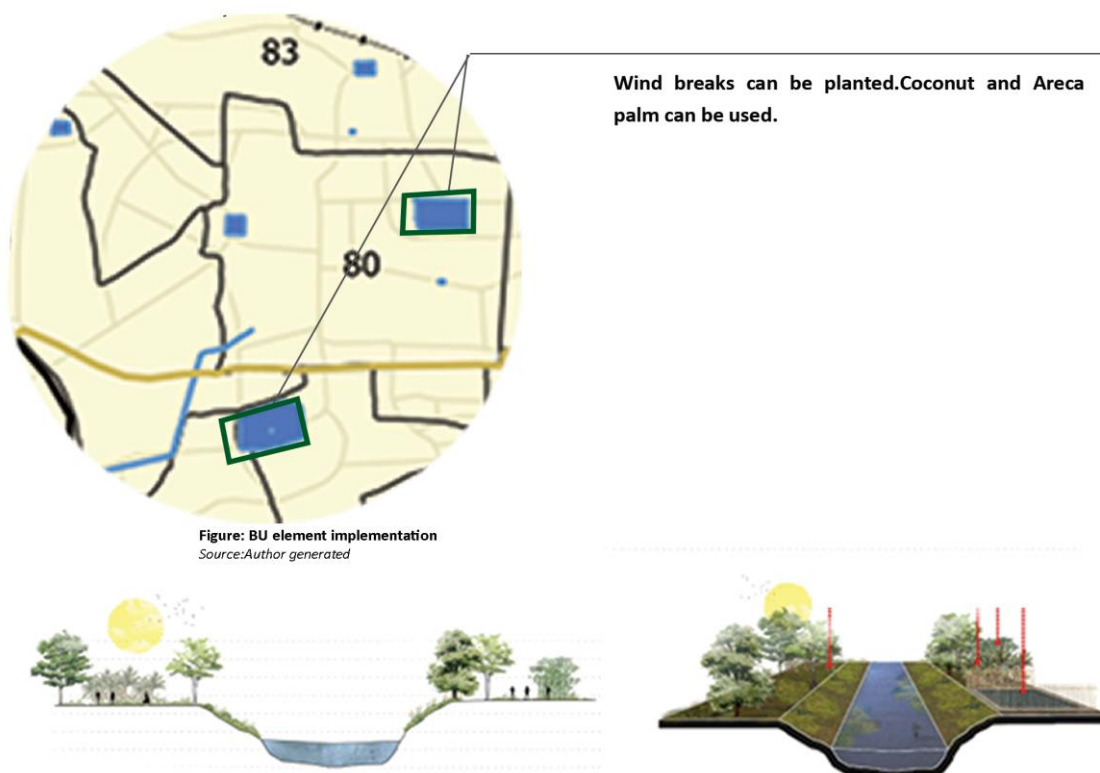


Figure 6. 23 BU elements implementation

Source: Author generated

Sreevaraham pond in a very dense built area act as a heat reducing element. Therefore, to protect it from deterioration BU elements like wind breaks and plantation along the banks should be done to avoid soil erosion.



Permeability

Increasing permeable pavements

Due to the steep slope, low building density, and low permeable materials, as well as the low proportion of waterbody present compared to the norms necessary for a residential and commercial area, the permeability is low. Replace paved and concreted surfaces with rain gardens, bioswales, and heat-reflective materials. Pervious concrete,

porous asphalt, and permeable interlocking concrete pavers are a few examples of permeable pavement types.

Nine road projects, including the relocation of water supply and power lines beneath corporation roadways throughout the city, were re-tendered by the SCTL in order to create smart roads and underground ducting.



Figure 6. 24 Althara Thycaud road

Source: Primary survey,2023



Figure 6. 25 Residential area road in Palkulangara ward under construction

Source: Primary survey,2023



Figure 6. 26 Permeable pavement

Surface treatments suitable for pedestrian or vehicular traffic which allow water to infiltrate into the ground.

6.5 Proposal 3

Indicator 3 –community and people activity (micro level)



Green Neighbourhoods

Redevelopment of recreational areas

Ensuring the per person requirement of open spaces by providing green loops including vegetated paths, community gardens etc. at the possible vacant lands in walkable distance in high density residential zone. The implementation can be carried out as a smart city project.

Through the redevelopment process the new park can incorporate several types of green infrastructure including bioswales, native vegetation, a reclaimed water irrigation system, pervious concrete in the overflow parking lot, and a green roof located over the public washrooms and maintenance facilities.

The parks and the infrastructures are least maintained due to the absence of tree shade and environmental elements in the surroundings as it cannot act as a recreational area for the neighbourhood.

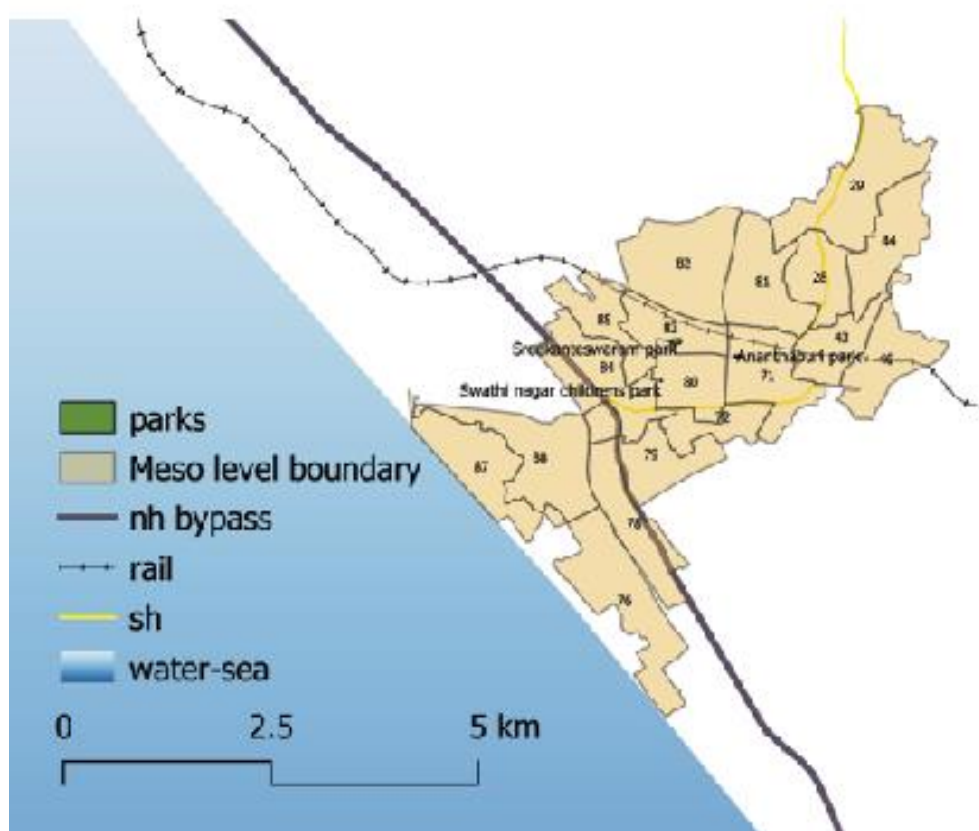


Figure 6. 27 Identified parks which are poorly maintained

Source: Author generated using Qgis



Figure 6. 28 Sreekanteswaram park
Source: Primary survey,2023



Figure 6. 29 Swathi nagar children's park
Source: Primary survey,2023

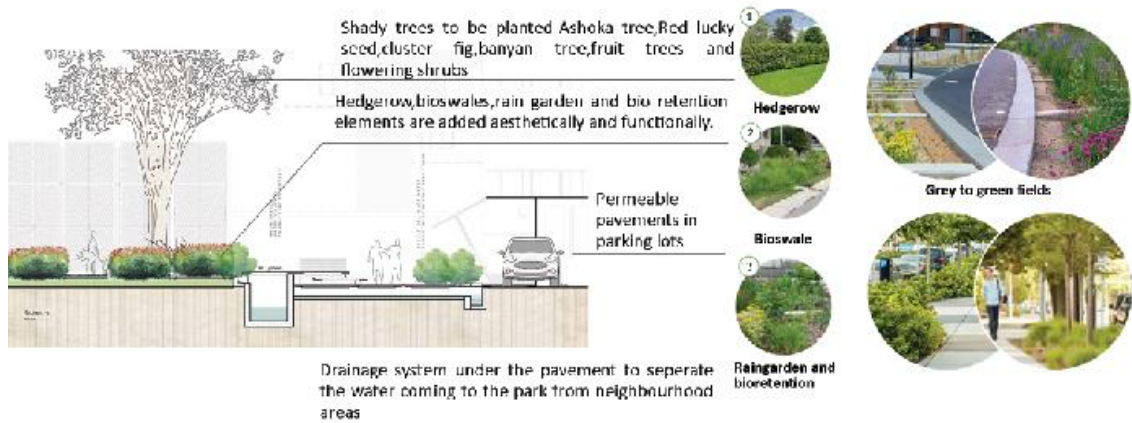


Figure 6. 30 Section showing BU implementation and elements used in planning
Source: Author generated

- The increase in ecological areas creates a sustainable environment and ensures a healthy living by reducing the climatic effects caused due to the absence of vegetation and natural bodies in the environment.
- The Biophilic urbanism elements can be applied at all levels of green neighbourhood to attain the reduction in temperature at the hotspot areas.



Promoting community engagements and nature club activities

The small-scale areas of land managed and maintained by groups of community volunteers.

Kudumbasree: Members of kudumbasree can promote more community works for the proper functioning and maintenance of parks and leftover open spaces.

Green initiatives: Among school children the need for promoting green areas should be understood and programmes that includes the tree planting etc. should be encouraged. For example, A Green Initiative program in Thamarakudy School, Kerala has taken an initiative to prepare 10000 bamboo seedlings

Active participation: Haritha Keralam Mission launched Pachathuruthu project on June 2019.Ensure the participation of community in the program initiatives by government.

Nature clubs: Promoting community activity through nature clubs and activities.



Green buffer zones around high density-built areas Street trees, buffer zones, green wall, green streets

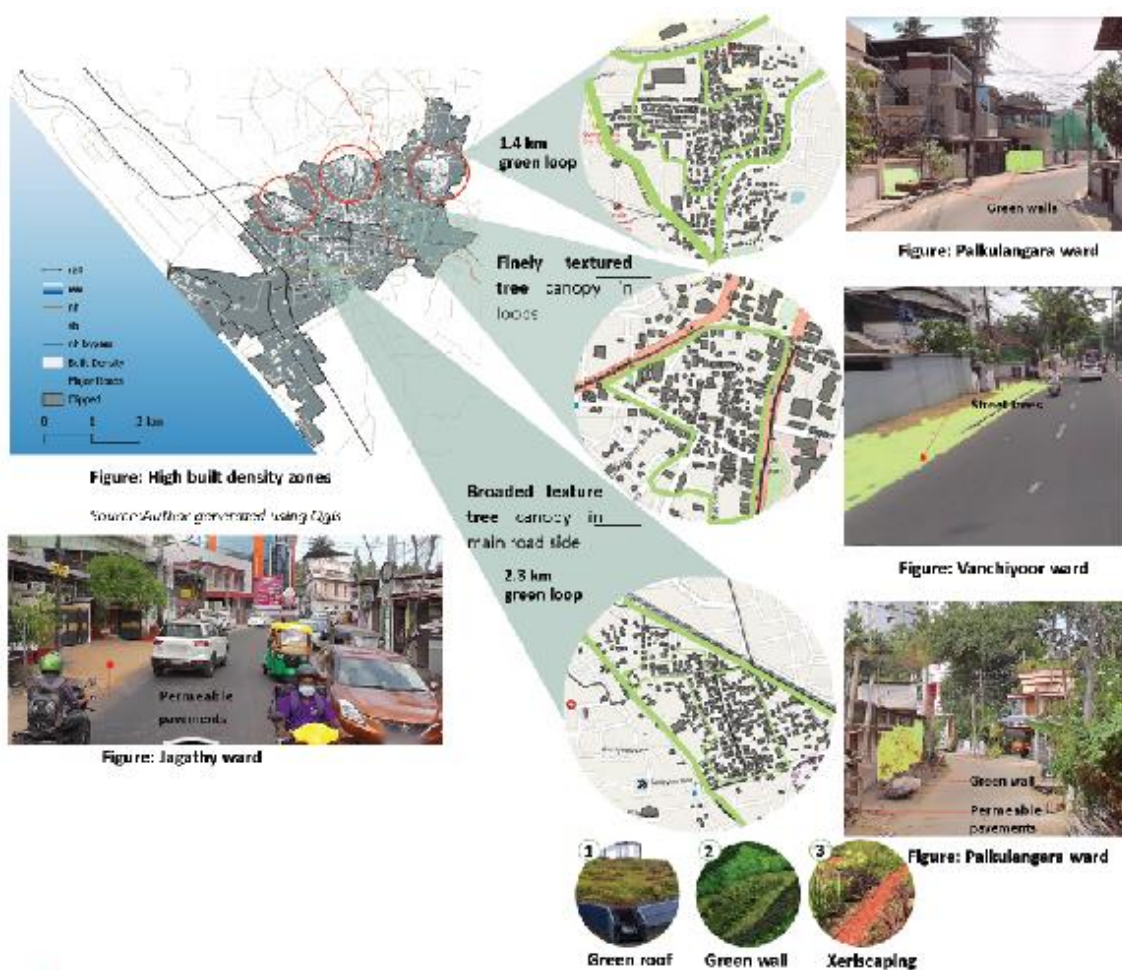


Figure 6. 31 Green buffer zones

Source: Author generated

Green roof and wall in high density-built areas as per the built area. A green roof byelaw can be set up providing with norms to provide a green roof for buildings exceeding the standards as per law. Community participation required will be more apt for this program.



Blue neighbourhood

Creating urban creeks and recharge pits

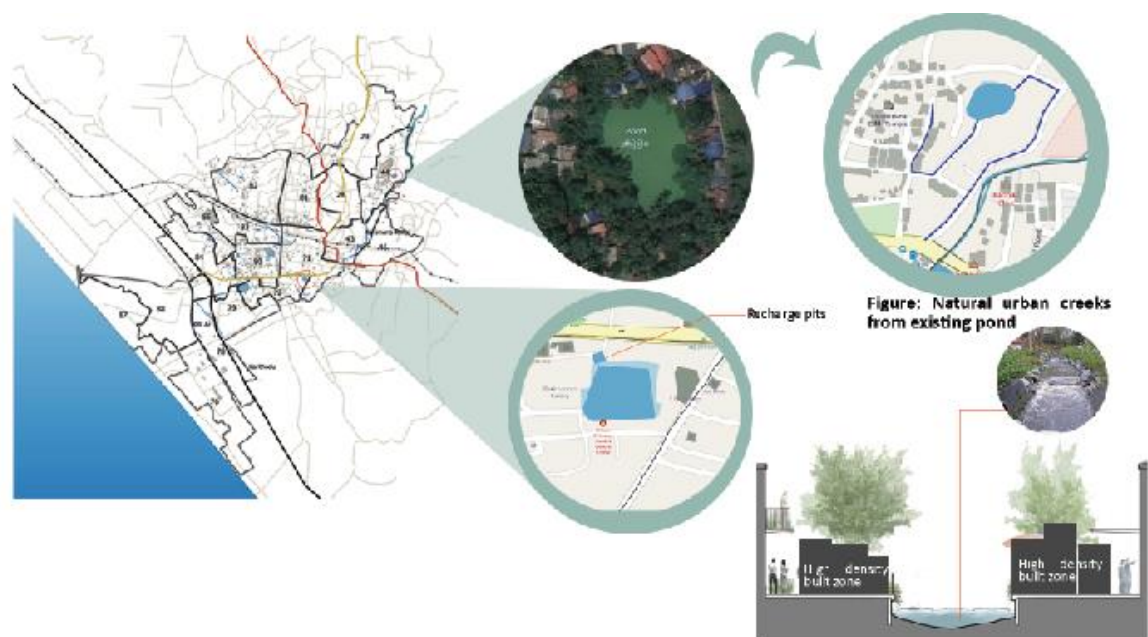


Figure 6. 32 Blue neighbourhood detailing

Source: Author generated

- Urban creeks through high density-built areas can reduce heat to an extent.
- The existing pond can also act as recharge pits. This can be attained through community participation among the residence association etc.

CHAPTER 7 CONCLUSION

The greatest benefits are derived from implementing biophilic urbanism elements across all scales in cities and it is capable of considering the multi-dimensional and interdependent complexities of many aspects of urban systems and infrastructure. The application of biophilic urbanism elements to urban heat island in Thiruvananthapuram city can reduce the heat stress when applied it in correct ratio which can be analysed by taking the count upon the biophilic urbanism elements through analyzing different elements w.r.t the study area. **The framework gives the quantitative analysis and the major issue to be tackled in the city such as absence of green cover, surface water, built canopy etc.** The proposals and strategies are derived by analysing the framework developed at different scales (macro, meso, micro) in which specific area identification and proposals implemented at meso and micro level considering the BU elements and UHI parameters as a limitation from the literature study.

Thiruvananthapuram is densely populated as known from the above study, the concentration of buildings, vehicles and human activities leads to the generation and retention of the heat, intensifying the urban heat island effect. **By incorporating biophilic elements such as the green roofs, vertical gardens, and street trees, the city can mitigate this effect by reducing heat absorption and creating cooling oases.** The proposed plans will increase the biophilic urbanism elements in the city reducing urban heat island in distinct areas such as **Jagathy, Sreekanteswaram, Palkulangara, Vanchiyoor as there are proposals mentioned in meso level and other wards** which are specified at meso level to be looked upon. **Both the government and community must be included in the process where the community will be benefited environmentally and ecologically.**

There will be an increase in **green cover from 25% to 33%** to maintain the ecological stability, **waterbody can be increased from 11% to 16%** and required green space per person standards will be met. **Vegetation in urban areas contributes to evapotranspiration**, the process by which water is evaporated from plants' leaves and released into the atmosphere. This process has a cooling effect, similar to sweating for

humans. The evapotranspiration from trees and plants can cool the surrounding air and reduce the overall temperature in urban areas. **The greatest strategy to lower UHI is to use more of the readily available, inexpensive, and simple-to-apply elements that are more prevalent nearby.** The framework and proposals can be inherited in the future development in maintaining the climatic aspects of the city through integrating the biophilic urbanism elements at standard ratio as per the standards in the framework and can be implemented at different levels of neighbourhood by integrating the elements of biophilic urbanism as derived from the study.

Biophilic urbanism is crucial in mitigating the impacts of urban heat islands due to its ability to **regulate temperature, improve air quality, facilitate evapotranspiration, manage stormwater management and enhance the well being of urban residents.** By incorporating nature in to urban fabric, cities create more sustainable, resilient, and comfortable environments for the inhabitants.

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APPENDIX

Household survey question

1. Ward number and name

2. How many people are there in your household?

3. Migrant or not?

Mark only one oval.

Yes

No

4. For how long you staying in this area?

5. Type of pavement material

6. Built density has increased over the last 10 years? If yes any discomfort?

Mark only one oval.

Yes

No

7. Does climatic changes like heat bothers your lifestyle? If yes how?

8. The environmental and climatic condition issues faced in the ward in last 10 years?

9. Any waterbody, paddy fields, open areas nearby?

10. Do you feel cool breeze at any time of the day?

Mark only one oval.

Yes

No

11. How do you rate the green cover available in the ward?

Check all that apply.

Poor

Good

Very good

Excellent

12. Do you plant trees around your house or conserve trees?

Mark only one oval.

Yes

No

13. Has the number of trees or vegetation around you increased or decreased over the years?

14. Any community gathering or recreation spaces available within the ward?

15. Any measures taken to reduce the heat like roof garden?

Mark only one oval.

Yes

No

16. Have you undergone any program to conserve trees or nature? If yes which program?

17. Are you satisfied with the facilities and accommodation you have?

Mark only one oval.

Not satisfied

Satisfied
