UN environment programme | copenhagen climate centre

GREEN AND BLUE SPACES

Contribution to reducing cooling demand and increasing resilience in cities. An analysis of urban contexts in fast-developing countries

Acronyms

GWP	Global Warming Potential
UNEA-5	The Fifth Session of the United Nations Environment Assembly
Ha	Hectares
NbS	Nature based solutions
e.g.	For example
CO_2	Carbon di-oxide
NO_2	Nitrogen di-oxide
PM	Particulate Matter
Rw	Weighted sound reduction index
UK	United Kingdom
GHG	Greenhouse gases
UHI	Urban heat island
LST	Land surface temperature
NDVI	Normalised difference vegetation index
NDBI	Normalised difference built-up index
NDWI	Normalised difference water index
TIRS	Thermal infrared sensor
USGS	United States geological survey
Km	Kilometre
OLS	Ordinary least square
EU	European Union
US	United States of America
ESCO	Energy service company
EIB	Green eligibility checker
INR	Indian national rupees

Contents

List of Tables

List of Figures

Executive Summary

Energy efficiency and nature-based solutions can help cities combat excessive heat amid rising temperatures. Energy efficiency mitigates excessive heat, whereas nature-based solutions adapt and withstand it. Better construction, building energy efficiency, and sustainable transportation policy, planning, and technology can help cities cope with high heat. Reduced energy consumption reduces greenhouse gas emissions and climate change. Nature-based solutions, such as green roofs, green walls, urban forests, and blue zones, provide several benefits, including local temperature management. Nature-based solutions can keep cities cool and liveable.

This study examines how energy efficiency and nature-based solutions could address high heat in global south cities. It will also assess important contributing variables, impediments, and potential to increase synergy between various mitigation and adaptation methods and explores business models to better integrate these current technologies for quick implementation.

City case studies of the effects of blue and green spaces on urban heat island effect (Rajkot and Mombasa) also help assess the necessary policy and planning conditions to improve opportunities to adopt energy efficiency and nature-based solutions to extreme heat situations.

1. Where mitigation and adaptation meet in the urban context - Multi-functional Nature-based Solutions for cooling and resilience

1.1 Introduction and objectives

Energy efficiency and nature-based solutions offer two important approaches for addressing extreme heat challenges in cities in the face of rising temperatures. While energy efficiency addresses extreme heat through a mitigation standpoint, nature-based solutions address extreme heat through an adaptation and resilience perspective.

Energy efficiency means achieving the same or better energy service for smaller energy inputs. In the context of extreme heat conditions in cities, this can involve a range of measures, such as better construction practices, improving the energy performance of buildings, and adopting sustainable policy, planning and technology best practices in the transportation sector. These measures can help reduce the demand for energy, which can diminish greenhouse gas emissions and mitigate the impacts of climate change.

In addition to improving the energy efficiency of buildings, cities can also adopt policies and programs that encourage the use of cleaner and more efficient sources of energy. This can include promoting the local use of renewable energy sources, such as solar, wind and geothermal resources.

On the other hand, nature-based solutions involve using natural systems, such as green roofs, green walls, urban forests, and blue areas to provide a range of benefits, including local temperature regulation. Nature-based solutions can help to maintain cooler air and reduce the heat in cities, making them more comfortable and liveable for residents.

Both energy efficiency and nature-based solutions offer many benefits for cities facing extreme heat conditions. Energy efficiency has multiple benefits, among which can help to reduce greenhouse gas emissions and save local financial resources by reducing energy costs; while nature-based solutions can provide a range of other benefits, such as improving air and water quality, human health, social well-being and providing habitat for wildlife.

This chapter will analyse the complementarity between energy efficiency and nature-based solutions in addressing the extreme heat effects in urban areas of the global south. It will also take stock of the major influencing factors, barriers, and opportunities to expand the synergies between these two mitigation and adaptation tools. A closer look will be put at the business models that cities can adopt to pursue better integration of these already existing solutions so that they could be immediately put into practice.

A few city case studies of the effects of the existence of blue and green spaces in selected cities (Rajkot and Mombasa) will also help to assess the necessary conditions, in terms of policy and planning, so that cities can better improve the opportunities to adopt energy efficiency and nature-based solutions to tackle extreme heat situations.

1.2 Factors causing extreme heat in urban areas

Evidence of higher air temperatures in cities has been compiled since the 19th Century but it was not until the 1970's that a collection of statistical references was documented, making possible the generalisation of the term urban heat island effect[1]. The urban heat island effect is a thermal anomaly verified in all types of urban areas, big or small that can influence temperature increase between 1 to 6 degrees [1]. The urban heat island effect depends not only on local factors but also on external factors.

The intrinsic causes of the heat island effect depend on aspects such as the size of the urban area, the general topography - which affects shading and the wind speed across the city-, as well as the density of the built environment, the tallness of buildings, the shape of the urban layout, and the physical properties of the construction materials and roads which influence albedo. The urban heat island effect is also affected by the exposure to external factors, such as the type and predominance of winds, overall local temperature and humidity and the existence of green and blue spaces[2].

Furthermore, two other factors also contribute to exacerbating this heating phenomenon. The first is related to the new tendency for the extensive use of air conditioning units which release waste heat back into the street from the mechanical operating cycle. This contributes to overheating the local environment, creating a vicious circle so that the more air conditioning is used the more it is needed to cool down, especially in narrow streets with low airflow.

The other is associated with transport, especially linked to the circulation of heavy-duty vehicles or massive traffic displacements in city centres. Normally these are connected to high concentrations of vehicles that release heat and air pollutants from running internal combustion engines, both factors contributing to higher temperatures, thereby strengthening the urban heat island effect.

Cities stand for about two-thirds of the global primary energy demand and emit more than 70% of the world's total greenhouse gases [3]. The building sector is responsible for around 40% of the total global energy demand[4].

High concentrations of air pollutants in urban areas severely impact public health, the economy, and the environment (both local and global). For example, in the city of Cairo have been measured increases in temperature between 3.1 and 6.7 °C, because of the urban heat island effect[5]. This may also apply to many urban areas in other rapidly growing cities worldwide. Along with fast-increasing urbanisation, poor construction practices and poor building operation and maintenance, cities have been steadily environmentally degraded. Finally, and adding to the problem, is the generalisation of large urban areas without any sort of green features, as space is required for construction or roads.

1.3 Energy efficiency and nature-based solutions combined to tackle extreme heat: the building sector

Buildings are the cornerstones of energy demand at the city level because construction practices can influence the energy needs of a building for many years to come. Energy-efficient buildings can have an important impact in situations of a heat island effect, helping to mitigate it.

Bioclimatic buildings

Traditional construction practices support buildings to perform better according to the local climate, especially when using local materials and techniques normally designated as vernacular construction. These techniques protect buildings from extreme heat by preserving the cooler air inside and preventing warmer air to be let in by using materials of low heat transfer, such as earth, and normally presenting small windows, among other features associated with careful natural ventilation strategies.

Modern bioclimatic construction solutions can also avoid the need for mechanical systems to bring thermal comfort to indoor areas, both in hot and cool climate zones. Bioclimatic construction values natural ventilation, appropriate shading, and use of natural light and in general adapts the building to the local climate by making proper use of solar gains, starting from the overall orientation of the building.

Building envelope

The building envelope refers to the outer layer of the building and is composed of walls, roofs, windows, doors, and floors. The materials used are critical in the future energy demand of the building because they act as preventing heat loss or gains in buildings if well selected and installed. Different materials have different physical properties also in terms of heat transfer coefficients (U-value), which quantify how effective a material is as an insulator. Appropriate planning and building design are important so that there is no lock-in effect of building envelopes that induce poor performance throughout the life of the building. Often, the poor passive performance of a building is compensated using mechanical systems that incur high energy demand to provide indoor thermal comfort.

Different climatic zones need different types of materials and thicknesses of insulation fabrics applied to buildings. Colder regions need the application of thicker layers of insulation material like mineral wool, fibreglass, expanded polystyrene, slag wool, cotton, and cellulose, while warmer regions benefit from highly reflective foils in radiant barriers and reflective insulation systems - reflecting away the solar radiation from the building.

Mechanical cooling equipment

The energy used by conventional air conditioning units is partially transformed into waste heat that is released to the neighbouring environment (outdoors) while cooling indoors, aggravating the urban heat island effect[6, 7]. In a city like Paris, research has found that it could be responsible for outdoor temperature increases of up to 2ºC [7]. This effect may even have the perverse impact of being more evident at night-time because of atmospheric layering, which prevents exhaust heat to be dissipated into the higher altitudes of the atmosphere. Moreover, the warmer the outdoor ambient air temperature in which air conditioning units run, the lower their energy performance is. However, alternatives to conventional air conditioning units exist, like geothermal heat pumps. Heat pumps can use the latent heat of the earth or the water bodies such as rivers, lakes or seawater in a heat exchanger while significantly reducing the energy needs for heating and/or cooling. These systems can help mitigate the urban heat island effect as well as achieve significant energy savings and therefore greenhouse gas emissions reductions. Urban district heating and cooling systems based on waste heat use from water bodies are becoming of a strong interest in deep retrofitting of neighbourhoods or in new urban areas to be developed in the global south.

Embodied carbon

The latest trends in construction are also adopting low embodied carbon materials, such as timber and recycled organic materials and fibres in a move towards zero-carbon buildings. For example, replacing petroleum-based insulation (e.g., expanded polystyrene) with cellulose as insulating material would achieve the same functional objective and significantly reduce the embodied carbon of the building. Other approaches can also reduce the embodied carbon of buildings, namely by taking it at the fundamental design phase or through product specifications according to Global Warming Potential (GWP) limits[8]. When tackling embodied carbon of buildings' construction materials, it can be argued that indirectly it is supporting mitigation efforts too.

Green walls and roofs can also act as insulators, both in cooler as well as in warmer climates, contributing therefore to improving the energy performance of a building. The presence of even thin layers of soil in roofs (10 to 20 cm) can reduce the cooling needs of a building between 31% to 37% as was tested in Thailand [9]. The presence of moisture in the roof soil also works as thermal insulation, especially in warmer climates or in the summer season, because it induces heat convection between the canopy and the water present in the soil, promoting evapotranspiration, thus air velocity increases and latent heat is removed[4]. Literature also mentions that wet green roofs can provide significant improvements in performance when compared to conventional insulated roofs by about 40%. On the contrary, but for the same reason, dry soil should be used in colder regions or in Winter to increase heat storage and improve thermal insulation[4].

Nature-based solutions

The European Commission defines nature-based solutions as "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. The Fifth Session of the United Nations Environment Assembly (UNEA-5) share many similarities with the European Commission definition and define nature-based solutions as 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits.'

Vertical greenery spaces (walls and façades) can add important green areas to the city, since horizontal space may be scarce for the purpose. Vertical walls can also reduce the temperature of the building by providing shade to the building's outer layer, triggering the evapotranspiration effect, providing thermal insulation, and serving as a barrier to the wind - the latter especially relevant in colder climates[4].

There is a verified direct relationship between the green density at the façade and the indoor temperature, therefore enhancing energy savings[4, 10]. Green leaves play a key role firstly in deflecting radiation, secondly in absorbing another part of it, and finally only the remaining passes up to reaching the wall of the building. This filtering effect indirectly reduces the need for running mechanical cooling equipment, when compared to bare walls. This advantage has varying effectiveness, depending on factors such as the density of the greenery, exposure to radiation, wind speed, moisture, and composition of the building materials[4].

All the building features above are starting to be embedded in national and local legislation in many parts of the world to guarantee that both mitigation features, as well as adaptation and resilience, are part of new buildings and deep retrofits. Building codes must adopt specific rules for their energy performance according to the climatic zone in which they are located as well as local construction practices and provide regulation for the adoption of nature-based solutions and embodied carbon principles.

Energy efficiency and nature-based solutions combined to tackle extreme heat: transport and mobility.

Roads and pavements

Buildings and road density affect the availability and accessibility to green spaces in a direct manner, but other factors weigh in, such as the topography and the overall urban design of the city[11]. On the other hand, the materials used in the roads and sidewalks, likewise the buildings, have a strong influence on the city surface temperature. Concrete and asphalt pavements are responsible for a significant contribution to the urban heat island effect because they have a low albedo and a high volumetric heat capacity, making cities easily reach 60ºC at the surface temperature on a warm day - approximately 20º C hotter than grass surfaces[11]. Nevertheless, alternatives exist as lighter-coloured pavements offer higher albedo, therefore reducing the surface temperature.

Urbanisation has been bringing fierce competition for urban space, where the tendency is for the greener Infrastructure to decrease in area, giving way to build structures and therefore contributing to aggravating the heat island effect[11]. The transport infrastructure is a rival in the availability of urban space because roads, tramways and railways occupy significant amounts of city space, let alone car parks.

Last mile logistics

When considering accessibility to the city centres, last-mile logistics could also play a relevant role in the usage of the road space when allowing heavy-duty vehicles to reach the destination of the goods they transport. The same can be said about commuting by private car to the city centre. Policies that counter these actions have an indirect energy efficiency gain by reducing the volumes of goods to be transported around and promoting public transportation while releasing pressure from the city centre, decreasing energy demand, and reducing local pollution.

Vehicle typologies

Internal combustion engine types of vehicles are particularly energy inefficient when compared to alternatives such as electric vehicles, and overall softer modes of transport, like cycling or walking. Moreover, the promotion of public transportation also improves the efficiency of displacements as accounted by the energy used per passenger and kilometre. The creation of policy and physical conditions for a transition to more efficient mobility solutions is considered part of urban strategies towards sustainability.

For the transition to happen in the transport of goods, alternatives should be put in place using lighter vehicles for the last-mile distribution of products and preparing facilities for logistical support outside the city centre. The mobility of passengers should be developed by increasing access to public transportation, creating dedicated lanes for cycling, and skating as well as the pedestrianisation of the streets – or at least allowing more space for pedestrians while reducing it for cars. When these measures are put in place, not only efficiency is improved, and pollution reduced but it also makes available space for trees, gardens, parks, and waterways.

1.4 Energy efficiency and nature-based solutions combined to tackle extreme heat: urban design.

Street trees

Street trees affect the urban temperature by the shade it offers, and by the evapotranspiration effect. Street trees can also block the wind, a situation which may be more important in circumstances of urban canyons[12] and in colder regions. Street trees can provide better thermal comfort to pedestrians and consequently also reduce the cooling needs of the nearby buildings[13]. The combination of street trees' availability with the overall street design and configuration can perform optimal strategies for the reduction of heat stress at the urban level.

Urban parks

The availability of large green spaces can provide urban planners with tools to address the urban heat island effect. For example, parks larger than 10 ha have the highest cooling effect distance and cooling effect intensity across the urban area [2]. Furthermore, planners should play with the urban geometry and the green and blue space geometries aiming for more impact and efficacy in cooling the city. The disposition of buildings not only according to the best orientation for solar gains but allowing for wind flows between streets and wind passage from greener areas could help cooling, while defining the best size and geometry of parks. The proper selection of the most suitable plant species may also improve the efficiency of urban cooling[14].

Blue spaces

There are several cases of buried water lines and rivers in cities that are now being brought back to the surface, allowing for the enjoyment of residents, and serving as temperature coolers in the urban space. The water-cooling island is a relatively new concept that refers to the capacity of water bodies to mitigate the urban heat island effect, meaning that the immediacy of a water body reduces air temperature that can be spread through a few hundred meters to the surrounding area[11]. Likewise, more attention is being put on the scientific analysis of the urban green space cooling effect, namely by the presence of large parks and its influence on the cooling of the surrounding areas.

The mitigation and adaptation methods should not be used in isolation in cities. All the above-mentioned techniques and technologies could be used separately but there is increased awareness that a combination of several solutions can have magnifying effects in terms of air temperature reduction and more liveable conditions. Combined strategies that include policy and planning targeting aspects such as the availability of green spaces of different scales, the availability of water bodies, the use of materials with high albedo in construction and pavements, and sustainable transport and mobility can display a ready-to-be-used toolbox for tackling extreme heat in urban areas.

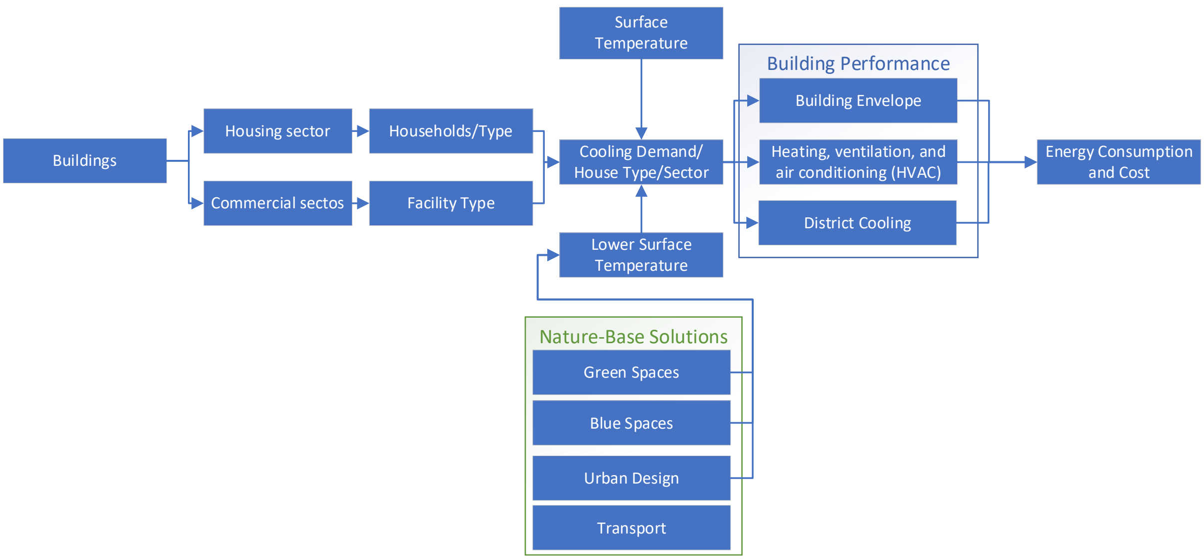


Figure 1:1 Urban cooling and Nature-Based Solutions

1.5 The multi-function of green and blue spaces

From the discussions in the preceding sections, the benefits NbS has for energy efficiency/resource efficiency and in mitigating the urban heat island effect are apparent. In addition to these, NbS also hold significant promise for sustainable urban areas as they have other multiple benefits across several sustainability challenges faced by cities. In addition to the two mentioned earlier, these include (as can be seen in figure 1.2) enhanced biodiversity, improved human health and well-being, better air quality, noise reduction, flood mitigation, improved aesthetics, and better water quality.[15-19].

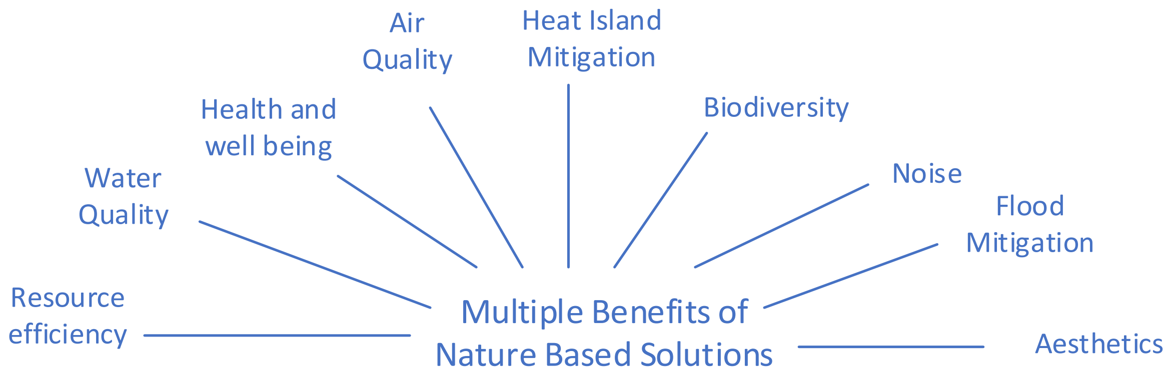


Figure 1.2: Multi-function of Nature Based Solutions in built environments (urban areas)

The health and well-being benefits of NbS are highlighted in several studies. Studies have found that dense urbanisation with very few green and blue spaces is linked to a higher risk of psychosis and depression in both women and men [20]. Greener cities have been linked to long-term improvements in mental health [21], which suggests that policies to increase green space in cities have long-term benefits for public health [20], and therefore need to be encouraged. Blue spaces have been suggested to have similar health effects in the empirical literature and blue space exposure are also found, like green spaces, to affect mental health biomarkers (depression, anxiety, stress, etc.) [22].

Urban green spaces help improve air quality and reduce GHG by carbon capture and sequestering. Researchers have found that the average home garden stores 2.5 x 10^3 g/m2 of carbon. Of this amount, 83% is stored in the soil (to a depth of 600 mm), 16% in trees and shrubs, and only 0.6% in the grass and herbaceous plants [23]. The rate of carbon fixation depends on several things, such as how much carbon is in the air, how much natural and artificial light there is, and how old the trees are. Younger plants tend to sequester more carbon than older plants, which is especially important for trees that live for a long time [24]. Greenhouse gas emissions vary in space and time (e.g. higher in wetlands than in forests and prairies). For more accurate estimates of carbon sequestration, it is essential to consider how these factors change on a small scale [25]. Also, less energy is used for air conditioning; less CO2 is released as less electricity is used[26].

In addition, plants can reduce pollution in several ways [27]. Plants can take in gaseous pollutants through their stomata, catch particles with their leaves, and break down certain organic compounds, like poly-aromatic hydrocarbons, in their tissues or the soil. Urban vegetation can also indirectly reduce air pollution by lowering surface temperatures by transpiration cooling and providing shade. Thereby, reducing photochemical reactions that create pollutants like ozone in the atmosphere. Putting plants in street canyons can cut the amount of NO_2 and PM_{10} pollution at the street level by up to 40% and 60%, respectively [28]. Green roofs or walls in polluted areas can be part of a plans to improve air quality.

Plants are often used to reduce noise in cities because they are good at blocking out sound. Laboratory tests show that green walls have much potential as a sound insulation tool for buildings. A weighted sound reduction index (Rw) of 15 dB and a weighted sound absorption coefficient (a) of 0.40 can be reached [29]. Green roof plots with different plant communities and substrate depths have a mean noise reduction coefficient ranging from 0.20 to 0.63 [18]. Thus, urban green Infrastructure that combines building design and retrofitting actions (like insulation and spatial planning) can help reduce noise and create a pleasant and healthy soundscape.

Biodiversity is the variety of life (its composition, structure, and function). It is shown as an interlocking hierarchy of elements on different levels of biological organisation, from genes to communities, and at all scales of space and time [30]. The amount of green space and its heterogeneity is one way to measure biodiversity [31], such as figuring out the relative amounts of bare ground, turf grass, rough grassland, herbs, shrubs, trees, and the built environment. It has been said that the biodiversity index is higher when habitats are spread out more evenly [31]. Monoculture agriculture, in which only a few crop species (arable or improved grassland) are grown, can make farmland less diverse in plants than in cities [31]. Urban habitats can help protect rare and endangered native species and are home to many species not native to the area. Both species can provide ecosystem services and social benefits and help protect biodiversity. The number of bee species, essential for pollinator services, is higher in greener cities than in farmland. [32, 33]. Likewise, bird species were the same in a green small town's housing developments and nearby arable farmland, but the number of birds was much lower on the farmland [34]. Biodiverse green roofs usually have different slopes and include habitat features like logs or large stones (called "brown roof features") to give spiders and beetles small places to live. Birds can also use these things to rest while they look for food. But these more varied roofs may need more structural support, especially if they are being added to an existing building. Brown roofs may also need different maintenance plans and may not always look better than green roofs.

Green Infrastructure can catch and store rainwater where it falls and reduce pollution by making it easier for sediment to stay in place. This helps create what are called "sponge cities." Plants can stop pesticides that would otherwise get into waterways through air drift [35]. Green roofs can reduce annual storm runoff by anywhere from 50 to 100 per cent, depending on the roof system, substrate composition and depth, roof slope, plant species used, pre-existing substrate moisture, intensity and length of rainfall, and length of dry weather before the storm [36]. Green roofs can help reduce the effects of rainstorms, mainly if used on a large scale [37]. Established plants and substrates can improve runoff water quality by soaking up and filtering out pollutants [36].

Urban agriculture, whether done indoors, in garden plots, or on walls and rooftops, can give people who live in cities a source of fresh food, a healthier diet, and a significant boost to their household budgets. Researchers have also used the terms "vertical farming," "Zero-Acreage Farming," "Continuous Productive Urban Landscapes," and "Plant Factory" to talk about different kinds of urban farming. Green roofs can be good places for pollination and bee conservation in urban areas[38].

As more cities invest in green Infrastructure, more jobs will likely open up for trained workers in this area and its supply chain, including nurseries, environmental management, restoration, and conservation. Green urban spaces have been shown to have economic benefits [39]. This kind of Infrastructure can give a local area a competitive edge through inward investment, visitor spending, new job creation, and better health and environment improvement.

Residents feel more connected to their community when natural features and open spaces make meeting other residents easier [40]; urban parks are places where people of different ethnicities can spend their free time [41]. It is vital to figure out the social value of green spaces [42]and how to get different ethnic groups involved to use nature-based solutions for urban renewal and build an inclusive economy.

1.6 Barriers to green and blue spaces in cities

Several obstacles can impede implementing and up-scaling of nature-based solutions for climate change mitigation and adaptation. O'Donnell, Lamond [43], in their study on barriers to blue-green Infrastructure for Newcastle in the United Kingdom (UK), found several barriers. The reluctance to support novel and new approaches or practice changes was the most significant barrier. Nature-based solutions are different from other systems and require unique protocols for deployment and maintenance, which are perceived as unknowns, and urban planners often consider it a risky proposition. Nature-based solutions' benefits for climate mitigation and adaptation have not yet been well evaluated for climate mitigation and adaptation targets like carbon offsets. Therefore, tangible benefits are often not known. This may be due to a lack of information on climate change-induced issues and the potential benefits of nature-based solutions.

Even though people are becoming more aware of how important green practices are, they often don't feel a sense of urgency when using NbS [44]. A low sense of urgency among political decision-makers about NbS can be a barrier to mainstreaming NBS. This is also because integrating nature-based solutions into the urban fabric often requires long-term planning, implementation, and maintenance processes, including apportioning financial resources. Even in cities where long-term policy plans are monitored for new, innovative solutions through adaptive monitoring, scientifically proven options and knowledge regarding these solutions are often not available when policy windows are open for new ideas. Davies and Lafortezza [45], through a thorough comparison of the planning and implementation of green Infrastructure in several European cities found that frameworks for green infrastructure policies tend to focus on long-term goals that may need to be changed when policy goals change during new political cycles. Overall, these things cause a gap between how open policies are to scientific results and ideas that are ready to be used [46, 47]. City departments' administrative structure and responsibilities are based on how cities have always (traditionally) been run. Nature-based solutions may have to fit into how decisions are made now, which can be challenging.

In addition to a lack of urgency by urban policymakers and administrators, a lack of public awareness and a negative opinion of NbS by the community tend to delay the NbS development process [48]. Some policymakers and/or residents may not be as aware or may have the perception that green installations on roofs and walls are harmful, e.g., are "dirty and host insects," thereby creating additional perception barriers [49]. Co-creating solutions with residents by involving them in the earliest planning stages is a crucial aspect of any NbS development procedure [47]. Additionally, a lack of support from local business can hinder the adoption of NbS. According to van Ham and Klimmek [50], the participation of local entrepreneurs and other members of the local community is essential for the effective development and maintenance of NbS.

This barrier relates to the ambiguity surrounding the optimal method for planning, designing, implementing, maintaining, and monitoring NbS. In this regard, there are currently no design standards and guidelines for maintaining and monitoring NBS that are customised to the specific characteristics of various cities. These criteria are vital for efficiently addressing context-specific difficulties emerging from a city's resources, institutions, and sociocultural traits [51].

Despite numerous studies indicating that NbS solutions are frequently less expensive than grey solutions [52], it is commonly believed that implementing and maintaining NbS solutions are more costly than a grey infrastructure [53]. However, there are instances in which the apparent benefits surpass the perceived costs; the "room for river" program is one such instance [54]. In any event, the notion of high costs may hinder the adoption of these solutions, particularly among private owners [55].

O'Donnell, Lamond [43] cite the lack of suitable locations as another obstacle to implementing NbS in urban areas. Numerous factors, such as the slope of the roofs or territory, the size of the sites (e.g., narrow streets or sidewalks), the type of the soil, contaminations in the soil, and the presence of underground utilities such as water pipes and power lines and car parks, can limit the suitability of any location for NBS implementation [56].

The final barrier relates to the growth paradigm and the growth symbol to which cities adhere. Despite economic and demographic decline, cities promote growth strategies and growth-dominated visions, which we call "the growth obsession barrier". Even under conditions of population decline, increases in built-up area, including spaces for commerce, Infrastructure, etc., appear to be the primary focus of development [57]. Focus remains on issues related to economic growth (creating jobs, attracting investments), while development of urban green spaces and the associated benefits of NbS receive less attention and funding. City budgets for green development and the maintenance of green spaces are frequently subject to severe budget constraints, whereas staff and related expertise are declining [58]. Tight financial and time budgets combined with reductions in staff and knowledge may also lead to not using existing funding options for green space implementation projects.

1.7 Conclusions

Nature-based solutions inspired by nature, which are cost effective and deliver environmental, social and economic advantage, and help create resilience by having several complementarities with energy efficiency, especially in cities facing extreme heat situations.

Urban form (design and layout of built form and the non-built form in cities), transport and use of cooling equipment like air conditioning are considered as intrinsic causes of the heat island effect and increased air pollution, impacting public health environment and economies. Apart from the resource and energy efficiency benefits , NbS has several other benefits, including improving residents' health and well-being, increased biodiversity, better air quality and GHG reduction, better water quality and flood mitigation. Therefore, encouraging NbS solutions in urban areas suffering from extreme heat conditions carries many benefits, and for sustainable urban development, these should be encouraged.

Nature-based solutions do not find space in the traditional methods of planning cities and development of built form, therefore, they can face perception and acceptance barriers. This is because not many urban areas are willing to change conventional planning methods. Most benefits of NbS are also not quickly known and quantifiable. Therefore developing business models for the use of NbS can also be at times, complex.

Given the benefits and the barriers that NbS face, the following two chapters review taking the case of two fast developing cities to identify the benefits of green and blue spaces and possible business model that can be used to implement these.

2 Nature-based solutions to tackle extreme heat: A Case of Rajkot City, India and Mombasa City, Africa

As discussed in chapter 1, nature-based solutions, which include using natural systems like green areas, bodies of water, etc., help with local temperature regulation. These land areas, along with built-up areas like roads and pavements and building density, affect the incoming and outgoing energy flows from the urban surface system, and in particular, the phenomena of the Urban Heat Island (UHI) [59]. The energy absorbed by the urban surface system from solar radiation and generated by human activity (roads, buildings, etc.) is balanced by warming the air above the surface, evaporating as moisture, and storing it as heat in surface materials captured as Land Surface Temperature (LST). LST combines vegetation and surface temperature, as they both respond to solar radiation. It is estimated from the brightness temperature captured by remote sensing satellites (for example, Landsat 8)

The cities' green, blue and grey areas can also be identified using remote sensing images. Li, Stringer [60] used enhanced vegetation index as an indicator, calculated following USGS approaches and found that in East African cities (Khartoum, Addis Ababa, Kampala and Dar es Salaam), urban blue-green Infrastructure was found to moderate the surface urban heat island effect. Chen, Bagan [61] and Bekele, Hailu [62] characterise the urban area and have looked at the relation of land surface temperature with three indices of spatial components that are: normalised difference vegetation index (NDVI), normalised difference built-up index (NDBI), and normalised difference water index (NDWI). NDVI, NDBI, and NDWI index values are also used to identify green, blue and grey land areas.

Fast developing cities of Rajkot in India and Mombasa in Kenya are used as cases to study the relation between green, blue and grey areas within these cities and land surface temperature. Land surface temperature (LST) data were derived from Landsat 8 thermal infrared sensor (TIRS) images from the United States Geological Survey (USGS, glovis.usgs.gov/), and other land use indices were derived using other bands of from Landsat 8 OLI/TIRS data. Data and methods are further described in section A 1 of Annexure 1.

The following section discusses and describes the two case cities of Rajkot and Mombasa.

2.1 Case cities

The city of Rajkot (population 1.2 million), located in the western part of India (Figure 2.1) in the state of Gujarat, with a compound annual growth rate of 2.5%, has the sixth-highest growth rate in all Indian cities [63]. This fast-developing city has an urban fabric of mainly high-density low-rise construction (ground +one floor). Rajkot is an industrial town with numerous small-scale industrial units. It is estimated that Rajkot will have a population of 2.6 million by 2031. The city of Mombasa (population 1.2 million according to the 2019 census) is a coastal city located in the southwestern region of Kenya (Figure 1). It is the second-largest city in Kenya and the most significant international seaport in East Africa. The city has a growth rate of 2.54%, like Rajkot, and it is one of the fastest-growing cities in the world, and together with its peri-urban development, the city has an estimated area of 229.6 km^2, of which a significant portion, that is 65 km^2 is water mass[64]

Figure 2.1: Location of Rajkot, India and Mombasa, Kenya.
(Source: Google Earth)

Table 2.1 gives the land distribution in Rajkot from the Draft Comprehensive Development Plan for the year 2031. More than half of the land in the city is used for residential purposes; blue land use accounts for 2.3%, and recreational spaces, primarily gardens and parks (green land use), account for around 5% of the land use. Thus, indicating that a large portion of the city land use is grey (built-up). The proposed land use in the master plan of Mombasa and its break are given in Table 1. A large portion of the proposed urban development area, that is, 19.4%, is water mass, and most of the residential development, 21.3% of the total development area, is residential development proposed exclusively with nature and low and medium density development. A significant proportion of space is also under mangroves and green conservation and controlled development areas.

Table 2.1: Land use of Rajkot City and Mombasa

Land use Category	Land Use for Rajkot (Proposed for 2031)		Land Use for Mombasa (Proposed)	
	(km2)	(%)	(km2)	(%)
Residential	62.3	59.4	102.1	35.5
Commercial	2.2	2.1	26.0	9.1
Industrial	6.4	6.1	28.4	9.9
Transport	18.0	17.2	10.3	3.6
Green	5.9	5.6	53.1	18.5
Water bodies	2.4	2.3	53.5	19.4
Other	8.1	7.7	14.6	5.0

(Source: Rajkot Draft Comprehensive Development Plan 2031 (second revised) and the master plan of Mombasa)

The maximum temperature varies from 27°C to 41°C in Rajkot. During the summer (March, April and May), the maximum temperature ranges between 36°C to 41°C. Summer is the driest period of the year. The average minimum temperature in Rajkot is between 12°C to 26°C. Tropical wet and dry weather prevails in Mombasa. The season largely determines how much rain falls. April and May are the wettest months, while January and February have the least rain. Mombasa, situated close to the equator, experiences very minor seasonal temperature variations, with highs ranging from 28.8 to 33.7 °C.

2.2 Green and Blue Land Use and Land Surface Temperature

Figure A 3, Annexure 1, is the conceptual diagram of the methods used to build this study project. ArcGIS Pro was used to analyse Landsat data to calculate the NDVI, NDBI, NDWI, and LST indices. Section A2 in Annexure 1 further describes the methods used to quantify these indices and also study their spatial relation using Moron's i value Ordinary Least Square (OLS) regression model, and Geographic Weighted Regression model.

Both cities, that is, Rajkot and Mombasa, have high temperatures. The temperature variation in Mombasa is marginal compared to Rajkot. Therefore, in Rajkot, we have looked at the green cover during summer and winter. Detailed analysis is only done for time extreme temperatures using LST values in May 2022, and green and blue cover in May 2022.

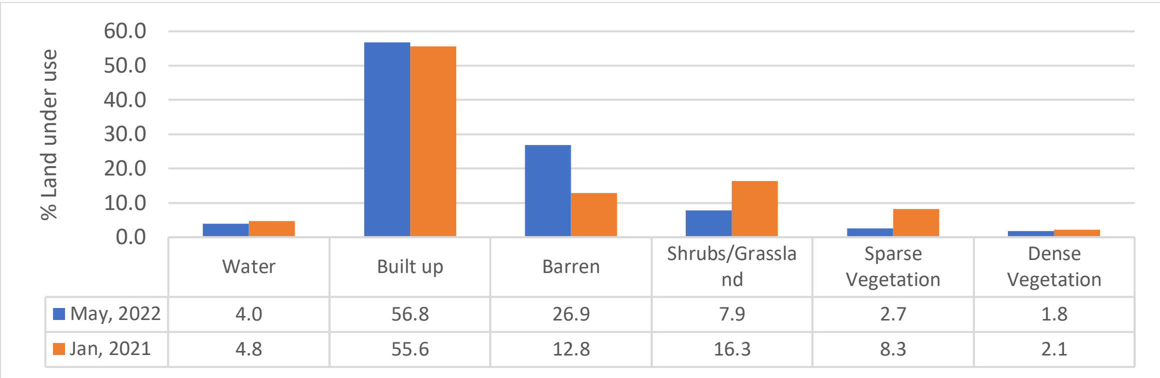


Figure 2.2: Land use from NDVI images, Rajkot

Figure A 5, Annexure 1 shows the NDVI values and their classification into land uses for both cities. In Figure 2.2, we compare the land use derived from two images of the town of Rajkot to check the influence of temperature on land use cover. The proportion of barren land is higher in the May 2022 image than in the January 2021 image. An indication that extreme heat in the region during May converts shrubs, grassland, and sparse vegetation to barren land. The dense vegetation is also less in May, but the decrease in the dense cover is only marginal compared to sparse vegetation and shrubs. The built-up areas are constant in both images, indicating that these are close to ground reality.

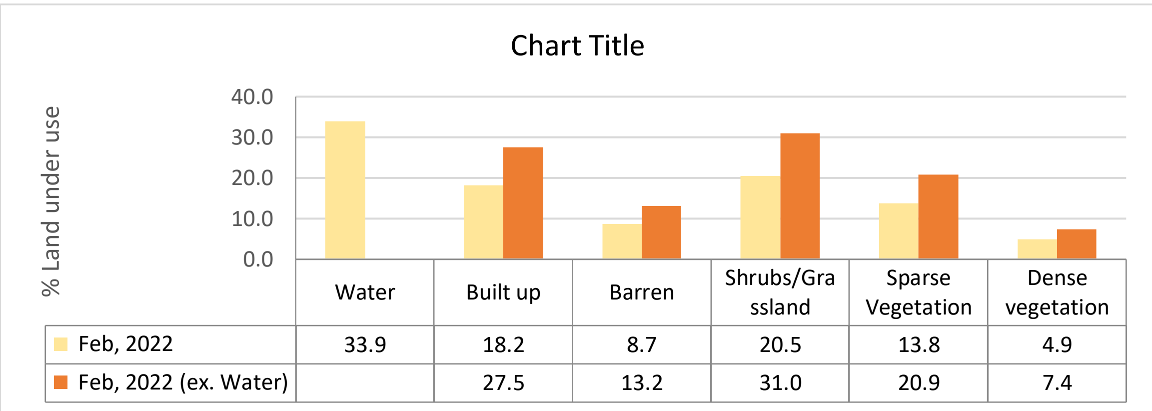


Figure 2.3: Land use from NDVI images, Mombasa

In Figure 2.3, statistics of NDVI values for Mombasa and the area around it (grouped in the same land use categories as done for Rajkot) are shown. When compared with Rajkot, Mombasa is greener, and the percentage of land with dense vegetation is also high in Mombasa. As was indicated earlier, Mombasa is surrounded by water. Therefore, in the image, a large part of the image is covered with water. Consequently, we have also looked at land use percentage only for the land area. The share of green cover is still high, and the build-up rate is low in Mombasa, even when considering land use excluding water.

Figure A6, Annexure 1 shows the land surface temperature computed from the Landsat 8 data in both cities. In Rajkot and its surroundings, wide variations in the LST were observed. The LST for the May 2022 image varied in the range between 27.1°C to 47.7°C, with barren land in the peripheral location registering the highest temperature and temperature over water bodies being the lowest. There is also a good visual correlation between the dense vegetation areas and LST temperatures.

Table 2.2: LST Descriptive

Land use from NDVI	Rajkot			Mombasa		
	LST (°C)					
	Mean	Median	Standard Deviation	Mean	Median	Standard Deviation
May 2022				February 2022		
Water	28.64	27.96	1.73	13.47	14.59	4.5
Built up	43.04	43.7	2.45	20.49	21.42	5.25
Barren	43.04	43.7	2.45	20.42	21.07	4.32
Shrubs/Grassland	40.91	41.12	2.24	20.45	21.45	5.2
Sparse Vegetation	39.54	39.72	2.49	19.71	20.52	5.57
Dense Vegetation	36.63	38.05	3.27	18.95	18.6	2.66

Table 2 is descriptive statistics of the LST data derived from images from May 2022 and January 2022. There is more than a 6°C temperature difference in the mean temperature between dense vegetation and built-up/barren areas in the image derived from May 2022 and about 3°C difference among the same land uses in the January image. There is also a clear pattern, indicating that an increase in green cover leads to a lowering of temperature. Mombasa has milder temperatures than Rajkot; therefore, the temperature variations are lower than in Rajkot. But similar patterns can be observed; water has a significantly lower temperature compared to land surfaces, barren land and built-up areas have the maximum temperature, and dense Green is relatively cooler, on an average about 1.5°C cooler compared to built-up areas.

Figure A11 and A12., Annexure 1, shows the influence of blue and green Infrastructure on LST. LST values at the centre of the large water body are significantly lower when compared with the LST found on the ground surface. In Rajkot, the inner portions of the lake have a temperate of 28°C compared to open land located 400 m. away has a 15 °C higher temperature (43 °C). In Mombasa, the temperature is around 15 °C at the location about 150 m from the coast inside the sea. But if we move about 650 m inside of the seacoast in the land mass, that is, 800 m from the location where the temperature is 15 °C, the temperature increases to 23 °C a sharp 8 °C increase. Thus, air over water bodies is around 25-35% cooler compared to barren land; however, temperature loss is also very rapid as we move away from the water body if the adjoining land use is barren land, road or built-up area. Green cover or a high proportion of green cover near water bodies diminishes the loss in temperature. The influence of Green on LST temperature is marginal when compared to water bodies and locations that have high and dense green areas (red box) are about 5-6 °C cooler when compared to areas in close proximity that have very little or practically no green land use (blue box).

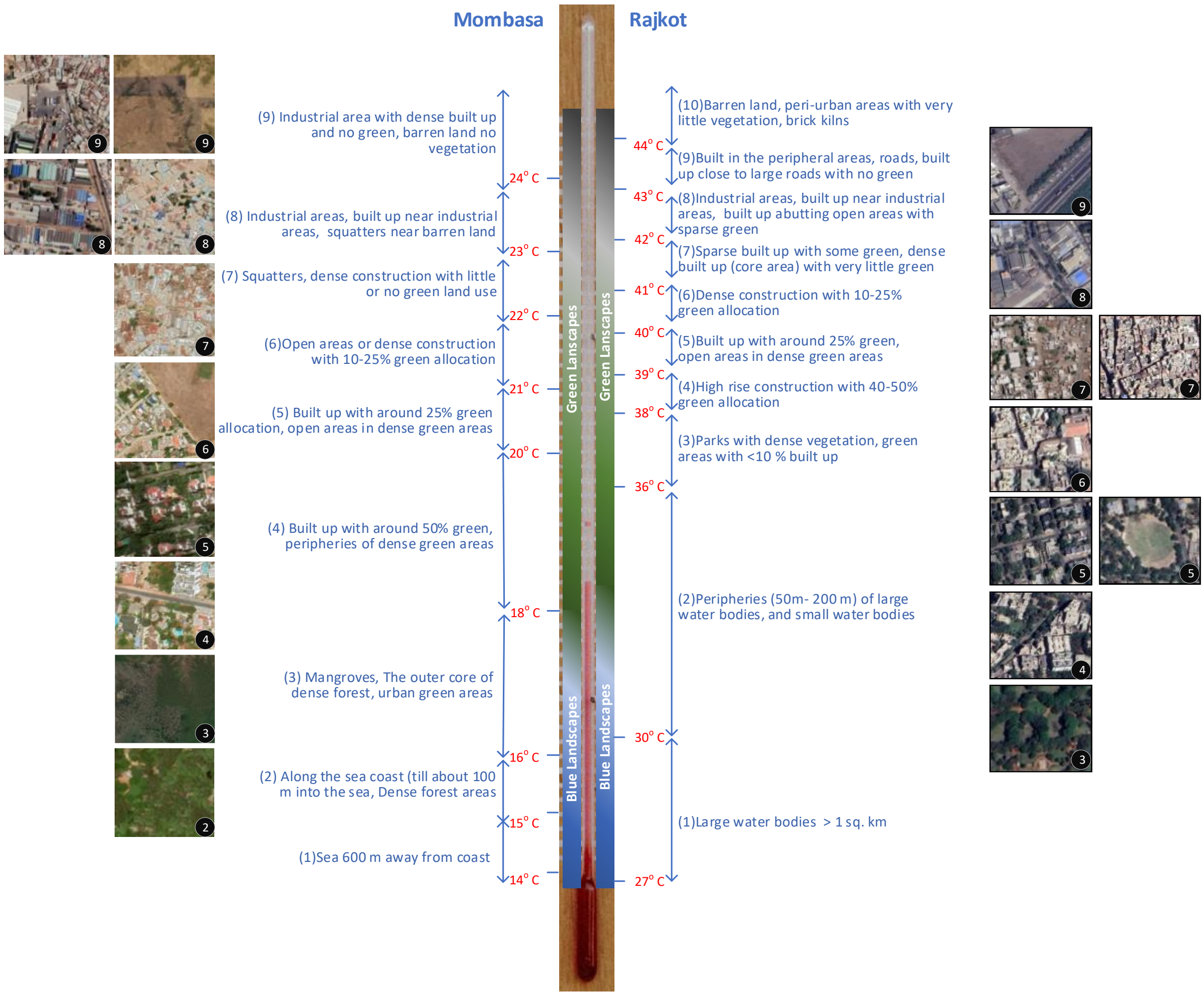


Figure 2.2: Urban Design and LST Rajkot and Mombasa

It is clear that blue and green Infrastructure profoundly influences urban temperature in Rajkot. And Mombasa. What is apparent is that barren land heats up very quickly under the sun. Likewise, the grey land use also heats up fast. However, locations that are barren land have the highest temperature. As seen in Figure 2.4, where different urban form elements in the city and LST during May 2022 are shown, the following can be concluded in the town of Rajkot.

- Water, especially central parts of large water bodies, considerably reduces urban temperatures. As can be seen in figure A11, there is about 15°C difference between the temperature at the centre of one of the large ponds in the city's peripheral area and a nearby barren land 400 m away.
- Boundaries of water bodies (about 0-90 m inside from the edge) and the immediate peripheries of the water bodies are relatively cooler (30-36 °C), but heat loss is rapid after that, especially if the land is barren.
- Parks with dense green cover have temperatures around 36-38 °C, which is also about 9 °C lower than the maximum temperatures observed in the city.
- Location, which had high-rise buildings and a green cover of about 50%, also had relatively low temperatures in the range of 38-39 °C.
- Locations with about 25% green and little or no barren land surfaces have a temperature around 40 °C.

- Dense built-up with very little barren land surface and about 10-25% green land use have temperature anywhere between 40-42 ºC
- Industrial areas and locations with brick kilns have higher temperatures
- Barren land in the peri-urban areas which no green cover has the highest LST

Like Rajkot, clear relations between urban form land surface temperature can be observed in Mombasa. These relations are summarised in Figure 4 and discussed below.

1. Off coast and out 600 m into the sea is where the temperature is lowest, around 14 ºC
2. Locations near the coast in the bay areas around Mombasa city is around 15 ºC; that is, water close to about 150m from the land area is around 15 ºC. Likewise, dense Green along the mangroves and the north-eastern coast also have a temperature around 15 ºC
3. Less dense parts of mangroves and built-up areas along the peripheries of dense Green have temperatures in range between 16 ºC to18 ºC
4. Built-up areas with a high level of green cover (around 50%) have temperatures in the range between 18 ºC to 20 ºC
5. As observed in Rajkot, the LST increase with a reduction in green cover and squatters and densely built-up areas have relatively much higher temperature
6. Among the built-up areas, industrial areas with tin sheds have the highest LST
7. As observed in Rajkot, barren land has the highest LST, which is higher than 27 ºC

From an urban design perspective, even though water has the most profound influence on reducing the urban temperature, it is practically impossible to locate water bodies across the city. However, there are several water bodies across the city, as seen in figure 4; future city plans need to conserve these water bodies and possibly plan for reviving some old water structures that were part of the city's natural drainage system in the old days. An effort could be made to fill the Aji river, which runs dry during the summertime, with water like in Ahmedabad. It is also essential to maintain the peripheral areas of these water bodies, these can ideally be dense green or built-up areas with a minimum of 50% green cover. Any barren land around water bodies rapidly increase surface temperature, thus green cover around it is essential. As we mentioned earlier, the moderate climate is conducive to vegetation growth in the city of Mombasa. The master plan also has some good initiatives for conserving greens and mixing built-up with a good proportion of green areas. However, the city will have to revisit its housing strategy and find ways and means to reduce squatter settlements. As seen in figure 4 are places with a minimal green cover and high temperatures. In both cities, the industrial areas are often overlooked. It was observed that industrial areas have a minimal green cover. Industrial sites should be mixed with urban forest areas so that the temperature at these locations can be moderated. Possibilities for industries to have green roofs can also be explored.

2.3 Conclusions

This chapter aimed to explore the methods for urban heat island identification and the rapid identification of blue and green Infrastructure in urban areas using remote sensing images. Two cities, one in India (Rajkot) and one in Kenya (Mombasa), were taken as case areas.

The urban surface temperature was quantified for both cities using Landsat 8 data. Land surface temperature (LST) estimation has been carried out using the Mono-window algorithm, and land use change and vegetation cover were identified through the Normalised Difference Vegetation Index (NDVI). Results indicated that the spatial distribution of the land surface temperature was affected by the land use land cover change and the built environment, which is in line with the discussion in the chapter on energy and resource efficiency.

The relationship between build form and its design or lack of it and attention to green and blue spaces profoundly influence land surface temperature. The observed results showed that the open land, the central portion of the city area with minimal green and the industrial regions exhibited the highest surface temperature compared to the surrounding open area. The areas with dense built-up displayed higher temperatures, and the areas covered by vegetation and water bodies exhibited lower temperatures. A strong correlation is observed between Land surface temperatures with Normalised Difference Vegetation Index (NDVI). These built patterns are outcomes of urban planning policies and effectiveness. Urban development planning and policies can draw inferences from the finding of this chapter.

Due to several limitations on two of the several benefits of NbS and how they interface with energy efficiency within cities discussed in the chapter could be studied, which will call for more detailed work involving possible fieldwork.

The next chapter discusses the possible business model that cities can use to encourage NbS solutions.

3 The economic nexus between energy efficiency and nature-based solutions

3.1 The market sensitivity to energy efficiency

An energy-efficient building has lower operating costs in terms of energy use per square meter when compared to a less efficient building. National or local policies can regulate how well-performing buildings should be through the enforcement of building codes. On the other hand, the energy labelling of buildings informs potential real-estate buyers or renters of the building's energy performance. Building codes and labelling are two sides of the same policy which serve as a pull and push to tackle mitigation of the buildings sector. Buildings are the biggest carbon dioxide emitting sector, accounting for about 37 per cent of the total global emissions and are responsible for about 40 per cent of the energy use just in the EU area.

As building codes apply mostly to new buildings or deep retrofits, the biggest potential for energy efficiency lies in existing buildings. So, national, and local governments should put in place and enforce policies that tackle existing buildings, stimulating their better performance. Currently, only about 158 countries identify buildings as a sector of focus in the 2021 Nationally Determined Contributions (up from 88 countries in 2015)[65]. Interestingly, in France, since 1st January 2023, it has been illegal to rent a property with the lowest energy efficiency rating (G rating), while for buildings with the lowest efficiency levels (F and G), landlords will not be able to increase the renting value over time[66]. These regulatory actions are put in place to stimulate investments in efficiency measures.

Yet better-performing buildings may imply an upfront higher property price. In the EU and the US, there is evidence of a direct correlation between higher rankings of the energy label of a building and its sale price per square meter[66, 67].

There is a wealth of literature about the economic savings of energy efficiency measures applied to buildings. This analysis is accurately based on auditing, applied energy measurement equipment and assessment of the return on investment of energy savings.

An area not so well developed is the analysis of the correlation between the influence of the energy performance of buildings and their market value. These types of analyses entail complexity as it needs to isolate the energy performance of a building from other factors like accessibility, safety, comfort, and healthiness, some of those quite subjective. This means that some buyers may not be willing to pay a higher investment price for a better-performing building, prioritising other considerations, such as accessibility, distance to work, or distance to social and green areas.

However, early studies show that there is an impact on the property price of the building energy performance that could range from 5% to 15% depending on several factors, such as if it is a rental or a purchase, the methodologies applied, and the variables considered[66]. Nevertheless, results seem to show an indication that the energy performance of a building has an impact on its property value, i.e., the better the energy performance, the higher the price per square meter.

Hedonic pricing analysis is normally used to explore the relationship between certain features, such as energy or sustainability and the market value of a building. However, hedonic analysis is not perfect as market data is volatile and it is difficult to extrapolate to other areas. More studies coming to light may lead to a clearer bottom line that a better-performing building may imply higher market value.

In developing countries, building regulations are often scarce, incomplete, or outdated so, such a direct correlation is less straightforward to assess. Comparisons could be done between the property value and the energy demand of the same property, assuming the higher the property value, the higher the expenditure on energy indicator. This may be justified based on the higher availability of financial resources to pay for the energy bills. However, this analysis is blind regarding the energy performance.

Financing energy efficiency retrofits in buildings could have a quick return on investment, such as by replacing inefficient appliances, or longer returns that are normally associated with the building envelope (wall, roofs, floor insulation, and the replacement of windows). To overcome the barrier of longer returns, and if energy prices do not spike, it is normally compensated by public disposal of grants for efficiency investments, on-bill financing, conventional loans or in the form of energy-as-a-service. The latter can be presented in several formats the most innovative and popular are the lighting-as-a-service or cooling-as-a-service.

The energy-as-a-service market mechanism can involve the participation of the private sector using energy performance contracting. This business model normally involves a third-party investment by an energy service company (ESCO) which then recuperates its investment based on a service contract that could have a fixed fee or be based on monthly savings. Several modalities of this option are available in the market in terms of contracting and targeted clients. ESCOs essentially act as project developers as they integrate a series of components, such as project design, procurement, financing, implementation, and operation.

3.2 The market sensitivity to nature-based solutions

Nature-based solutions are generally considered a public good, such as a park or a city pond, benefitting residents or who visit these areas. Building integrated nature-based solutions, such as green roofs and green facades, on the other hand, tend to be of a private nature and benefit first instance just the residents, though by gaining critical mass it could be differentiating in a city context. While the first typology is normally associated with public finances, the latter is dependent on private real estate development.

Public nature-based solutions are dependent on public budgets, often cutting across several municipal department approvals and subject to competing priorities throughout short election cycles. Building integrated solutions are on the other hand, dependent on private actors, real estate developers and citizen preferences. However, there are signs of upcoming integration of nature-based solutions in buildings, resulting from the discussions of new building regulations to incorporate these features, especially targeting extreme temperature management. This development opens the possibility of deploying regulation that simultaneously aims at a better performance of buildings and using nature as a mitigation and adaptation feature.

The proximity to nature-based solutions and its development using private capital is normally regarded as market-driven gentrification, targeting higher or middle-income housing residents[68] This may lead to the conclusion that higher proximity to green or blue areas is often associated with higher property value, at least in developed countries. In the case of developing countries, some green areas on the outskirts of cities may however not necessarily mean a higher land value, because these are often either barren land or poorly managed areas. Therefore, a high frequency of lower-resource residents is found in such neighbourhoods.

Financing nature-based solutions face market failures, because of the difficulty in accounting for the externalities associated with its prevalence, such as valuing a few degrees of lower temperature in cities, lower hospitalisation rates due to heat stress, and fewer cases of mental health, just to mention a few[68].

While building-integrated green roofs and facades can rely on private capital for their financing, it is less evident how can the private sector see the return on their investments in a garden or by planting city street trees. Different strategies and business models need to be put in place to create the dynamics for generating higher revenue for cities and simultaneously higher participation of the private sector in investments.

Here, the public sector has a role in helping to de-risk private sector engagement by enforcing environmental regulations, developing demonstration projects or enabling public-private partnerships.

Development banks are now starting to take onboard nature-based solutions when evaluating how environmentally sound an investment is. As an example, the Green Eligibility Checker[1] of the European Investment Bank assesses an investment project for EIB green financing. This tool evaluates green roofs and walls and their contribution to energy savings and mitigation of CO_2 emissions, labelling the potential investments as "EIB Green".

Little has been written so far on financing nature-based solutions, but a few modalities could be explored.

3.3 The Energy efficiency and nature-based solutions economic nexus

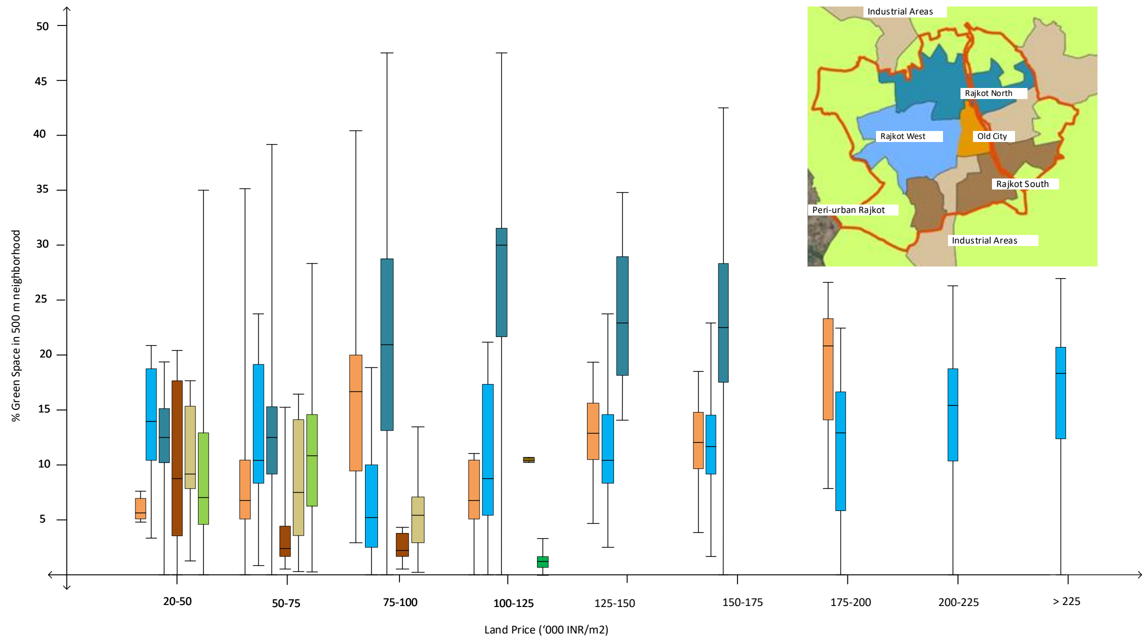
Both energy efficiency and nature-based solutions seem to add to the city property value, the better-performing a building is, and the more nature-based solutions it uses, the higher its estate value. This pattern promotes both techniques to have a multiplier effect while serving the purposes of mitigation and adaptation. Therefore, buildings that perform better towards environmental hazards, such as extreme temperatures, also have a higher market value. The bottom line could be that the higher the

[1] EIB Green Eligibility Checker

building value per square meter, the more revenues could be generated for the municipality, as property tax, for example.

Those extra incomes could then be re-invested in further development of green areas which would then add value to the area. On the flip side, there are also the avoided costs with excess hospitalisations and deaths because of extreme heat; for example, these would also add to the social positive externalities of including such improvements in the city space.

Blending energy efficiency and nature-based solutions business models could incorporate features of both techniques. Further integration of nature-based solutions features in building codes could support decarbonisation and the energy transition in developed and developing countries.



City Area	20-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	> 225
	% Land								
Old City	1.93	29.00	32.86	20.04	7.21	6.15	2.83		
Rajkot West	0.88	7.75	12.14	8.47	6.47	13.58	12.06	17.09	21.57
Rajkot North	33.05	15.35	24.83	19.49	3.69	3.49			
Rajkot South	58.02	27.30	9.90	2.05	1.02	1.71			
Industrial Planks	24.91	59.50	14.33		1.25				
Peri-Urban Rajkot	85.31	13.02	1.67						

Figure 3.1: Relation between property values and green spaces

Figure 3.1 shows the relation between the availability of green spaces in the neighbourhood of 500 m around the property and property rates. Green areas are quantified from the NDVI values calculated for the city of Rajkot (figure xx in Chapter xx). The property rates are taken by the study on the hedonic land price model for the city of Rajkot (Munshi 2022). Residential property rate values are grouped against the percentage of green area in the neighbourhood for five different development areas in Rajkot city.

These five development areas in the city differ in terms of their spatial layout and type of development. The core city Rajkot (Old City) is typical pre-colonial period development, with attached buildings, narrow streets, and high residential and commercial density. To the west of the City core area (Rajkot west) is the most prosperous area in the city of Rajkot, with a good road network and civic amenities. The northern portion of the city is where the population is mixed, and the quality of Infrastructure and amenities is slightly lower compared to Rajkot west. Rajkot also has two distinct industrial areas. The residential development around these areas mainly comprises slums and poor residences.

In the city core, around 80% of the residential property values are in the range between (50-125 thousand INR), and the percentage of green is the lowest in areas where the property values are also the lowest. Generally, the property values increase with the increase in green. However, a large proportion of the area in the city core, around 20% (property rates between 100-125 thousand INR), has a low percentage of green in the neighbourhood. Rajkot west has the highest property rates in the city, and a large proportion of it is in the ranges higher than 150 thousand INR. In most parts of Rajkot west, property rates increase with the increase in green cover in the neighbourhood. Likewise, in Rajkot north also, the property rates increase with the increase in green cover for the most part, that is, in areas where property rates are lower than 125 thousand INR, after which the green cover falls with an increase in property rates. In the locations where there are industries and squatter settlements, a large proportion of land has low land value and green cover.

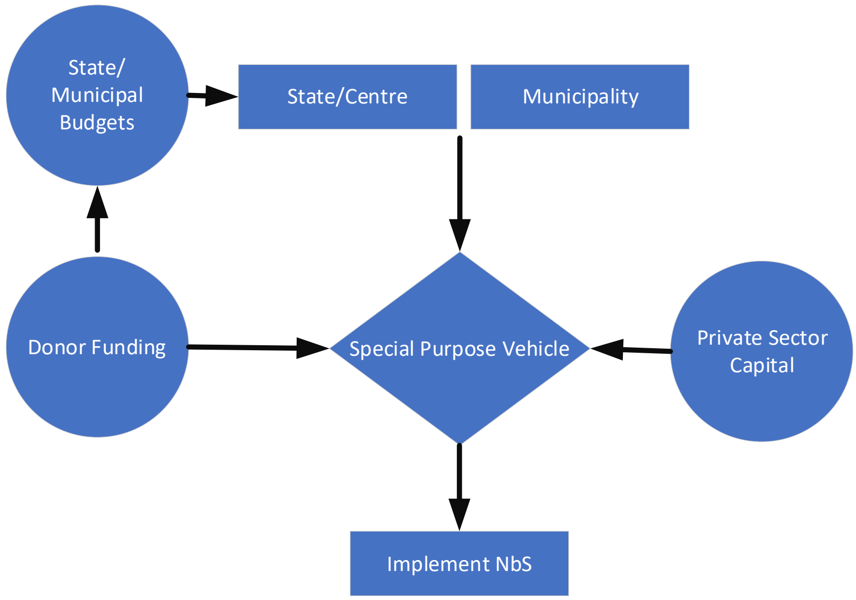


Figure 3.2: Conceptual Model for implementing Nature-based Solutions.

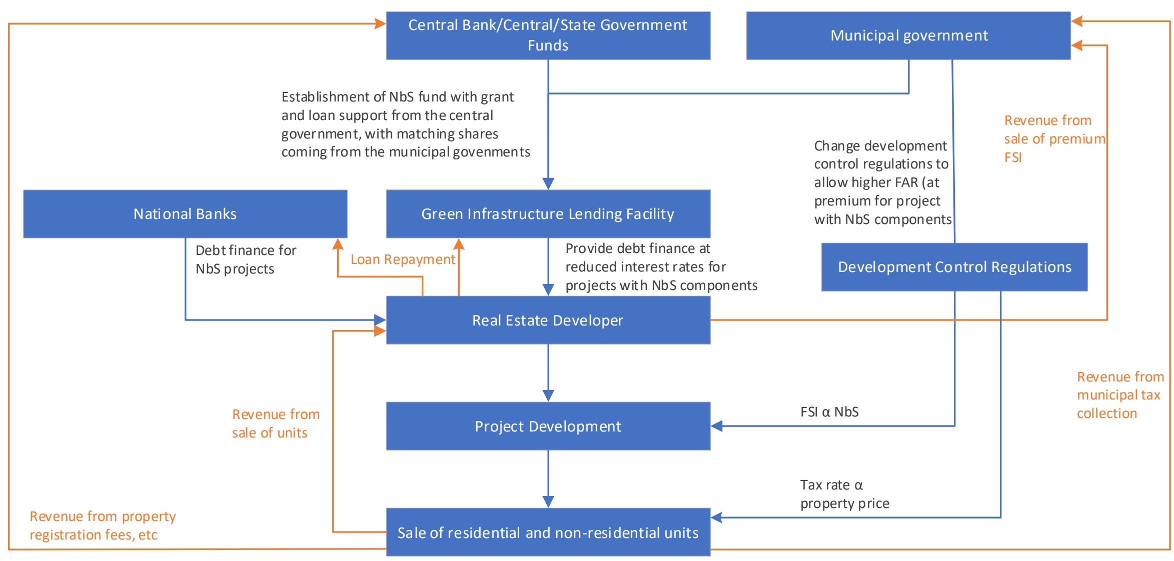


Figure 3.3: Conceptual Model for operationalising Nature-based Solutions.

From Figure 3.2, it can be seen that even without any active support for Nature-based Solutions, there is a profound influence of the presence of green spaces on land values, especially at locations where other infrastructure and services provision is also good. Thus, green landscapes add value addition to residential properties, which can be captured using land value capture mechanisms to fund the development and maintenance of such places. Figure 3.3 is a conceptual diagram showing value capture mechanism can work. A special-purpose vehicle called a green infrastructure lending facility can be formed, which provides debt finance to real estate developers for the project with NbS components and more than 25% of the land allocated as green cover. The municipal corporations can support this development by providing additional incentives for provided green cover as development rights which can be purchased against a fee. The benefits of adding green and other NbS solutions to real estate development can increase the property values of the projects; the sale of these properties will generate revenue for the real estate developer, used to repay the debt to the SPV. Land value tax in the form of registration fees and fixed property tax can provide revenue for the state (property registration) and the municipal corporation (property tax). The SPV can channel these to maintain and further plan and implement NbS solutions.

3.4 Conclusion

A business model for implementing nature-based solutions in urban areas should focus on developing sustainable green Infrastructure, promoting eco-friendly business practices, and raising awareness among urban residents. These business models can take several forms, but the obvious benefits they have for urban residents and the marginal utility that NbS has for them are realised as increased land and property prices.

NbS solutions have been linked to the housing market by improving the quality of life for residents. Nature-based solutions can enhance the aesthetic value of the neighbourhood, provide recreation opportunities, and increase natural light, leading to improved mental well-being. Thus properties that are located near nature-based solutions have been found to have a higher market value, as these properties offer homeowners an array of benefits. This advantageous relationship between nature-based solutions and the housing market encourages urban planners to incorporate nature-based solutions into designs to attract investors and enhance community engagement in a sustainable way.

The added value that NbS generates can be captured using land value capture mechanism and business models can be developed around it for cities to design, implement and maintain nature based solutions.

References

1. Oke, T.R., *The energetic basis of the urban heat island.* Quarterly journal of the royal meteorological society, 1982. **108**(455): p. 1-24.
2. Aram, F., et al., *Urban green space cooling effect in cities.* Heliyon, 2019. **5**(4): p. e01339.
3. International Energy Agency, *Empowering Cities for a Net Zero Future: Unlocking resilient, smart, sustainable urban energy systems*. 2022.
4. Besir, A.B. and E. Cuce, *Green roofs and facades: A comprehensive review.* Renewable and Sustainable Energy Reviews, 2018. **82**: p. 915-939.
5. Aboulnaga, M. and M. Mostafa, *Mitigating Heat Islands Effect in Mega Cities through Districts' Prioritisation for Urban Green Coverage Applications: Cairo–Egypt as a Case Study.* Renewable Energy and Environmental Sustainability, 2019. **4**: p. 5.
6. Schibuola, L. and C. Tambani, *Performance assessment of seawater cooled chillers to mitigate urban heat island.* Applied Thermal Engineering, 2020. **175**: p. 115390.
7. de Munck, C., et al., *How much can air conditioning increase air temperatures for a city like Paris, France?* International Journal of Climatology, 2013. **33**(1): p. 210-227.
8. Jungclaus, M., et al., *Reducing embodied carbon in buildings: low-cost, high-value opportunities.* S. l, 2021.
9. Permpituck, S. and P. Namprakai, *The energy consumption performance of roof lawn gardens in Thailand.* Renewable energy, 2012. **40**(1): p. 98-103.
10. Yin, H., et al., *Cooling effect of direct green façades during hot summer days: An observational study in Nanjing, China using TIR and 3DPC data.* Building and Environment, 2017. **116**: p. 195-206.
11. Mohajerani, A., J. Bakaric, and T. Jeffrey-Bailey, *The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete.* Journal of environmental management, 2017. **197**: p. 522-538.
12. Alcazar, S.S., F. Olivieri, and J. Neila, *Green roofs: Experimental and analytical study of its potential for urban microclimate regulation in Mediterranean–continental climates.* Urban Climate, 2016. **17**: p. 304-317.
13. Wang, Y. and H. Akbari, *The effects of street tree planting on Urban Heat Island mitigation in Montreal.* Sustainable Cities and Society, 2016. **27**: p. 122-128.
14. Feyisa, G.L., K. Dons, and H. Meilby, *Efficiency of parks in mitigating urban heat island effect: An example from Addis Ababa.* Landscape and urban planning, 2014. **123**: p. 87-95.
15. Gómez-Baggethun, E. and D.N. Barton, *Classifying and valuing ecosystem services for urban planning.* Ecological economics, 2013. **86**: p. 235-245.
16. Blue Green Solutions. . 2016 20 January 2023].
17. Musy, M., et al. *VegDUD project: Role of vegetation in sustainable urban development*. in *ICUC: 8th International Conference on Urban Climates*. 2012.
18. Xing, Y., P. Jones, and I. Donnison, *Characterisation of nature-based solutions for the built environment.* Sustainability, 2017. **9**(1): p. 149.
19. Almassy, D., et al., *Urban Nature Atlas: A database of nature-based solutions across 100 European cities.* Report of H2020 Project Naturvation, 2018.
20. Sundquist, K., G. Frank, and J. Sundquist, *Urbanisation and incidence of psychosis and depression: follow-up study of 4.4 million women and men in Sweden.* The British Journal of Psychiatry, 2004. **184**(4): p. 293-298.
21. Alcock, I., et al., *Longitudinal effects on mental health of moving to greener and less green urban areas.* Environmental science & technology, 2014. **48**(2): p. 1247-1255.
22. Hermanski, A., et al., *The effects of blue spaces on mental health and associated biomarkers.* International Journal of Mental Health, 2022. **51**(3): p. 203-217.
23. Jo, H.-K. and G.E. McPherson, *Carbon storage and flux in urban residential greenspace.* Journal of Environmental Management, 1995. **45**(2): p. 109-133.

24. Getter, K.L., et al., *Carbon sequestration potential of extensive green roofs.* Environmental science & technology, 2009. **43**(19): p. 7564-7570.
25. Klimas, C., et al., *Valuing ecosystem services and disservices across heterogeneous green spaces.* Sustainability, 2016. **8**(9): p. 853.
26. Rosenfeld, A.H., et al., *Cool communities: strategies for heat island mitigation and smog reduction.* Energy and buildings, 1998. **28**(1): p. 51-62.
27. Raskin, I., R.D. Smith, and D.E. Salt, *Phytoremediation of metals: using plants to remove pollutants from the environment.* Current opinion in biotechnology, 1997. **8**(2): p. 221-226.
28. Tomson, M., et al., *Green infrastructure for air quality improvement in street canyons.* Environment international, 2021. **146**: p. 106288.
29. Pérez, G., J. Coma, and L.F. Cabeza, *Vertical greening systems for acoustic insulation and noise reduction*, in *Nature based strategies for urban and building sustainability*. 2018, Elsevier. p. 157-165.
30. Savard, J.-P.L., P. Clergeau, and G. Mennechez, *Biodiversity concepts and urban ecosystems.* Landscape and urban planning, 2000. **48**(3-4): p. 131-142.
31. Whitford, V., A.R. Ennos, and J.F. Handley, *"City form and natural process"—indicators for the ecological performance of urban areas and their application to Merseyside, UK.* Landscape and urban planning, 2001. **57**(2): p. 91-103.
32. Baldock, K.C., et al., *Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects.* Proceedings of the Royal Society B: Biological Sciences, 2015. **282**(1803): p. 20142849.
33. Baldock, K.C., et al., *A systems approach reveals urban pollinator hotspots and conservation opportunities.* Nature ecology & evolution, 2019. **3**(3): p. 363-373.
34. Patankar, S., et al., *Which traits influence bird survival in the city? A review.* Land, 2021. **10**(2): p. 92.
35. Vineyard, D., et al., *Comparing green and grey infrastructure using life cycle cost and environmental impact: A rain garden case study in Cincinnati, OH.* JAWRA Journal of the American Water Resources Association, 2015. **51**(5): p. 1342-1360.
36. Liu, H., Y. Jia, and C. Niu, *"Sponge city" concept helps solve China's urban water problems.* Environmental Earth Sciences, 2017. **76**(14): p. 1-5.
37. Versini, P.-A., et al., *Use of green roofs to solve storm water issues at the basin scale–Study in the Hauts-de-Seine County (France).* Urban Water Journal, 2016. **13**(4): p. 372-381.
38. Krishnan, S., et al., *Sustainable urban agriculture: A growing solution to urban food deserts*, in *Organic farming for sustainable agriculture*. 2016, Springer. p. 325-340.
39. Holy-Hasted, W. and B. Burchell, *Does public space have to be green to improve well-being? An analysis of public space across Greater London and its association to subjective well-being.* Cities, 2022. **125**: p. 103569.
40. Kim, J. and R. Kaplan, *Physical and psychological factors in sense of community: New urbanist Kentlands and nearby Orchard Village.* Environment and behavior, 2004. **36**(3): p. 313-340.
41. Peters, K., B. Elands, and A. Buijs, *Social interactions in urban parks: Stimulating social cohesion?* Urban forestry & urban greening, 2010. **9**(2): p. 93-100.
42. Kim, G., *The public value of urban vacant land: Social responses and ecological value.* Sustainability, 2016. **8**(5): p. 486.
43. O'Donnell, E.C., J.E. Lamond, and C.R. Thorne, *Recognising barriers to implementation of Blue-Green Infrastructure: a Newcastle case study.* Urban Water Journal, 2017. **14**(9): p. 964-971.
44. Trell, E. and M. van Geet, *The governance of local urban climate adaptation: Towards participation, collaboration and shared responsibilities.* Planning Theory & Practice, 2019. **20**(3): p. 376-394.
45. Davies, C. and R. Lafortezza, *Urban green infrastructure in Europe: Is greenspace planning and policy compliant?* Land use policy, 2017. **69**: p. 93-101.
46. Frantzeskaki, N. and N. Tilie, *The dynamics of urban ecosystem governance in Rotterdam, The Netherlands.* Ambio, 2014. **43**(4): p. 542-555.

47. Kabisch, N., et al., *Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action.* Ecology and Society, 2016. **21**(2).
48. Wamsler, C., et al., *Environmental and climate policy integration: Targeted strategies for overcoming barriers to nature-based solutions and climate change adaptation.* Journal of Cleaner Production, 2020. **247**: p. 119154.
49. Turner, V.K., K. Jarden, and A. Jefferson, *Resident perspectives on green infrastructure in an experimental suburban stormwater management program.* Cities and the Environment (CATE), 2016. **9**(1): p. 4.
50. van Ham, C. and H. Klimmek, *Partnerships for nature-based solutions in urban areas–showcasing successful examples.* Nature-based solutions to climate change adaptation in urban areas: linkages between science, policy and practice, 2017: p. 275-289.
51. Zuniga-Teran, A.A., et al., *Urban resilience and green infrastructure systems: Towards a multidimensional evaluation.* Current Opinion in Environmental Sustainability, 2020. **44**: p. 42-47.
52. Sarabi, S., et al., *Uptake and implementation of nature-based solutions: an analysis of barriers using interpretive structural modeling.* Journal of Environmental Management, 2020. **270**: p. 110749.
53. Fernandes, C.O., et al., *Between tree lovers and tree haters. Drivers of public perception regarding street trees and its implications on the urban green infrastructure planning.* Urban Forestry & Urban Greening, 2019. **37**: p. 97-108.
54. Ruangpan, L., et al., *Nature-based solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area.* Natural Hazards and Earth System Sciences, 2020. **20**(1): p. 243-270.
55. Tsantopoulos, G., et al., *Public perceptions and attitudes toward green infrastructure on buildings: The case of the metropolitan area of Athens, Greece.* Urban Forestry & Urban Greening, 2018. **34**: p. 181-195.
56. Miccio, C.E., *Barriers to implementing low impact development approaches in Washington State roadways and highways*. 2010, Washington (State). Dept. of Transportation. Office of Research and Library ….
57. Haase, D., N. Kabisch, and A. Haase, *Endless urban growth? On the mismatch of population, household and urban land area growth and its effects on the urban debate.* PloS one, 2013. **8**(6): p. e66531.
58. Baur, J.W., J.F. Tynon, and E. Gómez, *Attitudes about urban nature parks: A case study of users and nonusers in Portland, Oregon.* Landscape and Urban Planning, 2013. **117**: p. 100-111.
59. Sundborg, Å., *Climatological studies in Uppsala: With special regard to the temperature conditions in the urban area*. 1951.
60. Li, X., L.C. Stringer, and M. Dallimer, *The role of blue green infrastructure in the urban thermal environment across seasons and local climate zones in East Africa.* Sustainable Cities and Society, 2022. **80**: p. 103798.
61. Chen, C., et al., *Quantitative analysis of the building-level relationship between building form and land surface temperature using airborne LiDAR and thermal infrared data.* Urban Climate, 2022. **45**: p. 101248.
62. Bekele, N.K., B.T. Hailu, and K.V. Suryabhagavan, *Spatial patterns of urban blue-green landscapes on land surface temperature: A case of Addis Ababa, Ethiopia.* Current Research in Environmental Sustainability, 2022. **4**: p. 100146.
63. Mahadevia, D. and T. Gogoi, *Rental housing in informal settlements: A case-study of Rajkot.* Centre for Urban Equity, CEPT University: Ahmedabad, India, 2011.
64. Kithiia, J. and R. Dowling, *An integrated city-level planning process to address the impacts of climate change in Kenya: The case of Mombasa.* Cities, 2010. **27**(6): p. 466-475.
65. UNEP, *Global Status Report for Building and Construction*. 2022, United Nations Environment Programme.

66. Popescu, D., et al., *Impact of energy efficiency measures on the economic value of buildings.* Applied Energy, 2012. **89**(1): p. 454-463.
67. Notaires de France. *La valeur verte des logements*. 2020; Available from: https://en.calameo.com/read/0051251980338a489ab14?page=1 (2021).
68. Toxopeus, H. and F. Polzin, *Reviewing financing barriers and strategies for urban nature-based solutions.* Journal of Environmental Management, 2021. **289**: p. 112371.

Annexure 1

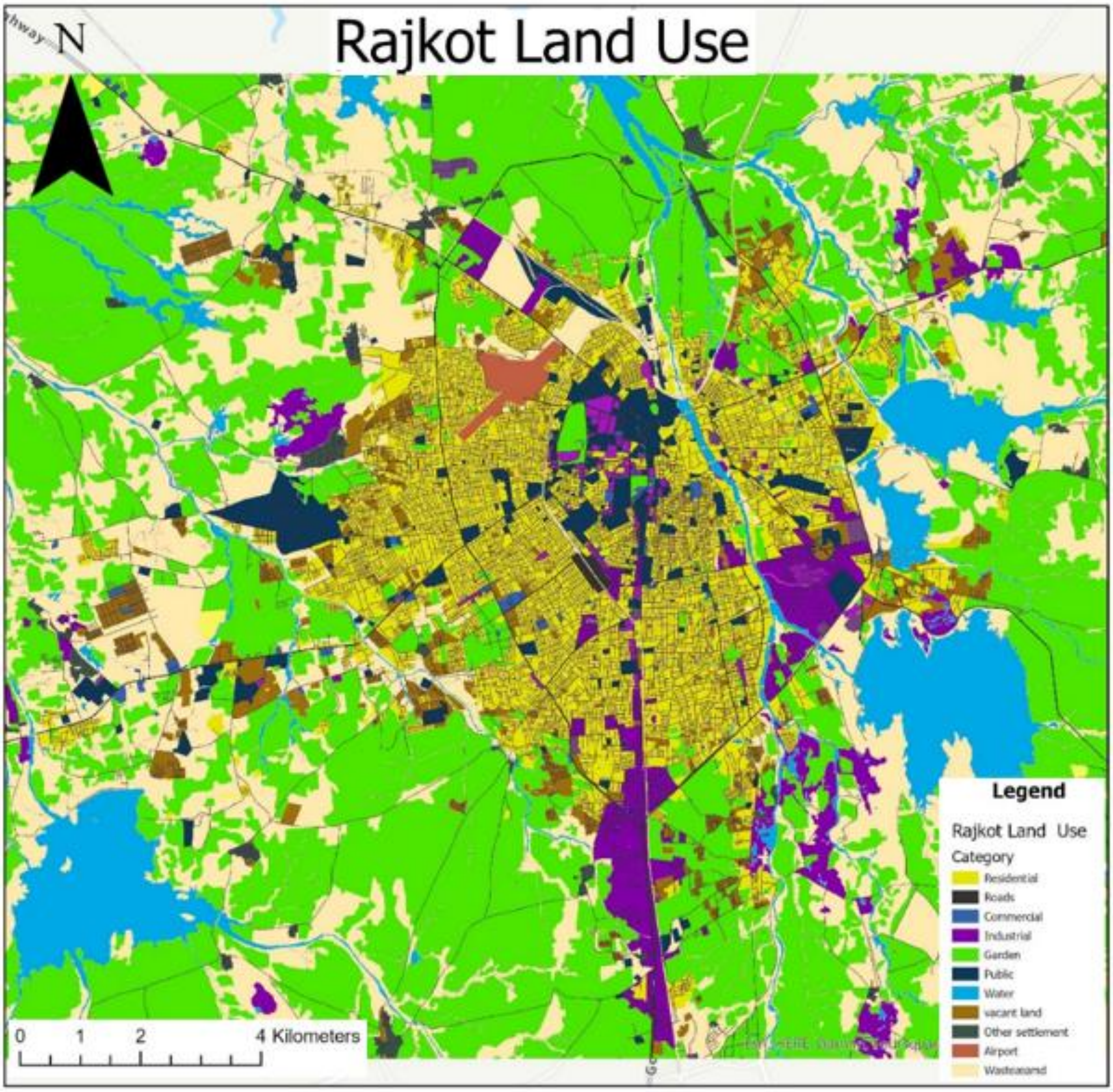


Figure A.1: Land use of Rajkot
Source:Bhuvan

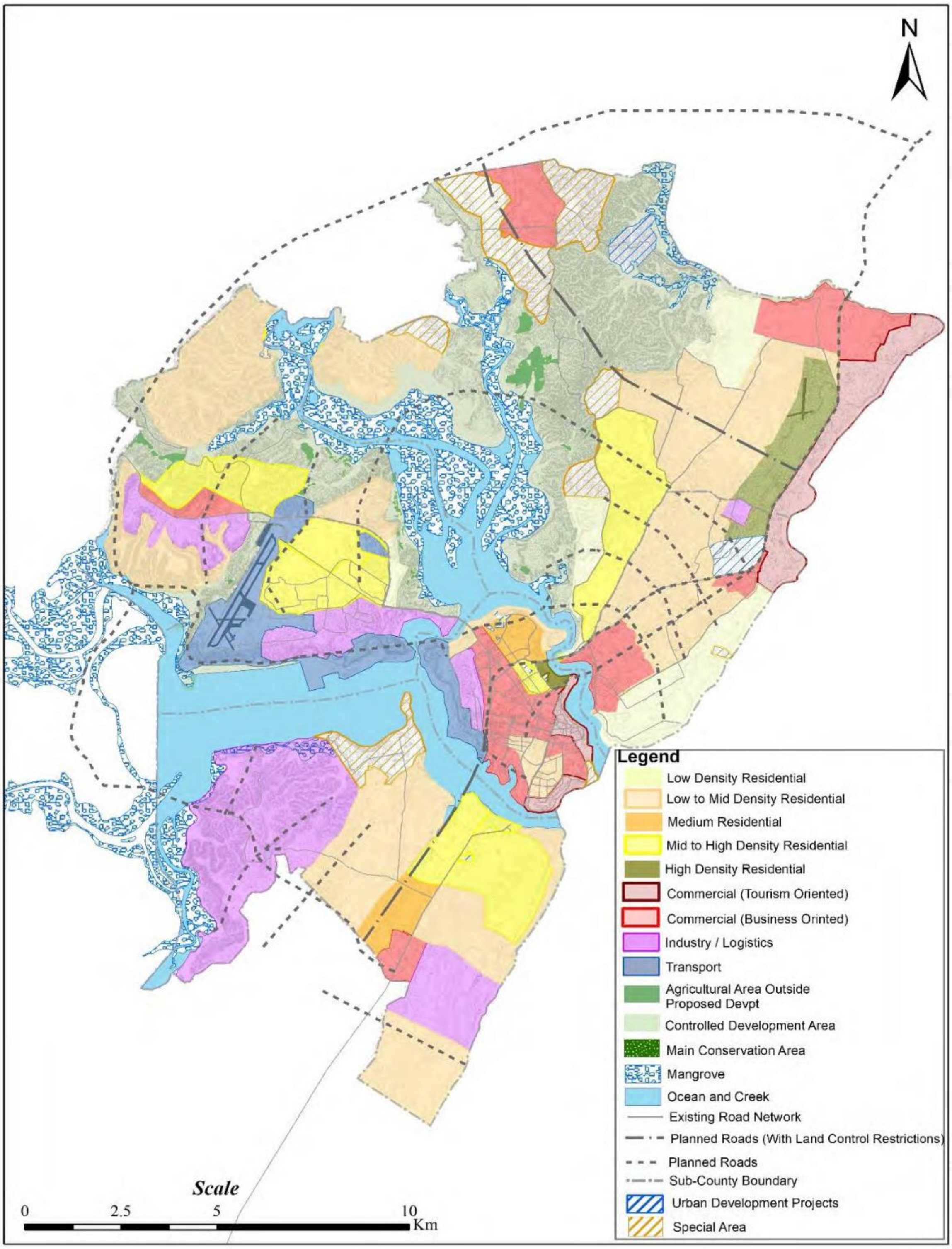


Figure A.2: Land use of Mombasa (Proposed in the master plan)

Source:
http://www.gatecitymp.mombasa.go.ke/sites/default/files/Mombasa%20Gate%20City%20Master%20Plan%20Pamphlet_light_2.pdf

A.1 Data and Methods

Land surface temperature (LST) data were derived from Landsat 8 thermal infrared sensor (TIRS) images from the United States Geological Survey (USGS, glovis.usgs.gov/) and other land use indices were derived using other bands of from Landsat 8 OLI/TIRS data. This data is described in Table 4

Table 4: Data Sources

Rajkot					
Data set	Band name	Central band/band width (μm)	Spatial resolution	Acquisition date	Source
Landsat 8 OLI/TIRS	Band 2 (Blue)	0.45–0.512	30 × 30 m	02 May, 2022	https://earthexplorer.usgs.gov/
	Band 3 (Green)	0.53–0.59	30 × 30 m		
	Band 4 (Red)	0.63–0.67	30 × 30 m		
	Band 5 (NIR)	0.85–0.87	30 × 30 m		
	Band 6 (SWIR 1)	1.56–1.65	30 × 30 m		
	Band 10 (Thermal 1)	10.60–11.19	30 × 30 m		
Mombasa					
Landsat 8 OLI/TIRS	Band 2 (Blue)	0.45–0.512	30 × 30 m	19 Feb, 2022(Data from 19 Feb 2019 and 22 Jan 2021 was use to account for cloud cover)	https://earthexplorer.usgs.gov/
	Band 3 (Green)	0.53–0.59	30 × 30 m		
	Band 4 (Red)	0.63–0.67	30 × 30 m		
	Band 5 (NIR)	0.85–0.87	30 × 30 m		
	Band 6 (SWIR 1)	1.56–1.65	30 × 30 m		
	Band 10 (Thermal 1)	10.60–11.19	30 × 30 m		

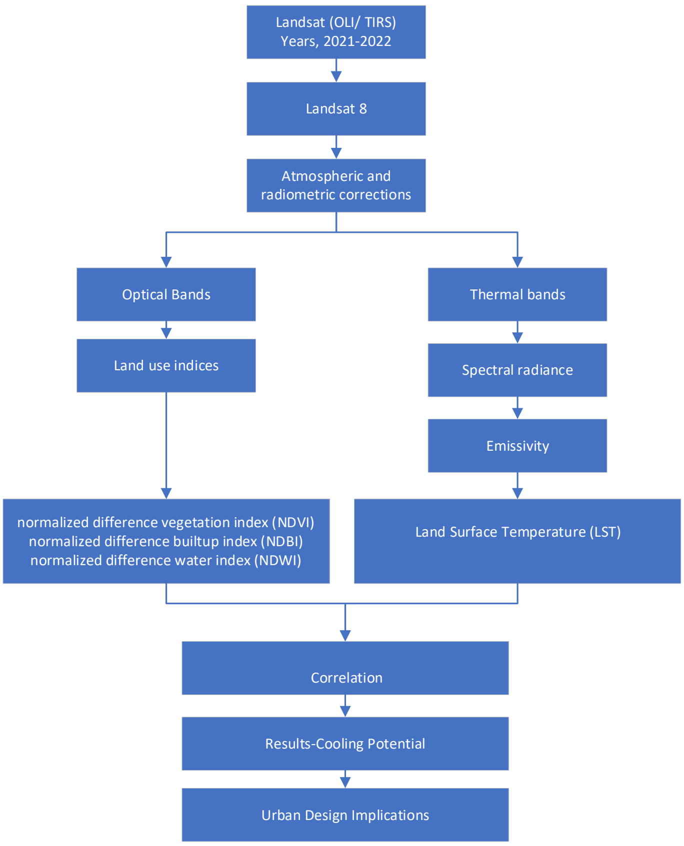


Figure A.3: Conceptual Diagram

Figure is the conceptual diagram of the methods used to build this study project. ArcGIS pro was used to analyse Landsat data in order to calculate the NDVI, NDBI, NDWI, and LST indices. The land surface temperature (LST) of the study area was obtained using a mono-window technique based on Landsat 8. The temperature readings from above are expressed in terms of a black body, therefore, the brightness temperature must be adjusted by the actual object attributes to extract the LST (Guha & Govil, 2021). LST is calculated in this study using the thermal bands from Landsat 8 TIRS band 10. There was also an option to use band 11 of Landsat image but due to band 11's higher stary light inaccuracy and greater calibration uncertainty, Landsat 8 TIRS band 10 is favoured (Balew & Korme, 2020; Guha, Govil, Dey, & Gill, 2018).

A zero cloud data for Mombasa was now available, therefore, the image from 2022 which had the least cloud cover, that is, less than 7% was used. This the image taken on 19th February, 2022. Two other Landsat 8 remote sensing images taken around the same time period were used to deduce the data which is lost due to cloud cover in image from February, 2022. The QA band for Landsat I image is used as a cloud removing mask, this is done using the graphical raster function in ArcGIS pro. Using this function the raster values in the QA file for areas which are under the cloud cover are assigned as no data values, for all the three data sets mentioned in Table 5. The raster clip function is used to clip the bands,3,4,5, 6 and 10 for all the three Landsat three images for Mombasa. The Mosaic function for raster images in ArcGIS pro is used to mosaic band for three images, that is, band 3 from February, 2019, band 3 from January, 2020 and Band 3 from February, 2022 are combined using mosaic function and likewise all the other bands are blended, except band 10. The mosaic band 3, band 4, band 5 and band 6 images are used to compute NDVI and NDBI and NDWI for Mombasa using methods described below. For Rajkot as there was no cloud cover in May, 2022 image there was no need to Mosaic the datasets. However in Rajkot as there is significant temperature difference the above stated indices were also computed for January, 2021 Landsat data.

To calculate NDVI and the proportion of vegetation (P_v) the following equations were used. Where NIR and RED are the near-infrared band and red band in Landsat images (band 5 and 4, respectively of Landsat 8 OLI/TIRS sensors), respectively. $NVDI_{min}$ is the minimum NDVI, and $NDVI_{max}$ is the maximum NDVI. NDVI value ranges between - 1 and + 1, and it enhances all vegetation and results in a positive value. Soil may have a near zero value, while waterbody features have negative values (John, Bindu, Srimuruganandam, Wadhwa, & Rajan, 2020).

Land surface emissivity is calculated using the following formula

$$LSE_i = \varepsilon_b \times (1 - P_v) + \varepsilon_v \times P_v + c$$

where εv and εb are the vegetation and soil emissivity values, respectively, i is the band number, and C represents the surface roughness (C = 0 for plain surfaces) taken as a constant value of 0.005. And ε_v and ε_b were taken as 0.987 and 0.971 for Landsat 8 band 10, respectively (Hussain & Karuppannan, 2021). The digital values arrived at are converted to radiance values using the following equation.

$$L_\lambda = M_L \times DN + A_L$$

where L_λ is the sensor's spectral radiance. M_L and A_L are the band constants, available in the header file of Landsat data. These radiance values are converted into brightness temperature using the following equation.

$$T_s = K_2/\ln\left[\frac{K_1}{L_\lambda} + 1\right]\text{-}273.15$$

where Ts is the brightness temperature value in Celsius, K_1 and K_2 are the conversions constants of thermal bands, available in the header file of Landsat data. The brightness temperature values are used to calculate the LST using the following formula.

$$LST = \frac{T_s}{1 + (\lambda T_s \sigma | hc) Ln(LSE)}$$

where λ is the wavelength of thermal bands, σ and h are the Boltzmann constant and Planck constant, respectively, c is the speed of light. The NDBI is calculated using the following formula.

For Mombasa, the three Landsat 8 images described in Table 3 were used to calculate the LST for all the three images for area which were not under the cloud or its shadow. Because the temperature on three days when the three images were captured were different, OLS regression was used to find relation between LST from February, 2019 and February 2022 images and January, 2020 and February, 2022. Location which are under could cover in the February, 2022 image but have now cloud in February 2019 are identified and for these locations the OLS regression equation is used to convert LST value from February, 2019 to February, 2022 and the likewise from January, 2020 to February 2022. This process has been explained in Figure below.

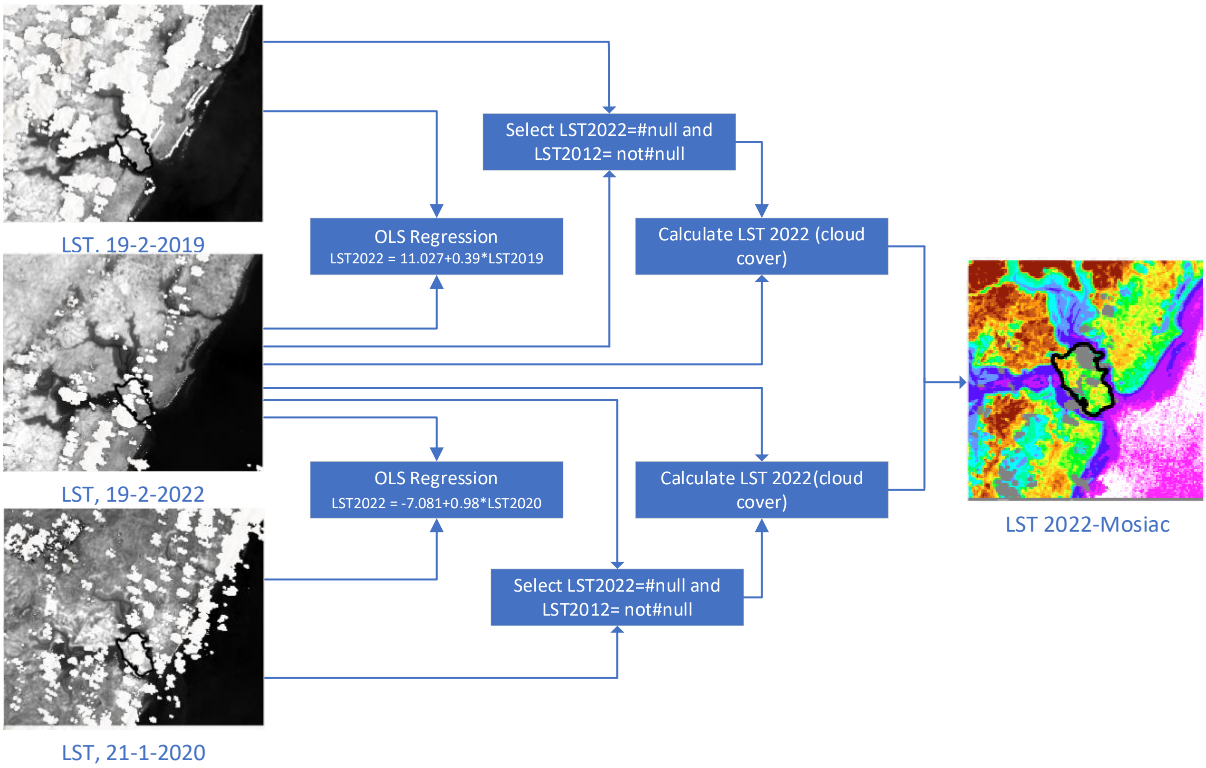


Figure A.4: LST calculation for area with could cover, Mombasa 2022

$$NDBI = \frac{(SWIR1 - NIR)}{(SWIR1 + NIR)}$$

Where SWIR is the short-wave infrared band (band 6 in Landsat 8 OLI/TIRS). The values of NDBI range from -1 to +1 where built-up areas tend to have higher positive values. Water bodies have negative NDBI values and values closer to zero NDBI values indicate areas with vegetation cover (Balew & Korme, 2020). NDWI is calculated using the following formula

$$NDWI = \frac{(Green - SWIR1)}{(Green + SWIR1)}$$

where Green is reflectance in the green band (band 3 for Landsat 8 OLI/TIRS). The result of the NDWI produces three results: in water with greater positive values and Built-up areas, soil and vegetation with negative values.

Figure is the conceptual framework showing how data is handled and analysed further. To understand the relationship between land use indices and urban temperature, The corelation between NDVI, NDBI, NDWI representing the different biophysical composition of urban areas is studies with LST.

The correlation between the land use indicators and urban heat indicator is studied using two spatial regression model forms the ordinary least square (OLS) regression and geographically weighted regression (GWR). The global regression model is a log-log OLS model; it takes the following form.

$$\log_e Yn = a + b\log_e x + b_1\log_e x_1 + b_2\log_e x_2 + \cdots .. + b_n\log_e x_n + \varepsilon$$

Where Y_n is the land value at location n and x_n is the vector of the nth explanatory variable. bn is the coefficient value, a is constant, and ε is the error term. To measure the degree of spatial autocorrelation between land values Moran'I value computed as described in (Diniz-Filho et al., 2016; Miralha & Kim, 2018). Non-zero values of Moran's I indicate that land values are more similar at a certain Euclidean distance.

In the global regression model the b_n value is constant for all places in the city. However, parameters may themselves be a function of geographic location and strength and the form of relationship can be different over space. For the GWR model the b_n varies across space and overcomes this limitation (A. Fotheringham, Brunsdon, & Charlton, 2002; A. S. Fotheringham, Brunsdon, & Charlton, 2003). Essentially it measures the linear regression at every data location with varying regression coefficients. ArcGIS® is used for GWR analysis, and the regression equation can be written as

$$\log_e Y_i = a_i + b_{i1}\log_e x_{i1} + b_{i2}\log_e x_{i2} \dots \dots \dots .. + b_{in}\log_e x_{in} + \varepsilon$$

where Y_i is the land value at the location being predicted, x_{in} is the vector of the nth explanatory variable at location i and b_{in} are the regression coefficient at location i for explanatory variable n. Thus the regression equation is for a specific location i in the city and is estimated by weighting all surrounding observation by the function of distance from location i. For the weighting matrix adaptive bi-square kernel, bi-square weighting scheme assigns a weight of one to the feature i and weights from the surrounding features smoothly and gradually decreases as the distance from regression feature increases, after a certain distance (threshold distance) the assigned weights will be virtually zero. The typical kernel function used in ArcGIS can be represented as (e.g. Bera, Mondal, Dolui, and Chakraborti (2018), Zhu (2016)).

$$W_{ij} = \left\{ \begin{matrix} \left[1 - \left(\frac{D_{ij}}{h_i}\right)^2\right]^2 & if\ D_{ij} \leq h_i \\ 0 & otherwise \end{matrix} \right\}$$

where W_{ij} is the observed weight given to the observation at point j for estimating the regression equation at the location i. D_{ij}denotes the distance from location i to sample point j, h_i is the bandwidth set to include p observation nearest to the location i.

AICc (Akaike's Information Criteria) is used to measure the performance of the model, the model with lower AICc value provides a better fit to the observed data and therefore, can be accepted. In addition to AICc, R2 and AdjR2 values are used to judge the goodness of fit.

A2 Results

In Figure 5 the results of NDVI for May 2022 and Mombasa for February 2022 are a shown. NDVI for Rajkot 2021 was also calculate as indicate earlier. Based on literature the land use can be classified from the NDVI values, where values below 0 are classified as water (as can be seen in blue colour in Figure . Values between 0 – 0.18 are classified as built up and open land the lower values (below 0.14) are mostly built up. In conditions like Rajkot and Mombasa it not very easy to distinguish barren land from built up areas as these have mixed signatures so they are difficult to distinguish. The darker shade of grey colour areas are built up in Figure and lighter shade of grey are open areas. NDVI values 0.18 - 0.27 and 0.27-0.36 are classified as shrubs/grass lands and sparse vegetation areas respectively and are shown as light green colour in Figure . The dark green colour locations are location with NDVI value higher than 0.36 and area and are dense vegetation areas.

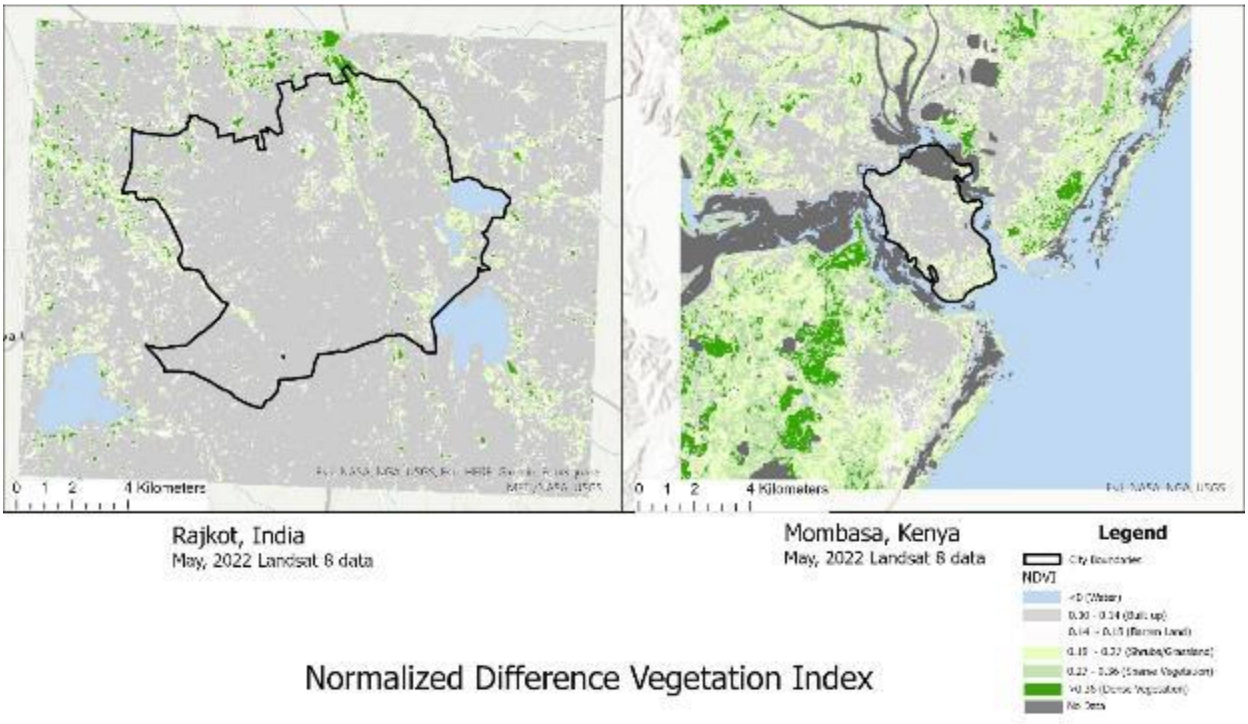


Figure A.5: NDVI Rajkot and Mombasa

Figure A6 the land surface temperature computed from the Landsat I data for the two images is shown. Wide variations in the LST were observed, the LST for the May, 2022 image varied in the range between 27.1^{o}C to 47.7^{o}C, with barren land in the peripheral location registering the highest temperature and temperature over water bodies was the lowest. There is also a good visual co-relation between the dense vegetation areas (Figure A 5) and LST temperatures.

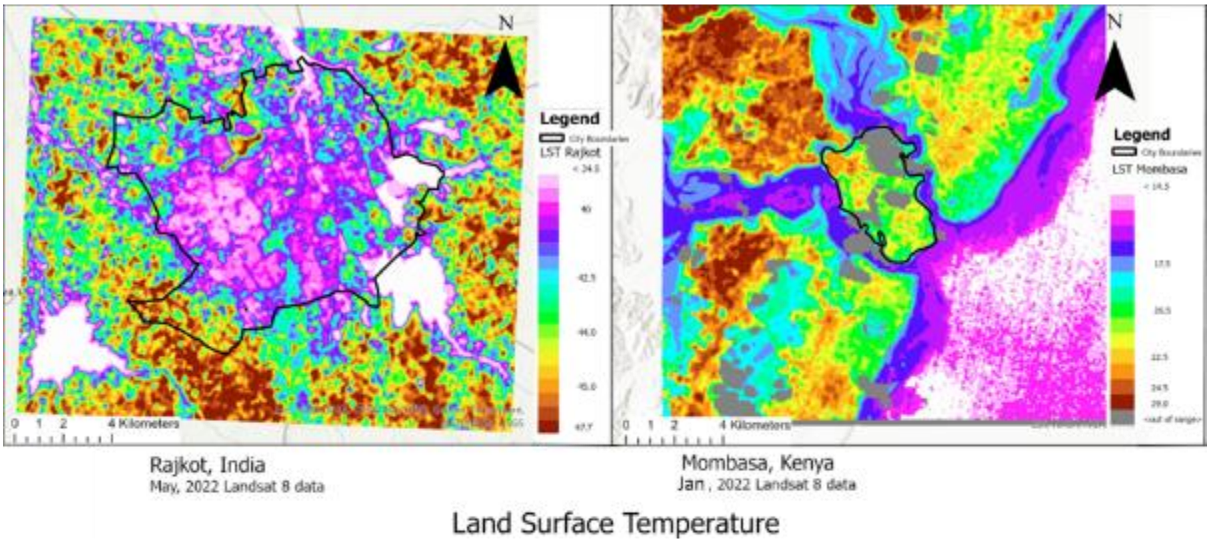


Figure A.6: Land Surface Temperature, Mombasa and Rajkot

Figure A7 has the NDBI values for both, Rajkot and Mombasa cities. In the value calculated for the Rajkot city, the built up, especially in the inner parts of the city does not have high positive values and seem ot smudge with water. However much clearer identification of built up from NDBI values can be done in Mombasa.

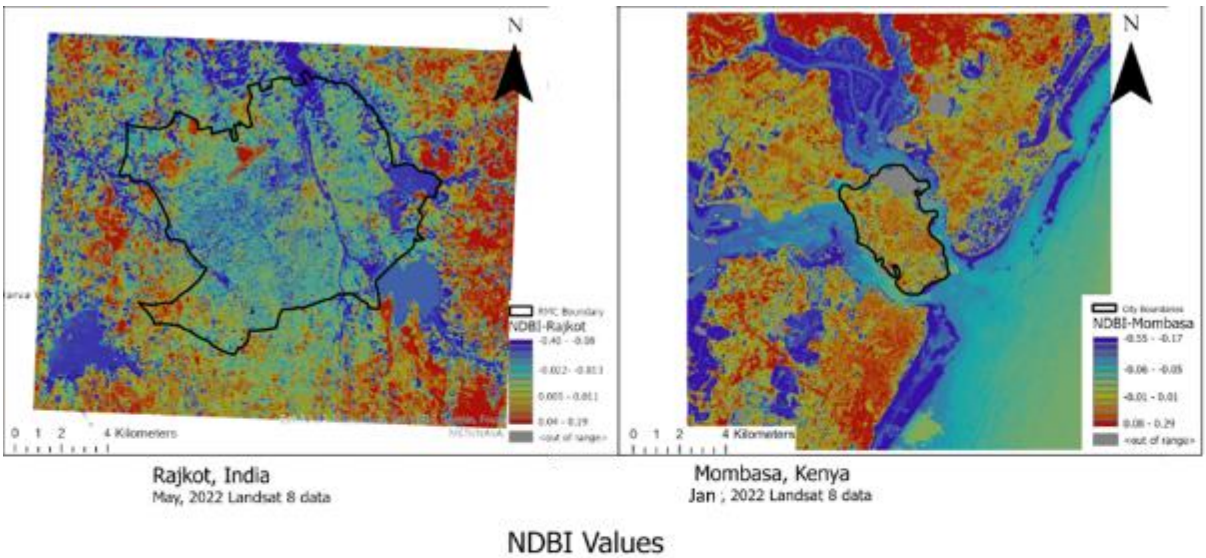


Figure A.7: NDBI values, Rajkot and Mombasa

Figure A8 has the NDWI values for both, Rajkot and Mombasa cities. The signatures vary for both cities, the water get clearly identified with values higher than 0. The built-up areas in Rajkot have close but zero negative values, shown as light blue colour in Figure A8, the open area are in light yellow colour. The built up in Mombasa has mixed signatures with open land and is show mostly at light yellow colour in Figure A8.

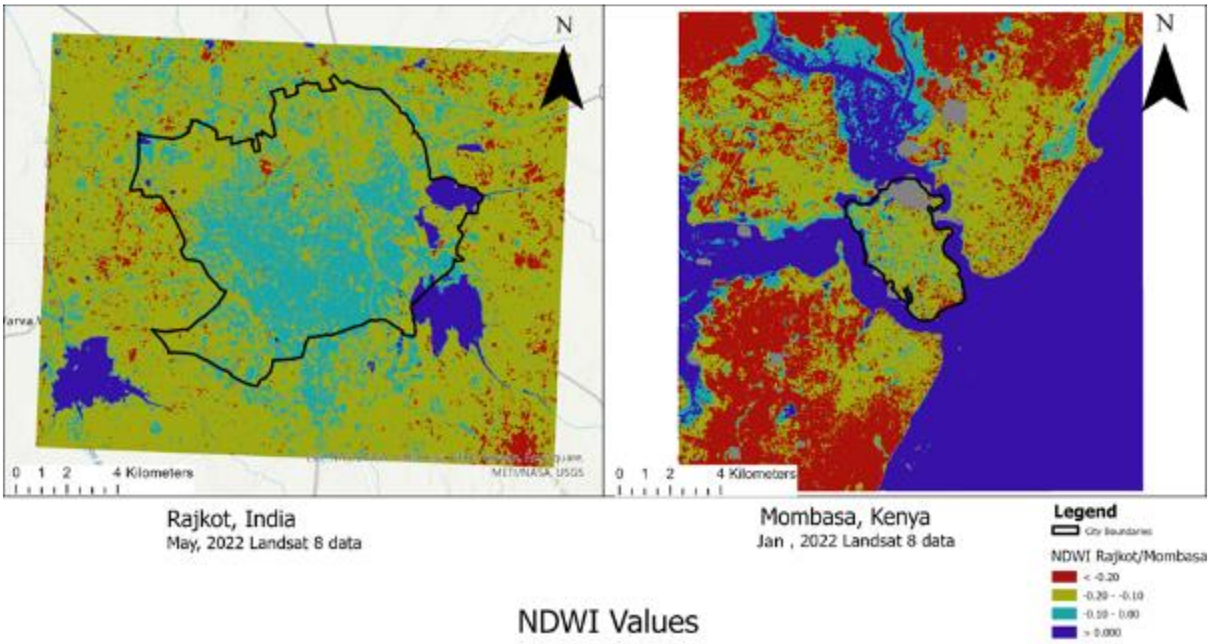


Figure A.8: NDWI values, Rajkot

A2.1 Spatial correlations

The Moran's I test shows spatial dependence exists in LST value (Moran's I = 0.838, P = 0.00, ZScore = 4225.23) for Rajkot and also for Mombasa (Moran's I = 0.840, P = 0.00, ZScore = 6251.59), the value indicate that the there is less than 1% chance that the clustering pattern is a result of a random choice in both cases.

Table 8: OLS Results

Variable	Coefficient [a]	StdError	t-Statistic	VIF [c]
Rajkot				
Intercept	41.1	0.0	2951.7	-----
NDWI	-21.6	0.3	-67.0	44.1
NDVI	-9.3	0.3	-29.1	15.7
NBDI	14.6	0.4	36.6	41.9
Number of Observations	353382	Akaike's Information Criterion (AICc)['d']		1459972.151
Multiple R-Squared['d']	0.40	Adjusted R-Squared['d']		0.40
Mombasa				
Intercept	18.4	0.0	4330.4	-----
NDWI	-11.9	0.05	-194.5	41.9
NDVI	3.5	0.06	53.2	15.7
NBDI	9.6	0.07	108.3	44.1
Number of Observations	356140	Akaike's Information Criterion (AICc)['d']		1394412.461
Multiple R-Squared['d']	0.79	Adjusted R-Squared['d']		0.79

The OLS results are presented in Table 7; the value of adjusted R2 is 0.40 for Rajkot and 0.79 for Mombasa, indicating that the regression equation explains 40 per cent of the variations in land surface temperature in Rajkot and 0.79 per cent of variation in Mombasa. The p-value of the entire equation is 0, indicating a high significance level of the equation. The VIF values for NDWI and NDBI in Mombasa and Rajkot are high, indicating the presence of very multicollinearity between three explanatory variables. Therefore, only NDVI is taken as a dependent variable for the GWR model.

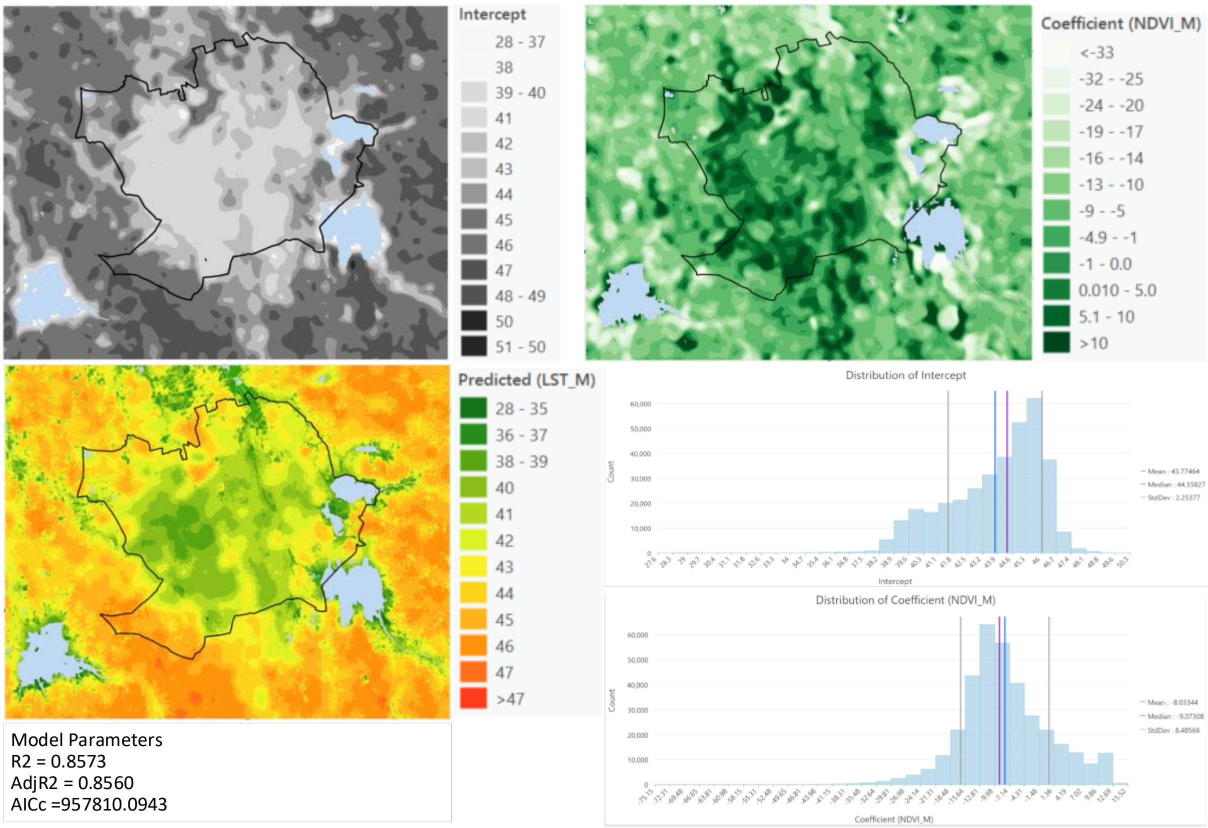


Figure A.9: GWR results Rajkot

Only NDVI was used as independent variables for the GWR model. In the final model (The location over water were excluded from the analysis and this could have skewed the relation). The results are presented in Figure A9. There is a significant improvement in the AICc values, and the adjusted R2 value also improves from 0.40 to 0.856. NDVI is an essential determinant of land surface temperature. The relation is a negative one and varies spatially. The coefficient values are low at the locations with higher LST, but the intercept values at this location is fairly high, and opposite is observed where the LST values were low.

All of these add up and link well with the urban design policies proposed by the government of Gujarat, which promote development of green areas in the cities. In the subsequent analysis we take a deep dive into the affect blue and green infrastructure have on temperature by looking at the actual ground realities using Google Earth images for Rajkot for the year 2022 and comparing it with the LST values calculated for both winter (January) and summer (may) periods.

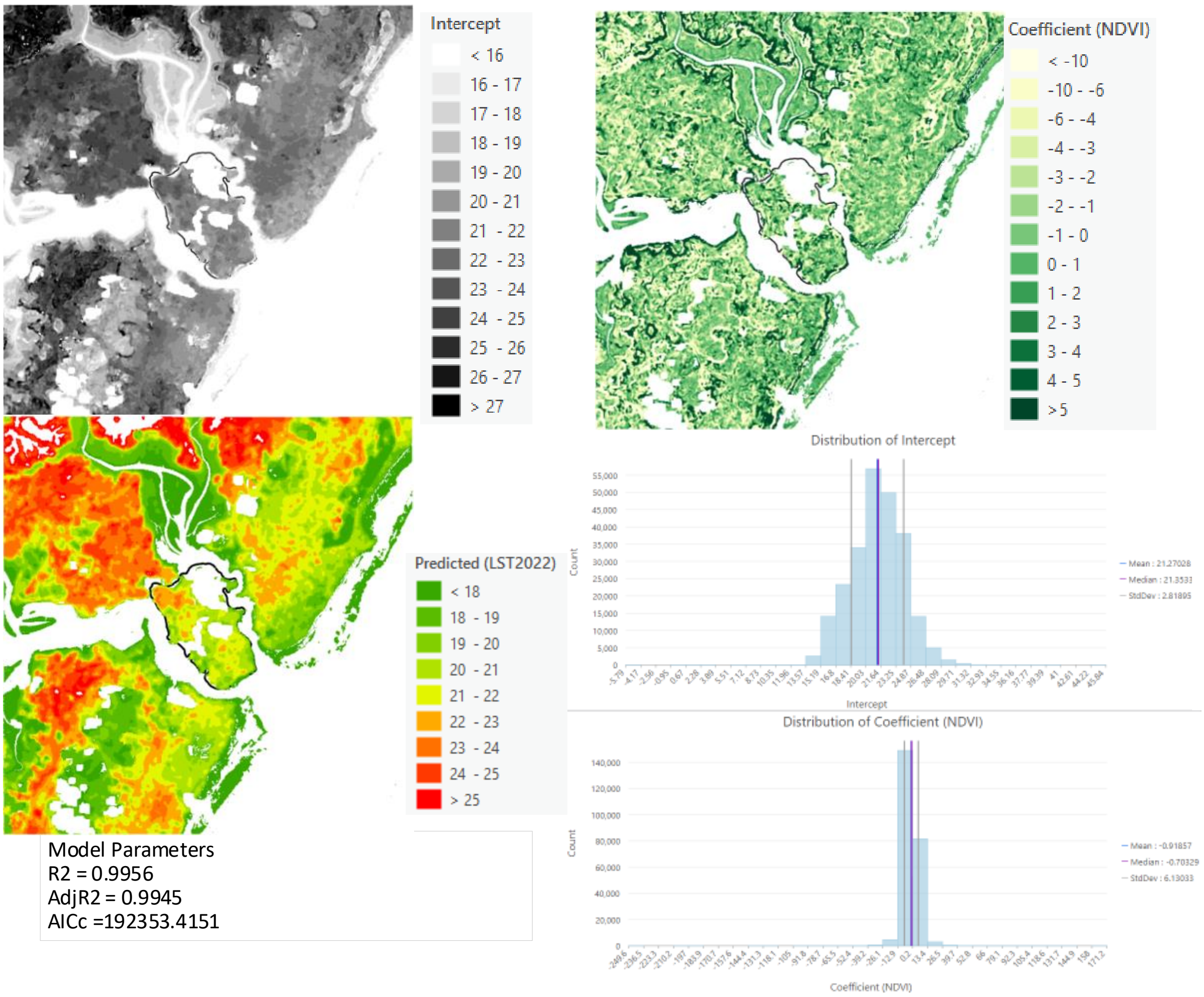


Figure A.10: GWR results Mombasa

In Figure A10, GWR results for Mombasa are presented (water in not included in this analysis). The predicted values are very close to the LST values from Landsat 8 band 10 data, which is also indicated by a very high R2 value which is very close to one. The spatial variations in the coefficient values of the dependent variable (NDVI) is more clustered around the mean when compared with Rajkot and more negative coefficient values are observed in the in land areas that is where high NDVI results in lower land surface temperature values. Along the cost the relationship is different, that is increase in NDVI value also results in higher land surface temperature, which the relation moisture (wet lands) has with LST.

4

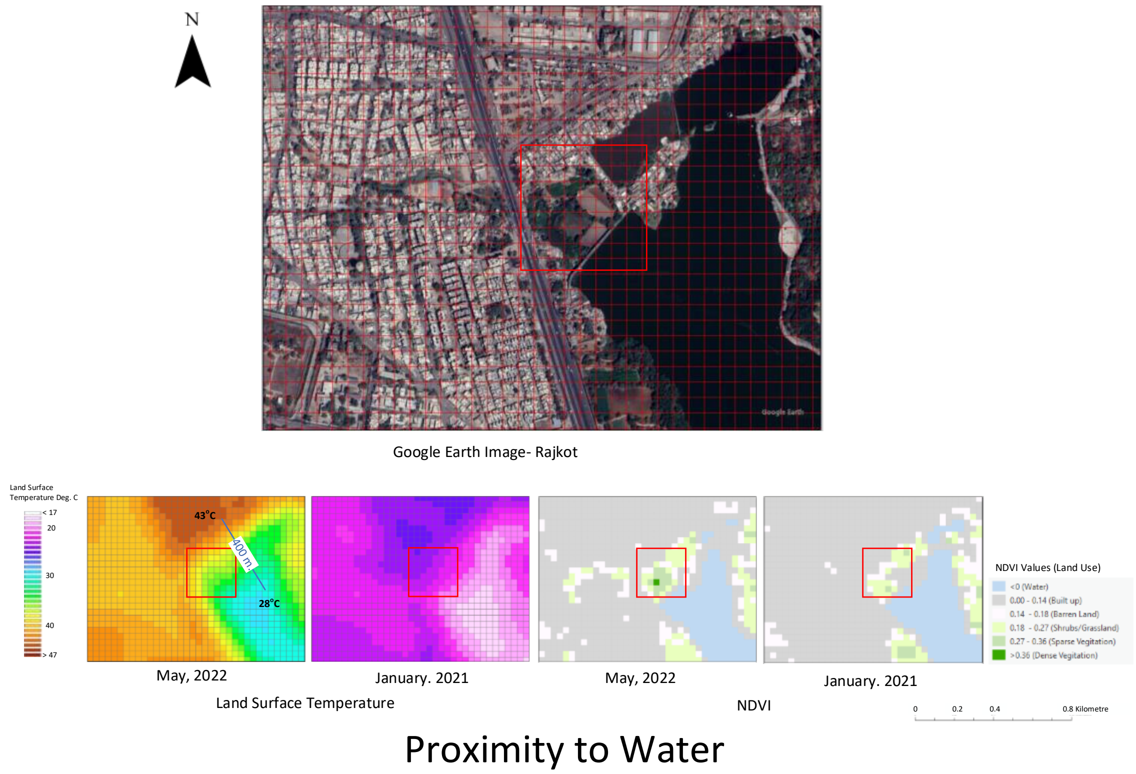


Figure A.11: Influence of proximity to water on LST

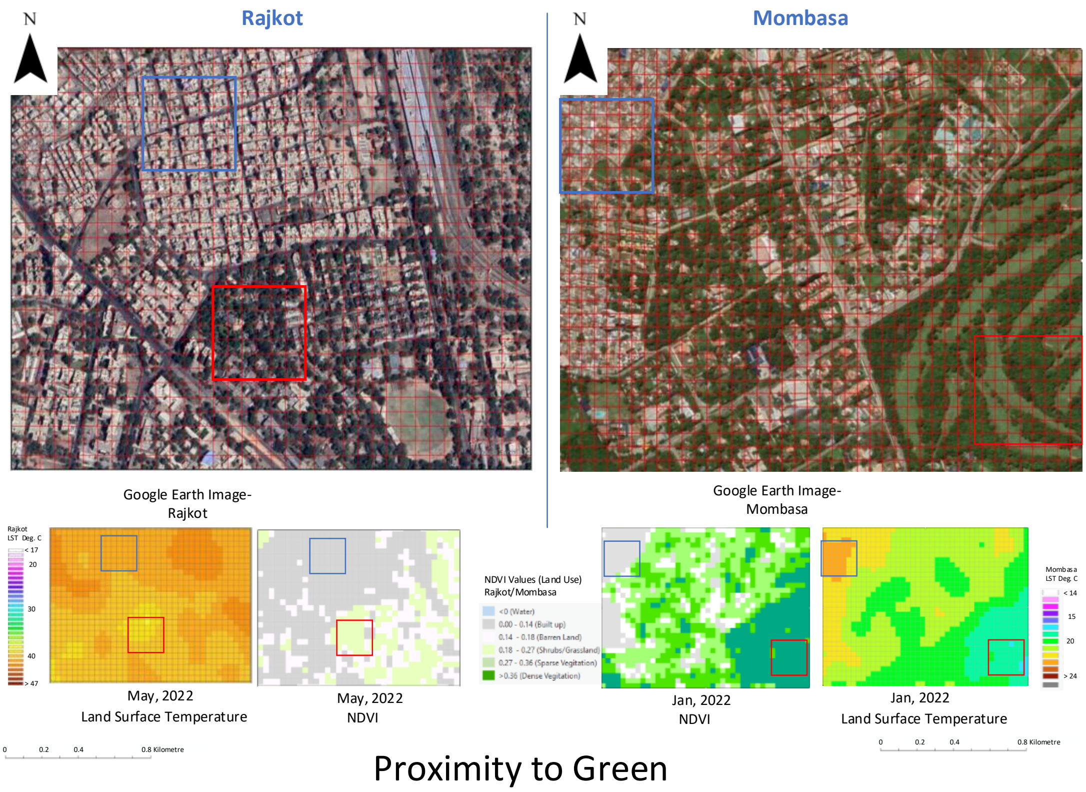


Figure A.12: Influence of proximity to Green on LST