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Master Thesis

Informal Settlements and Climate Change.
Strategies for adapting Hyderabad City to Heatwaves

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Vulnerability *is the systems physical,economic, social or political susceptibility to damage*

Hazard: *something that is potentially dangerous, e.g. climate and weather extremes.*

Exposure: *People and property are present in hazard zones.*

Climate Change*: Refers to significant, long-term changes mainly a consequence of human activities.*

Climate Adaptation: *the process of adjusting and preparing to face the impact of climate change.*

Climate Hazards*: Adverse events or conditions resulting from the change in climate patterns.*

UHI (Urban Heat Island Effect)*: Phenomena where Urban areas experience higher temperatures than rural areas.*

Heat Waves: *prolonged periods of excessive hot weather.*

Heat Hotspots: *Specific areas or locations with higher temperatures than surrounding areas.*

Climate Resilience: *the ability to recover from climate-related threats like floods, droughts, heat waves, etc.*

Climate Mitigation: *an attempt to lower the carbon into the atmosphere.*

Abbreviations:

IPCC: Intergovernmental Panel for Climate Change
UN-Habitat: United Nations Human Settlements Programme
GHMC: Greater Hyderabad Municipal Corporation
HMDA: Hyderabad Metropolitan Development Authority
HUDA: Hyderabad Urban Development Authority
PMAY: Pradhan Mantri Awas Yojana
JNNRUM: Jawaharlal Nehru Urban Renewal Mission

ABSTRACT

3.6 billion people live in highly vulnerable areas.informal settlements are increasing 10& every year globally.Adapting to climate change is the most challenging in the most vulnerable informal settlements in India due to rapid urbanisation and migration. Informal settlements are at high risk, and it is vital to identify and address the informal settlements that are more vulnerable to the effects of climate change. In informal settlements, residents are vulnerable to climatic events with limited infrastructure housing and adaptive capacity to cope. (UNISDR 2009, IPCC 2012, Revi et al., 2014)

The thesis explores the climate vulnerability of informal settlements in Hyderabad city. with a methodology to identify the most vulnerable informal settlements that are affected by heat waves. Investigating how informal settlements either contribute to or encounter climate change consequences. At the local scale in the Talab katta informal settlement, an attempt was made to analyse the heat profile. Based on the results, adaptive measures were proposed to upgrade green-blue infrastructure as one of the nature-based Solutions.

The thesis study offers practical insights for urban planning, neighbourhood scale and individual scale, investigating the Role of Green infrastructure adaptive measures in informal settlements to contribute to reaching the global Sustainable development goals for sustainable cities and communities.

Key Words: Informal settlements. Climate change, Heat Waves. Blue-Green Infrastructure, Adaptation

Chapter 0:Introduction

Research Questions

In the context of climate change, how do informal settlements either contribute to vulnerability or encounter vulnerability?

How Can Urban upgrading in informal settlements be specifically tailored to adapt to the challenges posed by climate change, considering the socioeconomic situation and environmental factors within these communities?

How to reduce the heat vulnerability of Charminar informal settlement? Can the Blue-green infrastructure approach be helpful and doable for these informal contexts?

Research Objectives

Understanding: The objective is to investigate current heat, Understand the Vulnerability of urban areas to the effect of climate change and identify the settlement that has to be addressed.
Analysing: Analysing the local scale heat profile.
Designing: Upgrading through Green-blue infrastructure.

Research Questions

What are the distinct climate challenges faced by Hyderabad city?
What are the major urban climate problems experienced by residents of informal settlements in Hyderabad?
Is there a discernible correlation between Urban Heat Island (UHI) effects and the location of informal settlements in Hyderabad?
Which informal settlements in Hyderabad are most vulnerable to climate hazards, particularly heat waves?
Why is Green Upgrading essential in mitigating climate hazards like heat waves in informal settlements?

Methodology Framework

The methodology involves a comprehensive approach to upgrading informal settlements in response to climate change, with a focus on heat vulnerability in Talab Katta, Hyderabad. The literature review discusses upgrading climate vulnerability in informal settlements such as heat waves. It employs a multi-step framework, including the Urban Heat Island Profile, to pinpoint vulnerable settlements, heat hotspot mapping, and guiding interventions during heat waves. GIS techniques are employed to map vulnerability, correlating slum distribution with thermal hotspots. A direct geographical survey, with interviews with local municipal planners, supplements data collection onward population and slum residents. The study further includes a heat simulation and investigates Blue-green infrastructure to address climate challenges.

Chapter 1: Introduction: Informal Settlements & Slums

Introduction

Chapter One The Literature review explores the issues surrounding informal settlements, understanding their Characteristics, their worldwide occurrence, and their formation causes. It explores the concept of upgradation globally, highlighting the role of streets in the upgrading process. The literature review also highlights informal settlements' vulnerability to climate change, connections to blue-green infrastructure, and specific challenges related to extreme heat, particularly in urban settings and southeast Asia.

1.1 Informal settlements or slums?

Slums and squatter settlements, commonly called informal settlements, exist in many urban areas of low and middle-income nations (Satterthwaite et al., 2020).@(Tuts & Bulkeley, 2013). Slums, impoverished residential areas, and informal settlements are widespread worldwide (UN-Habitat, 2015). Under various names, they can be found in urban environments worldwide (slums, favelas, tandas, squatter settlements, bidonvilles). Settlements outside the official legal and regulatory frameworks are known as informal settlements. These frameworks include those that record land ownership and tenure and govern planning, land use, building codes, and health and safety. These may be legally divided into formal housing units or homes constructed without government or local municipality permission. (Srinivas, 2015)

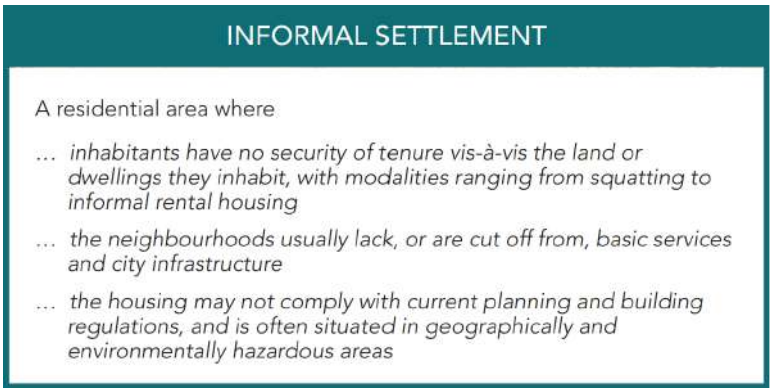


Figure 1: Defining an informal settlement by UN-Habitat (2015)

According to UN-Habitat (2015), slums suffer a severe and damaging lack of basic services and are removed from consideration in informal settlements, often in hazardous areas. In addition to the mentioned characteristics of informal settlements, Slums are areas characterised by a lack of quality and durable housing structures, insufficient living space, limited access to safe and affordable water, and inadequate sanitation facilities. People who live in slums are always at risk of diseases, violence, and forced eviction. The government of India also declared that the slums were considered illegal, and there was no need to put effort or workforce into cleaning them up (Aggarwal S, 2003). Mike Davis, in his book Planet of Slums, talks about “landlordism“. Certain neighbourhood organisations have positively used the term "slum" to counteract its negative connotations. In some countries, recognising informal settlements as "slums" grants access to basic services.(Suomela, 2019). The terms "slums" and "informal settlements" are often used interchangeably in this thesis study. (Núñez Collado & Wang, 2020).

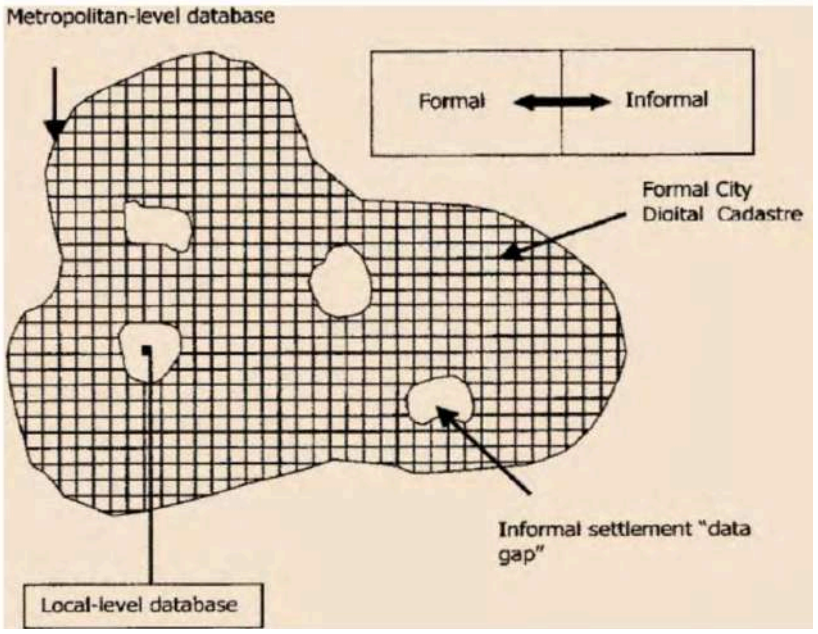


Figure 2: Image displaying informal settlements as ‘holes’ in the formal city
Source: Abbott, J. (2002)

1.1.2 Informal Settlements Global Stats

According to UN-Habitat (2013), approximately a quarter of the world’s urban population lives in slums. The slum population has increased from 894.9 million to 1.06 billion, indicating a rise of 18.4%. Sub-Saharan Africa has experienced the most

significant increase, with the total number of slum dwellers rising from 130 million to 230 million, i.e., 77.0%. Central Asia and Southern Asia follow closely, with the number of slum dwellers increasing from 250 million to 359 million, i.e., an increase of 43.6%. Similarly, In Oceania.

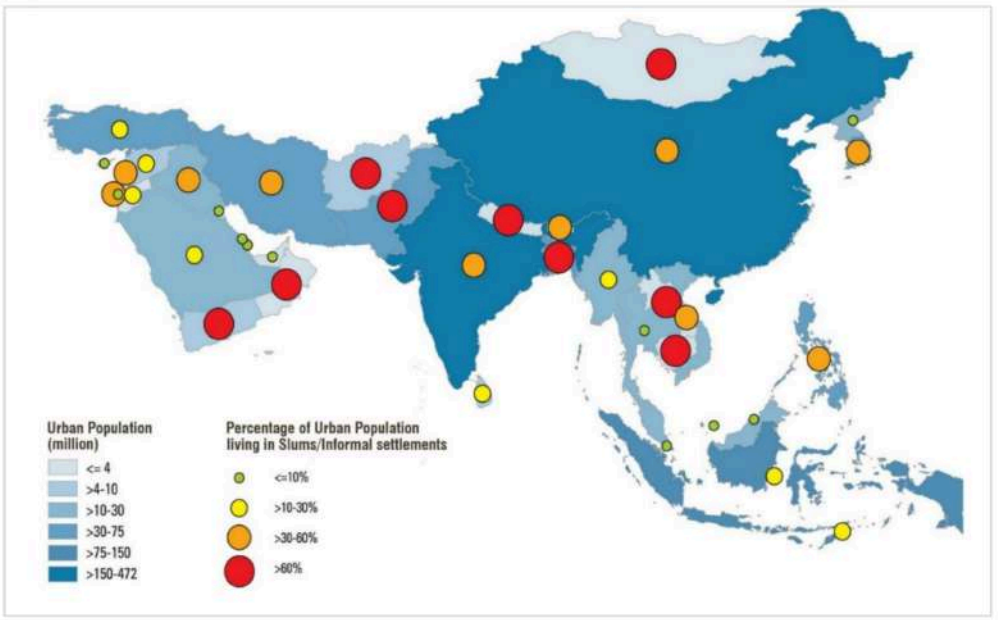


Figure 3: The presence of Informal settlements in the Global South (Source: UN-Habitat)

UN's Millennium Development Goals (2015) aimed to better the lives of hundreds of millions of slum dwellers. However, due to poor physical conditions and informal status, these settlements face environmental, political, and social issues (Malusardi & Occhipinti, 2003). The percentage of families in such slums is increasing globally (UnHabitat, 2005).

1.1.3 Why informal settlements exist:

Geographical location significantly influences informal settlements. The address is more important than how the houses look. It has been observed worldwide that when residents are relocated to a new location with adequate housing and basic services (Upgrading), they frequently sell or rent out their existing homes and return to informal settlements. The government's solution typically involves uprooting "slum dwellers" from their social and economic ties and placing them in the city's periphery. The alternative is frequently apartment towers, which are not flexible enough to grow and adapt to changing needs by design. These settlements allow their residents to

improve their financial circumstances by offering them living and work opportunities and rental income.

Informal Settlements offer rental stays or affordable land for self-build homes informally. This helps the dwellers who cannot afford formal housing due to their Socioeconomic situation. This helps them to stay hopeful about the working conditions, better living conditions, and being a part of a wider urban environment. In most South Asian developing countries, they settle down near vacant lands, dried-out water ponds, railway buffer zones, and unused govt lands inside the urban setting. (Ehebrecht, 2014)

1.1.4 Characteristics of Informal Settlements

Kanpur, India. Photo: B. Banerjee

Tongi, Bangladesh. Photo: B. Banerjee

Figure 4: Typical Street Views in Informal Settlements

Some settlements are built using corrugated metal, wood, and other light materials, creating shacks. On the other hand, other settlements are more consolidated and consist of permanent buildings made of brick and mortar or both.. Social problems and criminal activities such as mugging and other illegal gang activity are prevalent in many informal settlements. These problems are often linked to physical conditions such as small pathways or the inability to secure a shack. Indeed, the physical conditions, environmental impacts, and potential social problems such as crime, diseases, and poverty can threaten the residents and society. Settlements can take on different forms and structures depending on the material used in their construction. (Ehebrecht, 2014).

1.1.5 Criteria for Identifying Characteristics of Informal Settlements

Identifying informal settlements is crucial for understanding urban dynamics and addressing the challenges associated with unplanned and marginalised communities. The absence of proper building facades, single-storey structures, and organic geometrical shapes further distinguish these settlements.

Flooded settlement, Gonaives, Haiti. Photo: Marco Dormino

Kibera, Nairobi, Kenya. Photo: Julius Mwelu UN-Habitat

Flooded creek: Manaus, Brazil. Photo: B. Banerjee

Santo Domingo, Dominican Republic. Photo: M Guthrie

Favela Morro do Alemao, Rio de Janeiro, Brazil. Photo: Adrienne Acioly

Slums roofs Dar es Salaam, Tanzania. Photo: UN-Habitat

Figure 5: Types of Informal Settlements. Source: Multiple sources with photo credits

Informal Settlements can be classified globally according to their specific challenges and geographical locations. **Urban informal settlements** are common in cities and are characterised by poor infrastructure, overcrowding, and a lack of services. Slums

in rural or peri-urban areas are characterised by poor housing conditions and deficient basic amenities. Poor sanitation and flooding are problems that **coastal informal settlements** face, particularly in areas that are vulnerable to natural disasters. **Informal settlements on hillsides** or mountains have challenges because of their topography, whereas **industrial settlements** form around factories and expose people to dangers and pollution. Conflict-affected areas give rise to post-conflict or refugee slums, which pose challenges for social integration and temporary housing. Transit informal settlements around transit hubs or construction sites are characterised as fragile and unstable social areas serving temporary housing for short-term populations**.**

Typically found in poor urban lowlands near problematic utilities, informal settlements often lack official title deeds and municipal permits, reflecting their illegal nature. It is essential to know how the informal settlements are at a particular location. Each informal settlement has its specific situational problems, and understanding their core characteristics helps to understand and work towards improvement.

Table 1: Criteria to identify characteristics of informal settlement
source: Ghasempour, A. (2015)

Criteria	Description
Lack of Services and Facilities	Informal settlements lack essential welfare services and facilities, with a dominant focus on residential use and significantly lower service provision than urban areas.
Slum Areas	Slum areas are generally smaller than in other city areas.
Occupied Area	The occupied area within lots is higher than standard, resulting in limited open space in residential units.
Building Quality	Buildings in informal settlements often have severe wear and tear, characterised by low construction quality and a relatively short lifespan.
Building Facade	Buildings in these settlements commonly lack proper facades.

Number of Storeys	Residential houses are mainly single-storey due to residents' poverty, materials used, and unconventional construction methods.
Geometrical Shape of Parts	Houses in informal settlements form organically without pre-planned geometrical order, influenced by each family's ability to occupy land and the characteristics of the natural terrain.
Formation in Poor Urban Lowlands	Informal settlements often emerge in lands near troublesome utilities, suffering from environmental problems, and are considered potential locations for attracting informal settlers.
Ownership	Areas with informal settlements typically lack official title deeds; residents usually possess lands and homes through informal, illegal means.
Municipal Permit	Informal settlements lack municipal permits for construction, emphasising their illegal nature, and buildings are often constructed without proper authorisation.

The growth of informal settlements has become a major obstacle to urban development in developing nations. Over the past few decades, scholars and institutions at the international and national levels have focused on the issues posed by informal settlements. After researching this subject, it has been established that upgrading these settlements is closely linked with various factors, such as the participation of inhabitants in decision-making, the capacity of local governments, and the availability of resources. (Malusardi & Occhipinti, 2003).

1.1.6 What are the causes and effects Its Causes & Effects

Table 2 is an attempt to understand the issues that are faced in informal settlements. What are the causes for these issues, and how are they affected in the built environment? For most of the issues, the governmental (municipality level) point of action is higher than the individual level to reduce the problems of informal dwellers. An attempt to understand how individuals and governments contribute to improving the living conditions of slum dwellers by examining policy frameworks, urban planning strategies, and infrastructure development initiatives. The vulnerable often depend on the government due to their economic conditions. In most cases, the government focuses on the developed areas. It

ignores the management of roads, sewerage lines, waste and other Climate Hazards such as heat waves and floods in urban Profile.

Table 2: Causes & Effects of a typical informal settelements
Source: Authors Illustration

Issues	Type	Point of Action	Causes	Effects	Measures
Road Layout Lanes & streets	All Year	Govt	Rapid urbanisation, encroachment, lack of planning	Accessibility issues, congestion, hindrance to services, transportation	The government for planning and infrastructure, individuals for adherence to regulations
Drains/Nalas Drain to every house (Source & exit)	All Year	Govt	Poor waste management, inadequate drainage systems	Flooding, waterborne diseases, environmental degradation	Government for drainage planning and waste management; individuals for waste disposal awareness
Lighting Power Supply	All Year	Govt	Limited electricity access, lack of infrastructure, safety concerns	Increased crime, reduced safety, limited nighttime activities	Government for street lighting, individuals for community safety initiatives
Civic Landscape Tree Cover Hardscape Footpath Pavements	All Year	Govt	Limited public spaces, lack of parks, inadequate waste facilities	Heat Capture Poor aesthetics, limited recreation, compromised environmental quality	The mix of government for urban planning and individuals for community initiatives
Water Supply To every house	All Year	Govt	Limited access, inadequate sanitation, contamination issues	Waterborne diseases, hygiene issues, environmental pollution	Government for water infrastructure, individuals for water conservation
Building Materials Type of material used	All Year	Mix	Limited resources, financial constraints	Unsafe structures, vulnerability to disasters, lack of durability	The mix of government regulations for building standards, individuals for safe construction practices

Construction Type/Age Type of material used	All Year	Mix	Makeshift or poorly constructed houses	Vulnerability to collapse, inadequate shelter, perpetuation of poverty	Government for housing policies, individuals for responsible construction
Heat Stress No shading High density Less green infrastructure Less blue infrastructure	Seasonal	Mix	Overcrowding, lack of green spaces	Sunstroke Health risks due to extreme temperatures, discomfort	Mix of government for urban planning, individuals for green initiatives
Water Stress	Seasonal	Mix	Limited access to water resources, conflicts	Water scarcity, conflicts, challenges in hygiene and sanitation	Government for water resource management, individuals for water conservation

1.2 Informal Settlements Upgrading

Upgrading informal settlements is an important step toward meeting the basic needs of the most vulnerable urban populations. It is profoundly needed to protect the rights, livelihoods, health, and safety of the residents of informal settlements. The progressive upgrading of an existing informal settlement through intervention by the municipality and/or any other state organisations to create a habitable living environment.

1.2.1. Why upgrade informal settlements

When Upgrading informal settlements in situ, several factors come into play, including the physical conditions of the settlement, the economic and social environment, the level of community organisation, and the type and legality of land. Certain conditions can either enhance or hinder the potential(UN-Habitat, 2003).

Many vulnerable urban dwellers have no other option than to live in informal areas, which already house a sizable portion of the world's urban population, despite the belief that these areas burden society and cause endless issues and conflicts. Despite underestimated and underused capacities due to their illegal status, informal

settlements carry multiple values not only in terms of their socio-economic values but also in terms of the benefits and advantages they get by living in these areas. These make it worth improving the informal urban areas where a big segment of the urban population lives and will live in the future rather than trying to remove them(UN-Habitat,2003).

Table 3: Disadvantages & Advantages of approaches to upgrading informal settlements
Source: Author illustration

	Evacuation by force	**Clearance & Relocation**	**Clearance and site development**	**Upgrading in place**
Disadvantages	Displacements of families without replacement	People do not find jobs in the new location They return back to the city	Time-consuming.	More efforts need to be taken together
Advantages	None	None	The environment becomes suitable for living	Maintain Social ties. Providing basic services

1.2.2. Informal settlements global progress

In the 19th century, slum removal involved demolishing the existing slums and replacing them with public housing (UN-Habitat,2003). After WWII(World War II), informal settlements in rapidly growing cities in the global south expanded quickly. They were considered unhealthy and unsafe and lacked good living conditions compared to formal settlements. This resulted in slum dwellers being relocated to segregated developments on the outskirts of society(Huchzermeyer,2002). National policies on informal settlements have moved from a negative approach to the right approach. Governments now promote in-situ upgrading, enabling and ownership policies. However, forced evictions and resettlements still occur in poor developing countries. (UN-Habitat,2003)

Informal settlements have led to innovative solutions for improving living conditions. Appropriate upgrading policies have made them more socially cohesive, providing opportunities for secure land tenure, local economic development, and income improvements. Mentioned in the challenges of slum residents in a global report on

informal settlements in 2003. Dharavi in India is the best example of this situation. (UN-Habitat,2003)

Over time, the approach to informal settlement upgrading has shifted from in-situ upgradation to looking for solutions to the housing market crisis to meet the demand for housing Each policy intervention depends on many factors, so it must be contextually tailored (Khalifa, 2015).

Streets as a Concept for Upgradation in Informal Settlements

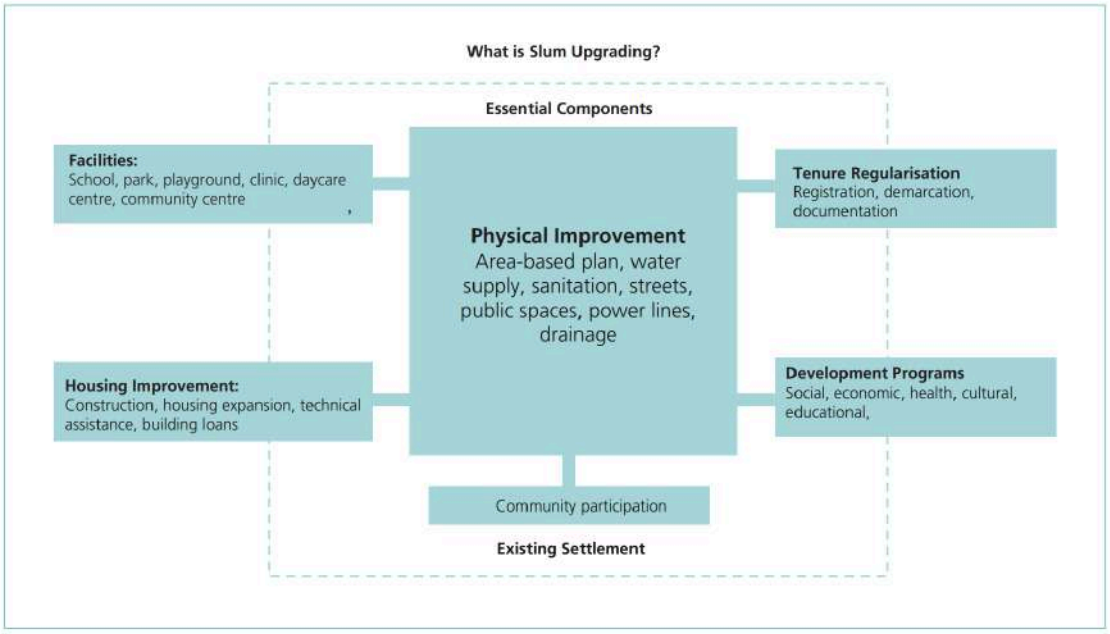


Figure 6: Slum Upgradation Main Components
Source: UN-Habitat. (2014)

Informal commerce, such as hawking and vending, small-scale manufacturing, repairs, garbage recycling, and cultural activities like processions, celebrations, and performances, all take place on the streets (Waller, 2017). Children often play, and residents have informal interactions in the streets of slums. Due to the small size of their houses, the streets frequently serve as outdoor extensions of living spaces where people wash, cook, socialise, and even sleep. As a result, the boundaries between public and private spaces get blurred through use. The safety of a slum is often closely tied to the

safety of its streets. Regular civic activities, like policing and garbage collection, can be seen as a sign of recognition for the community. Improving the conditions of slum streets is a powerful symbol of inclusivity and citizenship, which can encourage household investment even without legal tenure. Streets also play a critical role in rescue and relief operations, as slums are often prone to fires, floods, and landslides due to their vulnerable location, high density, and flammable construction materials. With the increasing frequency of extreme weather events caused by climate change, such disasters are likely to become even more frequent. That is why it is crucial to include disaster management in any street upgrades. (UN-Habitat, 2014)

A programme for upgrading slums is not simply a series of technical tasks to be carried out in isolation. Rather, it is a holistic and integrated intervention designed to enhance the physical attributes of a neighbourhood, as well as the quality of life of its residents (Bolay, 2011).

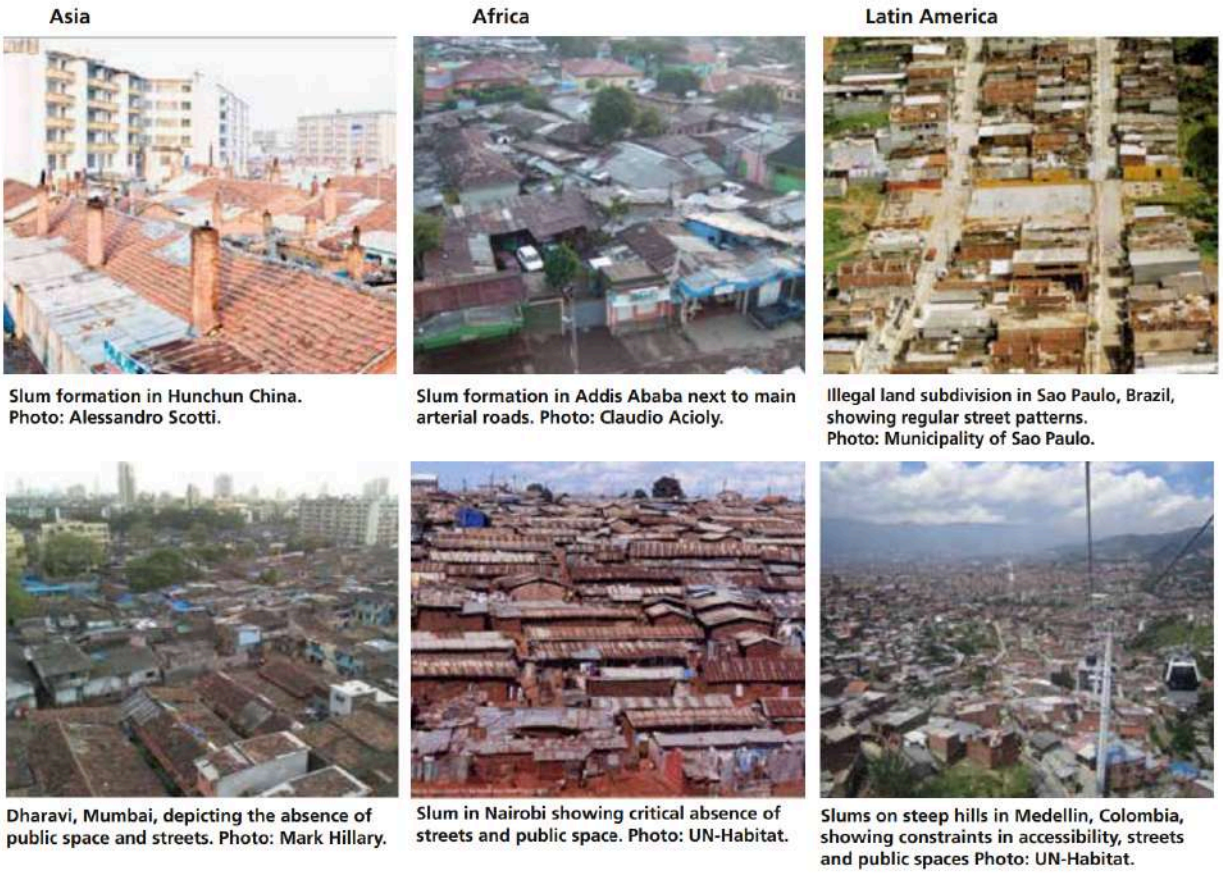


Figure 7: Informal settlements formation with streets in Asia, Africa, and Latin America
Source: Multiple Websites with Photo Credits

UN-Habitat recommends using streets as a means to naturally connect slums with the city, consequently promoting citywide slum upgrading. Streets play a crucial role in enhancing the quality of life in slums, particularly in densely populated settlements where the lack of streets results in various issues for both slum residents and the city in general. Opening new streets or improving existing ones is crucial, and these should be considered non-negotiable (Nzau, 2020).

1.3 Informal Settlements and Their Vulnerability to Climate Change

Rising global temperatures contribute to heatwaves, disproportionately affecting informal settlements where limited green spaces and inadequate housing infrastructure intensify heat-related health risks. Moreover, climate change can exacerbate water scarcity, leading to challenges in securing clean water for daily needs in these settlements. Flooding, a common consequence of climate change, poses a significant threat to informal settlements built in flood-prone areas, risking the loss of homes and belongings. The socio-economic factors intertwined with informal settlements, such as poverty and limited access to resources, further compound the challenges of climate change adaptation and resilience.

Strong evidence exists that urban environments modify local microclimates, with regional and global climate change implications. Urban systems affect various climate attributes, including temperature, rainfall intensity and frequency, winter precipitation (snowfall), and flooding. (Qian, Y, 2022)

1.3.1 Climate Hazards & Informal Settlements

Climate Change amplifies humanitarian emergencies like heat waves, wildfires, floods, storms and hurricanes.3.6 billion people live in highly vulnerable areas.informal settlements are increasing by 10% every year, making it vital to comprehend their risks, costs and potential, particularly with climate change environmental threats(UN-Habitat 2010/2011)

“Cities hold major populations, large portions of built assets and economic activities but are blighted by informal settlements. Most informal settlements are located on land at high risk from extreme weather, where the concentration of most health risks

and vulnerability to climate change for the slum dwellers they host" (Satterthwaite, 2007; Revi et al.,2008).

The Intergovernmental Panel on Climate Change assessments have shown that the climate is changing rapidly. As a result, we can expect to see higher sea levels, more frequent heatwaves, intense storms, heavy precipitation events, and the expansion of drought areas. Unfortunately, these climate hazards can profoundly impact human settlements, leading to significant loss of life, social disruption and economic hardship.IPCC, 2007).

The IPCC (2012) highlights informal settlements as one of the most risky elements of cities, mainly due to their location in perilous zones. For instance, informal settlements along low-elevation zones risk losses from rising sea levels that cause coastal inundation and erosion and extreme coastal events such as cyclones and storm surges. Inland areas, those on steep, unstable slopes, such as hillsides or dumpsites, are at risk of landslides from heavy and prolonged rains. Excess precipitation also poses a risk of flooding to slums along riparian zones and flood plains. Urban environments significantly impact local microclimates, which can have regional and global implications for climate change. Urban systems affect various climate attributes, such as temperature, rainfall intensity and frequency, winter precipitation, flooding, and thermal stress. Informal settlements are particularly vulnerable to urban flooding, heat island effects, air pollution, and water scarcity. Urban climate change risks are rising, warns the Intergovernmental Panel on Climate Change. Those living in inadequate areas are at higher risk of harm. (IPCC, 2014).

Informal settlements are vulnerable to climate change due to their physical exposure to hazards, but other non-physical factors also significantly impact their resilience. These factors include social, economic, and institutional dimensions, which are important in shaping their overall vulnerability. (IPCC, 2014). The IPCC(2014) has highlighted the need for increased resilience to achieve sustainable development by assessing urban vulnerability to natural hazards. (Godschalk, D R 2003)

Informal Residents are excluded from legal risk reduction processes as they are considered illegal occupants by the local government and ignored by politicians. (McKean, 2009). This situation can lead to the accumulation of risk and potential collapse of livelihoods for those who reside in informal settlements. Along with worsening living conditions and greater exposure to environmental hazards, the population residing in informal settlements may eventually decrease. These people

are especially susceptible to the detrimental effects of environmental change and the global climate and are frequently victims of inequality.(Agbor, 2013; Nenweli, 2015).

1.3.2 impact of climate change on Urban Populations Living in informal settlements

Table 4 provides a basic understanding of how it affects and impacts the population of slum dwellers residing in urban environments. Middle and low-income nations face the most extreme climate disaster deaths(UNISDR 2009).In informal settlements, residents are vulnerable to climatic events with limited infrastructure housing and limited adaptive capacity to cope(UNISDR 2009, IPCC 2012, Revi et al., 2014).

Table 4: Table showing how climate change could affect people living in informal settlements in urban areas

Likely impacts from climate change on informal settlements		
Projected changes	**Examples of likely impacts**	**Implications for residents of informal settlements**
Higher (and increasing) average temperatures,	Rise in mortality and illness from heat stress. Extended range and activity of some disease vectors	Density, little open/public space and often, iron roofs and poor ventilation lead to higher indoor temperatures. Lack of public health measures.
More intense precipitation events and riverine floods	Increased flood, landslide, avalanche and mud-slide damage resulting in injury and loss of life & property	risk of flooding with poor quality housing less able to withstand flooding lack of risk-reducing infrastructure.
Wind storms with higher wind speeds	damage to buildings, power and telephone lines and other urban infrastructure	increases in wind speeds can damage buildings, informal utility services are likely to be damaged or cut
Increased summer drying and associated risk of drought	Decreased water resource quantity and quality; soil quality; increased risk of fire; decreased crop yields and higher food prices	Informal settlement residents usually facing more water constraints and are more vulnerable to food and water price rises.
Sea-level rise	Coastal erosion, land loss, more floods from storm surges;	settlements close to the sea with poor housing and lacking infrastructure

Source: UN-Habitat pro-poor climate action for informal settlements,2018

Possible measures to adapt (Dr David Dodman,2018) for higher average temperatures Improved building design, setting up locally accessible health services, providing education, Investing in green space. In 2012, Douglas published a report suggesting that the lack of proper sanitation, inadequate waste water drainage,

improper garbage disposal, and poorly drained landscapes contribute to the spread of diseases such as diarrhoea and malaria among low-income residents. The situation is expected to worsen with the increase in climate variability, which includes rising temperatures and altered rainfall patterns. (Dodman, Kibona &Kiluma,2011).

1.3.3 Climate Change & Health in Informal Built Environment

The rapid rate of urbanisation and the increasing number of environmental, economic, and social problems will harm health and well-being in cities (Lawrence, 1999). Slum dwellings have no ventilation or natural light and are vulnerable to heat. Urbanisation has increased disease-producing agents, for example, toxic chemicals and car exhaust fumes. Also, Few slums do not have access to clean water and sanitation services (Mehta, 1992).

The World Health Organization (WHO) stresses that climate change significantly impacts human health, leading to a rise in death rates during natural disasters and heat waves. Developing countries like India have very little infrastructure and are exposed to vulnerability. These countries need to seek learnings from European countries that are effective in preparedness and response(WHO, 2023).

The combination of environmental and social factors increases the vulnerability of people living in informal settlements to heat waves. These communities often do not have the resources to access alternative water sources or take protective measures against extreme heat. Additionally, they may lack knowledge about the risks of heat waves and a lack of early warning systems and suitable adaptive measures to help them cope with their challenges. (Noah, 2018).

1.3.4 Connections between Informal Settlements & Blue-Green Infrastructure

Due to high density, narrow streets, and almost no green cover, the living environment becomes very toxic, adding to the existing problems of informal settlements and leading to heat capture. The lack of open spaces in crowded informal settlements often means few public areas can provide respite from high temperatures within homes.(Scott AA et al., 2017)

The issue of environmental sustainability, particularly regarding green infrastructure, is not receiving adequate attention from state and non-state entities in various

low-income informal regions. Ecological infrastructure, which can be comprised of natural or semi-natural systems, can effectively fulfil the infrastructure demands of these areas. The creation of green spaces and wetlands can bring about positive impacts that extend beyond their immediate solutions. These natural areas can be designed and developed to serve multiple purposes, such as managing water run-off, improving water quality, and sources for agricultural production. Integrating these functions into a single system can reduce the burden on local sewerage treatment plants by diminishing the volume of water that requires treatment. also mitigating the effects of urbanisation, such as flooding, pollution and heat waves.

Table 5: Summary of key ecosystem services in informal urban areas

Regulatory	Water Management	Runoff control management and flood mitigation; Greywater treatment	Adegun (2013); Button *et al.* (2010); O'Farrell *et al.* (2012); Douglas (2016)
	Moderating Micro-climate	Trees with canopy provide shade (decreasing ambient air temperature by 3–5 °C in summer in Bangalore urban area/slums)	Jabeen *et al.* (2010); Gopal (2011); Sudhira and Negrada (2013); Oluwafiyekemi and Julie (2015)
	Air Quality Regulation	Cleaning the air through removal of pollutants such as SO_2 and suspended particulate matter.	Sudhira and Nagendra (2013)

Source: Extracted from (O.B Adegun2012).

Green spaces within settlements provide temperature moderation and benefit the residents. This has been confirmed by the regular practices of using roof canopies or vegetation to reduce heat exposure in informal settlements in Dakar, Bangladesh(Jabeen et al., 2010). Roof gardens can help regulate the quantity and quality of runoff, while wetlands and riparian spaces can aid in flood control and treat greywater (Adegun, 2013; Douglas, 2016).
According to (Douglas, 2012), some natural elements in specific environments have been linked to adverse effects on individuals' physical and mental well-being in informal settlements.

Settlements near wetlands are often plagued by an influx of mosquitoes and other insects that breed in these waterlogged areas. This has been observed in Kumasi (Campion, 2012), Ouagadougou (Baragatti et al., 2009), and Kampala (Isunju et al., 2016), providing evidence of the phenomenon. Green infrastructure offers benefits that can enhance the quality of life, livelihoods, and the environment. Moreover,

sociocultural services can promote environmental justice and equity (Ferris et al., 2001).

Embedding Nature-Based Solutions (NBS) in urban areas will bring measurable benefits. This includes increased resilience to flooding, drought, heat waves, and air quality improvements. Green roofs are an essential type of Nature-Based Solution (NBS) that can help regulate building temperatures and reduce heatwaves' harmful effects on human health. Older adults with limited mobility are particularly vulnerable to heatwaves and have limited means to stay cool and create cooler indoor environments(Snep et al., 2020).

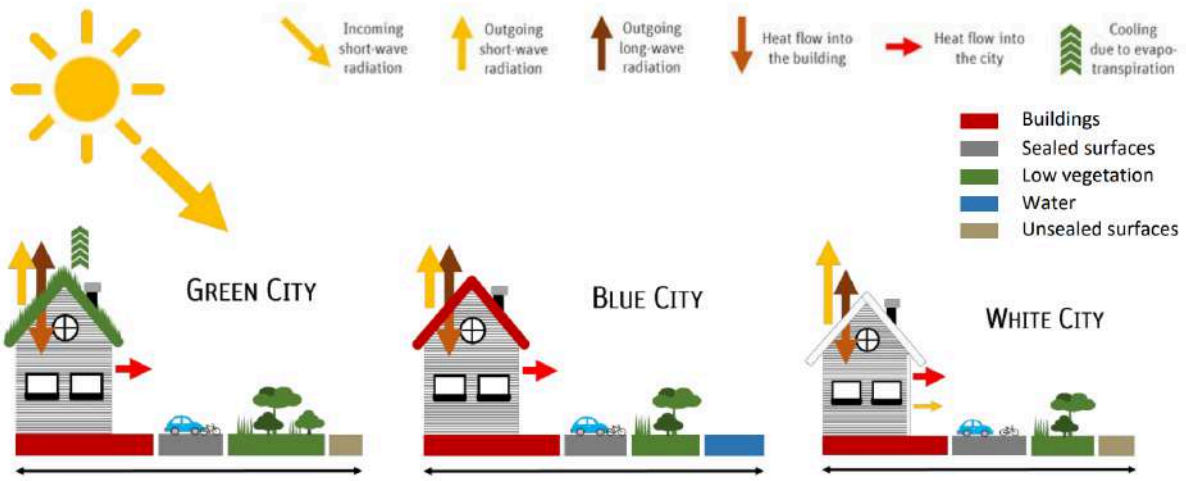


Figure 8: UHI in different clity layers

The implementation of Shading Infrastructure through the use of strategically located artificial canopies over outdoor areas and buildings has proven to be efficacious in mitigating radiative heat load while simultaneously ensuring convective flow across surfaces beneath. Such measures have been particularly successful in public areas, such as transit stops, play areas, and picnic areas, which are especially vulnerable to heat exposure. Artificial canopies show effective results in reducing heat impact, making settlements safe and more relaxing (Laue, Adegun 2022)

Building shade can be strategically used to provide shade for pedestrians and flowing urban areas. Examples are the plazas and transit shops. Depending on what time of the day and demographic, shading to these places should be planned accordingly **Trees offer essential ecosystem services, radiative shading, evapotranspiration and stormwater management. They also reduce the temperature in high-paved areas. Urban ventilation pathways**- Increasing natural airflow around buildings and

streets through blue and green infrastructure helps to reduce convective heat losses from surfaces. (Laue, Adegun 2022). Urban green infrastructure provides cities with opportunities for adapting to climate change(Gill et al., 2007). developing countries can consider multi-functional, soft engineering alternatives to grey infrastructure, as seen in the CLUVA project (Lindley et al., 2015) and Kithiia Lyth's work.

Table 6: Overview of climate adaptation measures for green spaces and materials. Source: Climate-proof cities (2011)

Climate adaptation options	Measures
Green spaces and vegetation	Public green spaces, parks, forests, gardens
	Trees
	Green walls
	Green roofs
Materials	Increase Albedo or reflectivity of roofs and walls; white paint
	Shading of streets
	Thermal mass

1.3.5 Extreme Heat Challenges in Urban Settings

Thermal Stress condition when the temperature becomes too extreme for the body to manage

Urban Heat Excessive heat conditions in urban areas.

Urban Microclimate refers to a distinct set of atmospheric conditions that prevail in a relatively small area, typically up to 100 meters.

Urban heat island (UHI) occurs when trees and vegetation are replaced by buildings and roads made of asphalt and concrete. This causes metropolitan areas to be up to 20 degrees Celsius warmer than surrounding suburbs and rural regions. The climate is affected by Urban Heat Island(UHI) through various physical processes such as heat getting accumulated in buildings during the day latent heat being released at night, and sensible heat being generated by human forms activities such as heating, air conditioning and traffic.it is escalated by various factors such as pollution, climate change, sprawl, lifestyle and urban design(Natali et al 2017).

Waste Heat It is the unused heat produced by machines, objects (such as automobiles or air conditioning), or processes (industry) transferred to the surrounding environment, adding to the UHI effect.

Heatwaves are prolonged periods of extremely hot weather. They can have a significant impact on society. Leading to an increase in deaths due to extreme heat. This is mainly due to Climate change causing more people to be exposed to high temperatures (WHO,2022). Heatwaves can negatively impact health and make neighbourhoods less habitable, especially in poorer areas. The UHI effect in cities multiplies as poorer neighbourhoods tend to have less greenery and more impervious surfaces.

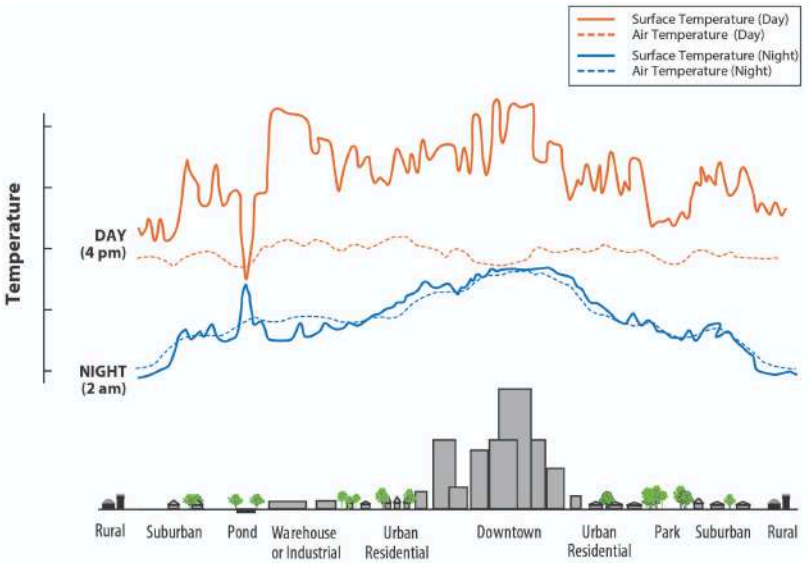


Figure 9: Illustration of Urban Heat Island effect in Urban Environment
Source: Earth Resource Observation & Science (EROS) Centre, 2019

Globally, extreme temperature events are increasing in frequency, duration, and magnitude. From 2000 to 2016, around 125 million people were exposed to heat waves. Urban areas are vulnerable to heat islands due to their typical land use land cover(LULC), population density, infrastructure systems, assets, and economic activities. Due to intensified urbanisation and population expansion, the available green covers and open spaces are transformed into Man-made constructions, forming a dome of stagnant warm air over the heavily built-up areas of the city(Zeba Nisar et al.,2023). The combination of such factors contributes to amplifying the effects of extreme weather events, jeopardising the health of urban dwellers.

The heat problem in Jakarta's informal settlements has been worsened by overcrowding and a lack of cooling infrastructure (Salsabila et al., A. 2023). Enhancing resilience to heat stress in low-income urban areas is crucial. Strategies at different levels, including landscape, building upgrades, and individual-level actions, can boost society's capacity to adapt to extreme heat. Unfortunately, informal settlements often struggle to respond effectively due to factors such as limited household incomes, weak socioeconomic status, and poor infrastructure.

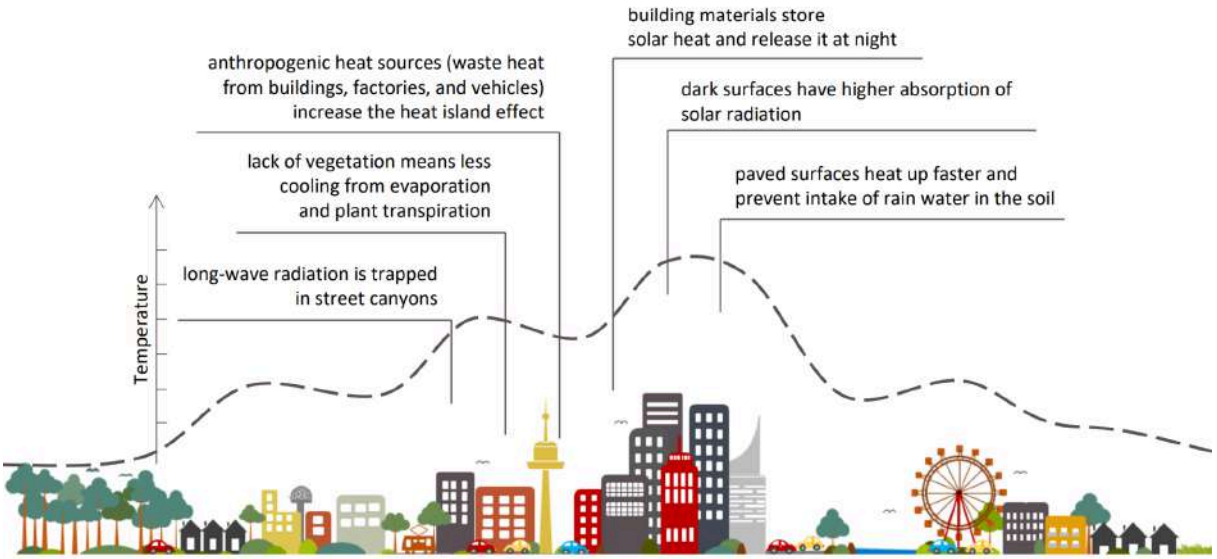


Figure 10. Schematic illustration of the UHI and factors contributing to higher temperatures in urban areas. The heat load is typically lower in rural surroundings than in dense built-up areas. The graphic also illustrates parks, water surfaces, forests, and open spaces that can create more excellent areas within the city.

1.3.6 Heat Challenges in Southeast Asia

Heat waves caused by extreme weather in India, Pakistan, and Bangladesh in 2022 have affected over a billion people. Urgent action is needed to address the pressing problem of rising temperatures and extreme heat events in the region's cities. (Kotharkar, R. 2022). Cities in South Asia are expected to welcome over 200 million new residents by 2030, almost equal to Pakistan's entire population. However, most of the urban infrastructure required for the year 2050 is yet to be built.

Over the past few decades, the land surface temperature in major cities of India and Pakistan has been consistently increasing. Cities such as Mumbai, Hyderabad, Delhi, and Lahore have experienced peak temperatures in 2022. The rise in urban problems and climate challenges is only going to worsen the situation if these cities are not adequately prepared.

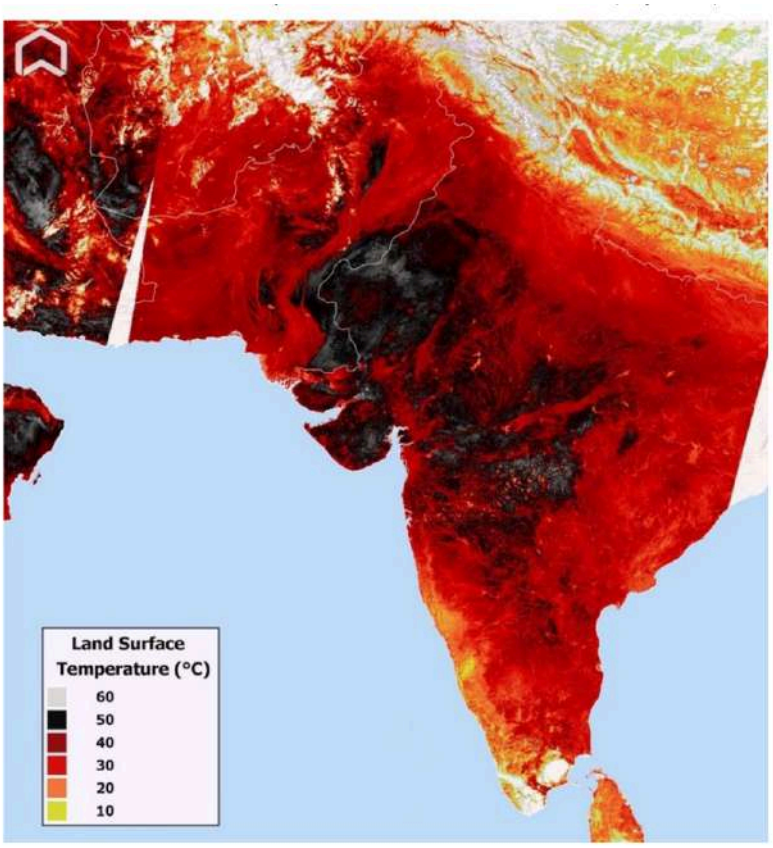


Figure 11: LST map of India & Pakistan; April 29, 2022
Source: Freedman 2022; image Antonio Vecoli via Adam Platform

Buildings have a significant impact on thermal comfort and heat exposure at the local level. The indoor air temperature is influenced by building design and materials, such as roofing and wall materials, window design, ventilation, aspect ratio, and internal and external shading.

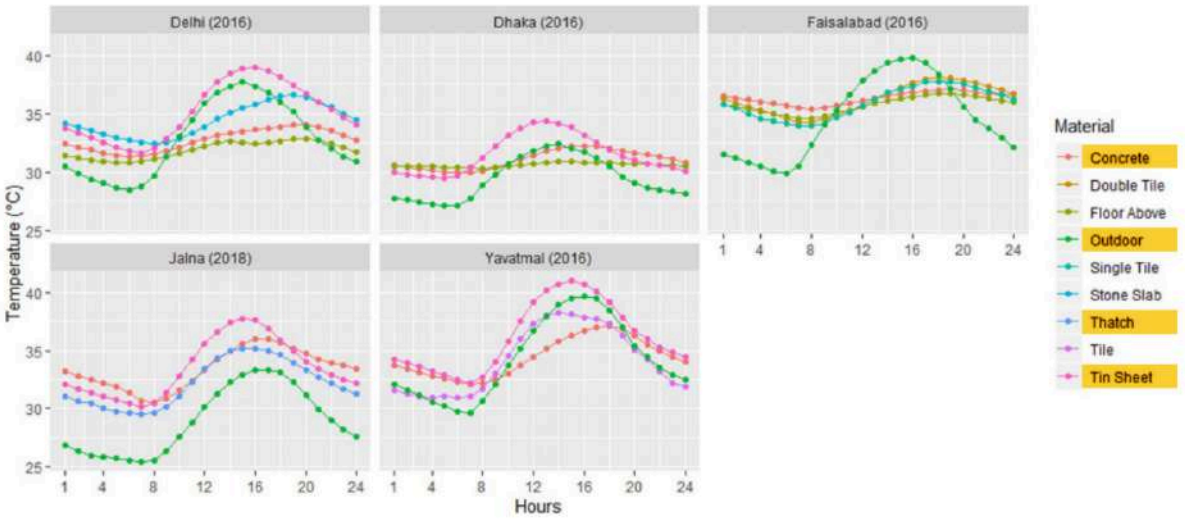


Figure 12: Indoor-outdoor (during the day) temperature variation for the summer months of May & and June(the temperature changes with materials)Source: Tasgaonkar et al.2022

As shown in *Figure 12*, the indoor temperature in tin-sheet houses is high, and roofs made from concrete and natural materials perform better. Roofs cover up to 20-25% of urban hardscape. If they are darkly coloured, they can absorb 80% of sunlight at the point of contact. Sunlight entering buildings can increase indoor temperatures, intensifying the Urban Heat Island effect. This can be minimised by using reflecting coatings on roofs or upgrading them. Cool roofs suit all buildings, especially single-story ones with high roof-to-wall ratio. (Global et al. Alliance 2012).

A case study was conducted to understand how small behavioural features inside a settlement can contribute to temperature differences. A study conducted by Rajan and Amirtham in 2021 evaluated the outdoor temperatures and humidity levels of eight neighbourhoods in Chennai's Thyagaraya Nagar district. According to the study, the design elements of streets, such as narrower streets with a low height-to-width ratio and less sky view factor, are the significant contributors to the temperature differences. This implies that the streetscape design determines the area's temperature.(Ranjan Amritham, 2021).

The locations in the figure were observed, and there was a significant difference During the day and night. Location 2 recorded the highest temperature of 40°C, approximately 5.8°C higher than other locations. During the night, Location 2 cooled down to only 35°C while all other locations cooled down by an additional 2- 4°C. This is because of narrow Streets with low height-to-width ratio, low sky view factor and

almost no green cover. This critical analysis helps us understand the factors that affect the behaviour of the neighbourhood.

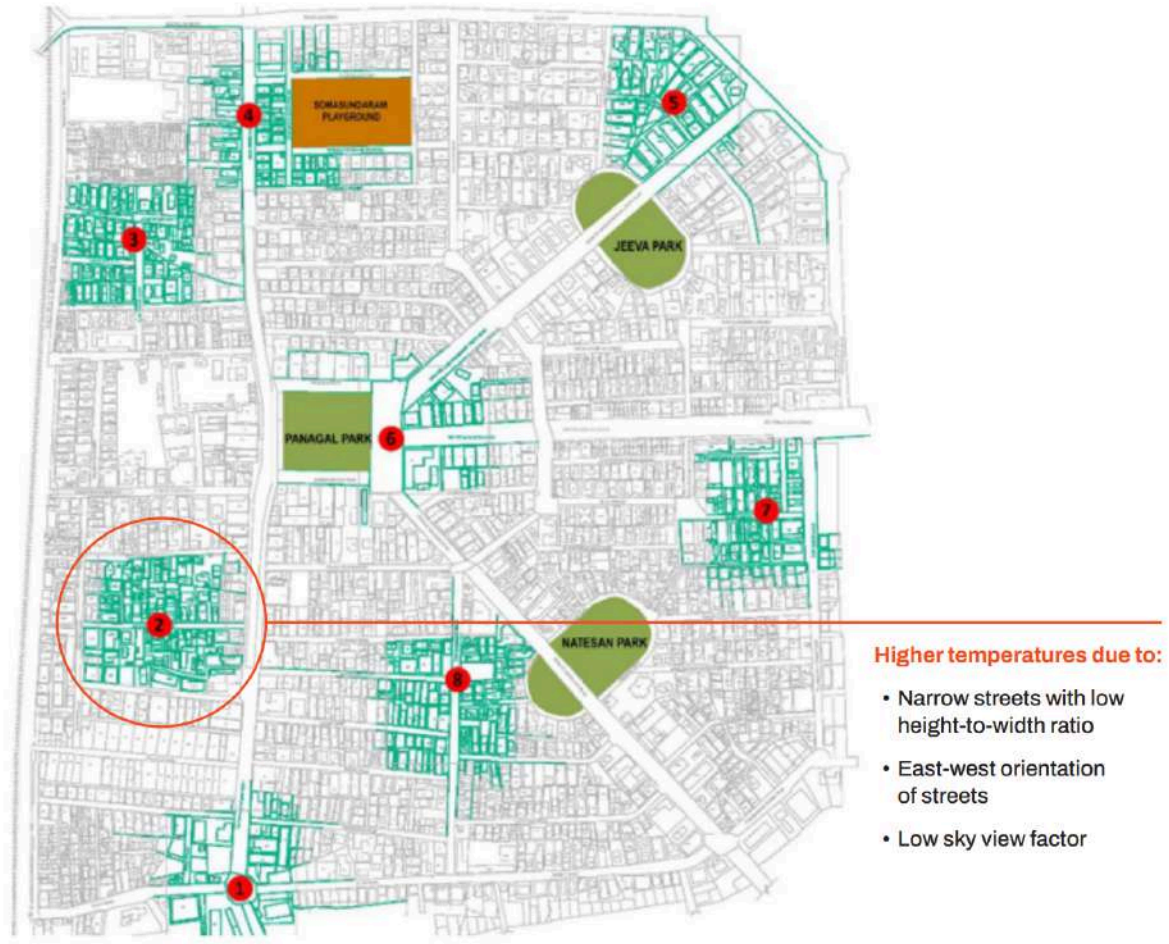


Figure 13: Eight locations (Thyagaraj Nagar) where temperature and humidity were assessed for two different months to understand the behaviour.
Source: Ranjan Amritham 2021: A case study analysis on Thyagaraj Nagar, Chennai

According to a recent study conducted on 262 urban green spaces in Bengaluru, it was found that these areas provide a significant cooling effect in the vicinity. The study revealed that these green spaces, on average, were 2.23°C cooler than the nearby areas. Furthermore, the study noted that these green spaces offer cooling benefits for an area of almost 350 meters beyond their boundaries (Shah et al., 2021). A study conducted over three years showed an average summer temperature decrease of 7.51°C near Sukhna Lake in Chandigarh City. The lake had a cooling effect up to 1,200 meters from its centre. (Gupta et al., 2019). These kinds of interventions are very much needed to address the spatial vulnerability. According to a survey conducted in Ahmedabad, India, informal settlement residents are exposed to temperatures up to 7.6 °C higher than those of formal housing residents.

Additionally, a study conducted in Lahore, Pakistan, found that formal settlements were better regarding insulation, ventilation, green spaces, and house age, resulting in lower indoor temperatures during summer(Mahadevia et al., 2020). Within informal settlements, the combination of heat-trapping buildings, overcrowding, using solid fuel burners indoors, and closed-off ventilation due to neighbourhood air pollution can lead to structural vulnerabilities. (Rana et al. 2022)

There is not enough research available on how informal settlements in South Asia are differently affected by heat and how they adapt to it. Moreover, most heat management plans and policies concentrate either on individual buildings or on national-level adaptation planning processes, neglecting informal settlements. (Kotharkar and Ghosh 2022; Adegun, Mbuya, and Njavike 2022).

City leaders can prioritise actions in six areas for heat resilience. These include promoting urban greening, cooling city spaces, engaging building owners, issuing heat wave early warnings, protecting heat-exposed workers, and mainstreaming heat risk reduction. These solutions help address multiple objectives: urban heat reduction, flood protection, carbon reduction, habitat and biodiversity benefits, and improved air, soil, and water quality. Future urban heat management efforts in South Asian cities must account for informality to target resources towards vulnerable households in riskier areas.. Integrating Green infrastructure adaptive measures strategically implementing Involving the community in participatory planning ensures that solutions are tailored to the needs and preferences of residents. This participatory planning approach at the local level enhances the local scale. It reflects local aesthetics and cultural practices, contributing to a sense of identity for the residents of informal settlements.

Chapter 2: *Methodology*

This chapter explains the complete purpose of the research, explaining the framework and how the methodology could help to answer the research questions of the thesis. It discusses the tools used and how it is going to reach to the results in a detailed step-wise manner

Chapter 3*: Hyderabad City, India,*

will provide a brief insight into Hyderabad's urban profile, geographic context, and climatic characteristics. It will also give an overview of the broader urban development processes that have led to the emergence of informal settlements in Hyderabad. It will also cover the evolution of informal settlements through time and provide a detailed study of the current situation locally known as the Charminar area, Which has seen an increase in informal settlements due to geographical expansion. Finally, the chapter will discuss the high risk of the urban heat island effect in the most densely populated informal settlements.

Chapter 4*: Results*

provides the results of the study. The methodology was used to identify the study area through the heat hotspot of Hyderabad city. Then, overlapping the slums map with the UHI effect was categorised This step leads us to the zone with more concentration of slums with high vulnerability to extreme heat. Ranking in the order of most vulnerable informal settlement. The QGIS tool was used to find these highly vulnerable areas. Once the site was found, a local heat simulation analysis was done, confirming its context with the geographical study to propose upgrading solutions through interventions to adapt to climate change.

Chapter 5*: Conclusions*

Discuss the proposed conclusions, answering the research questions through the site and proposed adaptation measures, linking the importance of upgrading informal settlements to reaching the global sustainable development goals for sustainable cities and communities.

Chapter 2: Methodology

Upgrading informal settlements for climate change requires identifying informal clusters (urban population living in slums) within the city. As a starting point, the climate issues in the city have to be identified, such as flood profiles, rising temperature patterns, and extreme events. This helps us to identify the most vulnerable urban informal settlements, which are influenced by various situations and patterns that are affected by various climate challenges and their already existing urban problems(lack of basic infrastructure, environmental issues and unhygienic living conditions).

The Identification of challenges faced by informal settlements greatly depends on their geographical locations. To accurately assess these settlements, contextual knowledge is crucial in selecting a suitable site based on the available data. It is crucial to identify slums vulnerable to climate change's detrimental effects. For instance, settlements suited along the river Musi are prone to flooding. While those with the old city fabric are more prone to heat waves. Informal settlements near industrial areas are prone to more pollution-related challenges, etc. The Thesis will focus on studying settlement clusters that are more vulnerable to heat waves. This will involve examining the urban heat island profile to identify if slum clusters are being directly affected. Once the slum clusters are identified, solutions to adapt to the challenges faced can be recognised and implemented.

This thesis study used a literature review and case study methodology. The literature review involved reading reports and articles related to informal settlements and their upgrading. This was important in understanding what informal settlements are, how they form and develop, how they impact cities, and why it is crucial to upgrade them.

Framework outline:

Step 1:**Identify the climate challenges in Hyderabad**

Step 2: **Identification of informal settlements in Hyderabad**

Step 3: **Recognising Urban Heat Island profile of Hyderabad**

Step 4: **Informal settlements that are most prone to UHI**

Step 5: **Assessing the talab katta informal settlement**

Step 6: **Simulation study at local scale**

Step 7: **Results**

Step 8: **strategic solutions to adapt to the heat waves in talab katta informal settlement**

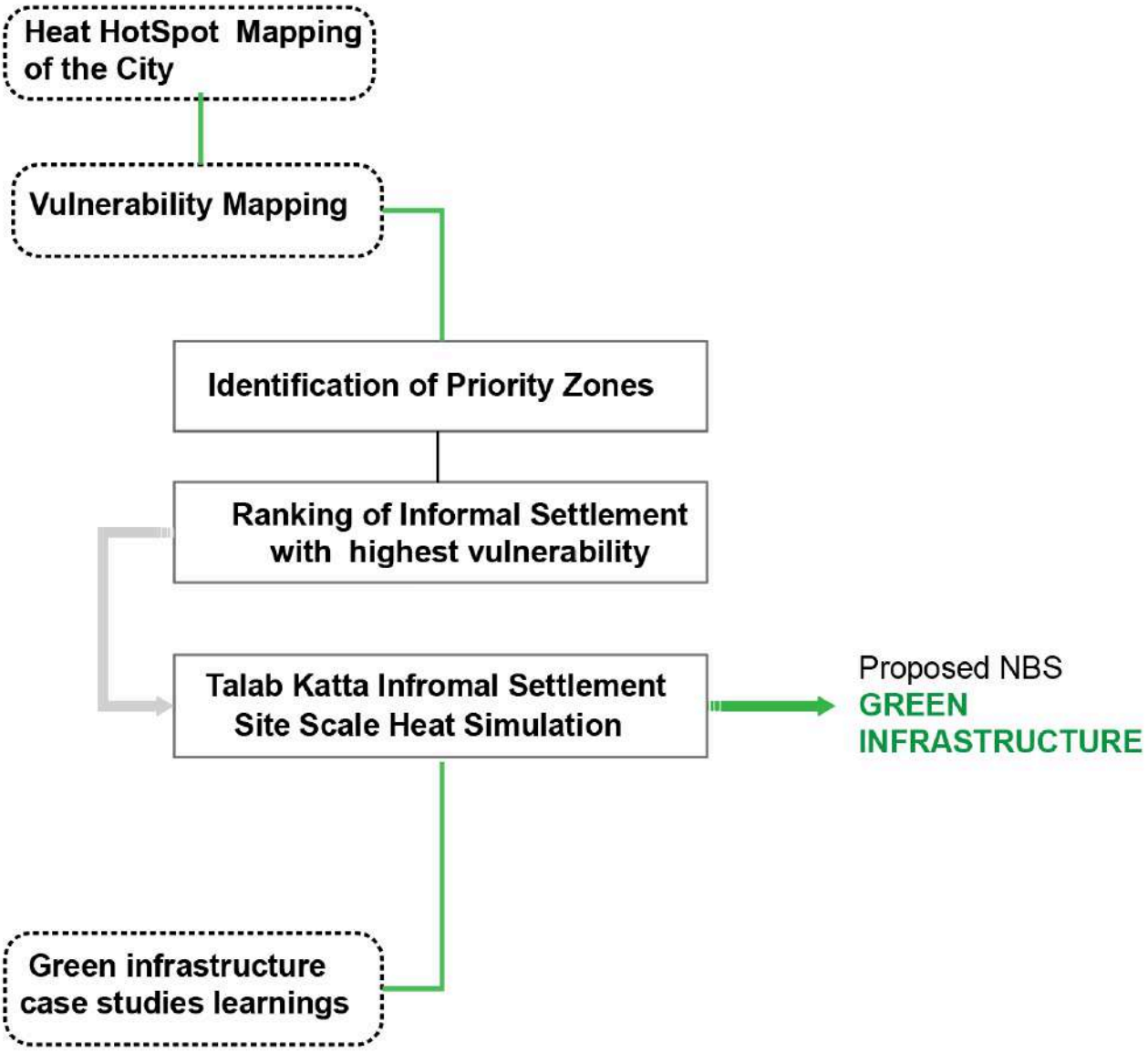


Figure 14: Methodology of the study

Source: Methodology adapted from (Zabarna, O 2020)

2.1 Heat Hotspot Mapping

Thermal Hotspot maps offers valuable insight into the distribution of hotspots within cities. By identifying these hotspots, interventions can be focussed where they are most needed during heatwave. These maps provide information on the accumulation of hotspots in certain areas, indicating that the population living there is at high risk of physiological and socio-economic stress due to heat. With this knowledge, specific measures can be taken to address the issue of heat stress for residents.

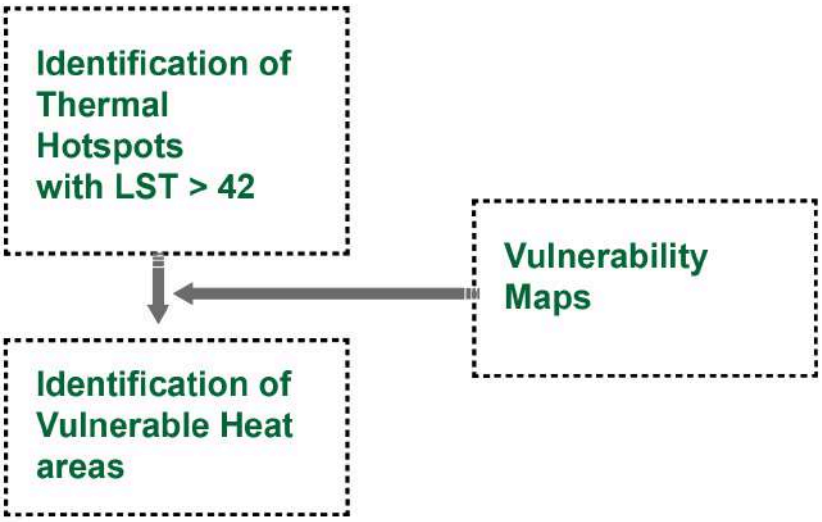


Figure 15: Use of data

The surface temperature maps were developed using data from the LANDSAT 8 satellite. Thermal heat spots were mapped using remote sensing techniques, specifically using Land Surface Temperature (LST) images derived from satellite data. The temperature data was superimposed on the ward boundary map of the city to identify Vulnerable areas with temperatures above 40 degrees Celsius.

2.2 Vulnerability mapping of heat stress

After creating heat hotspot mapping, Vulnerability mapping was done to identify zones where exposure to heatwave is greater. This process aims to rank the settlements according to the highest to lowest areas to identify and analyse at the local scale to get maximum results. (Makido, Y 2019).

Shapefiles of Hyderabad municipality wards were obtained from GHMC (Greater Hyderabad Municipal Corporation). The slum population was retrieved from Election data provided by the municipality of Hyderabad. Slum Distribution in Hyderabad city was mapped in GIS(geographical information system), and then they were compared to the LST Map to identify Thermal Hotspots.

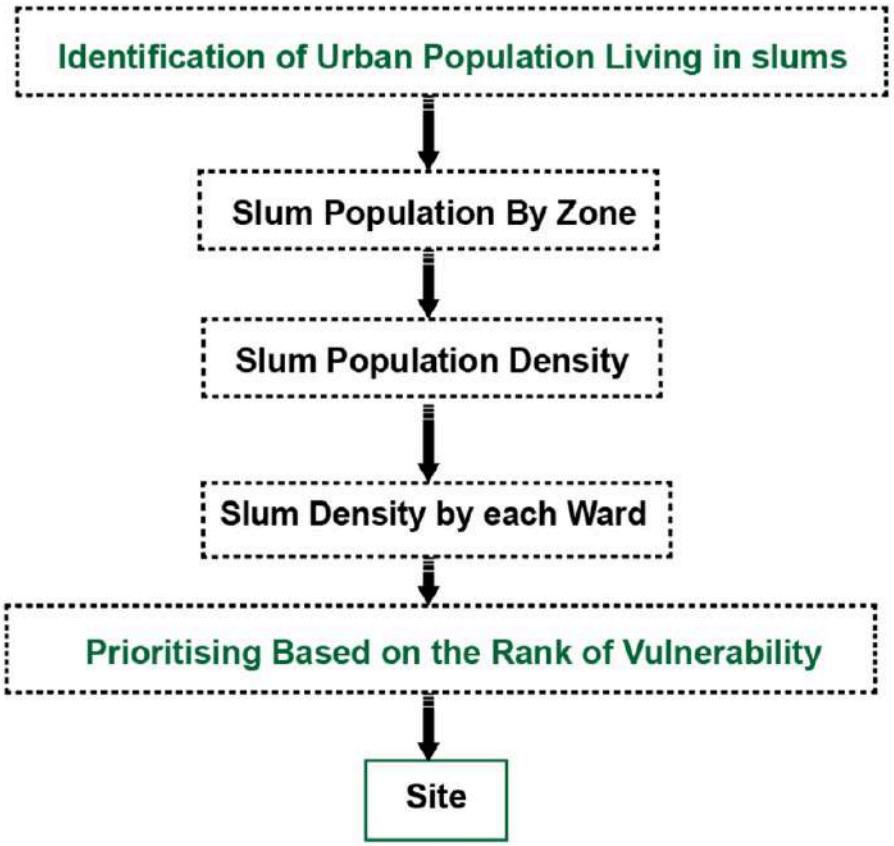


Figure 16: GIS Methodology

Source: Methodology for GIS maps adapted from Ellena et al. (2023) &(Makido, Y 2019)

2.3 Neighbourhood informal settlement: geographical survey

The site study was a direct and empirical investigation of their living conditions carried out through visual surveys and interviews with the locals. An interview with the local municipal planner, Dr.Rajender Reddy, helped strengthen the study's insights. Data regarding the ward population and slum resident profile was collected from GHMC. This helped reveal the risk indicators related to social and environmental problems. A descriptive analysis of the settlement, examining their existence and evolution, the challenges they pose to the settlement, and the urgent need for a response. This analysis was formed by various research reports and papers authored by experts, researchers, and entities such as public institutions and agencies.The existing thermal hotspots, vulnerability maps, and a geographical survey of the built environment in those areas will be used to analyse and determine the priority zones for slums. By leveraging the thermal benefit classification, we can effectively prioritize and implement interventions to full capitalize on the microclimate.

Neighbourhood informal settlement: heat simulation

The site will be assessed to check the heat behaviour through a simulation. The detailed methodology has been provided in the results chapter.

Investigating Green Infrastructure Solutions at the Local Scale

Nature-based solutions for heat adaptation in urban contexts are divided into Green Infrastructure (Use of greenery), Blue Infrastructure (Use of water bodies), and Grey Infrastructure (Use of Built architecture). The study of these will help us check the specific settlement's behaviour before and after the simulation. The detailed methodology has been provided in the results chapter.

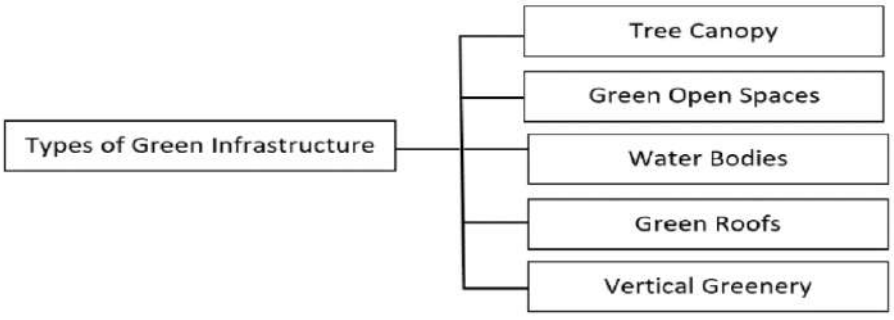


Figure 17: Types of Green Infrastructure

Chapter 3: Research context - Hyderabad

3.1 Hyderabad City, India.

Hyderabad, located in the Deccan Plateau, connects North and South India, showcasing diverse cultures and traditions. Significantly, the region's topography and government business have shaped Hyderabad's culture. Hyderabad is recognised for its great heritage, cuisine, and multilingual culture. Mohamed Qutub Qutb Shah, the sixth Qutb Shah ruler, founded the city in 1591. Between the 11th and 14th centuries, many Moghul rulers did preservation and development. The city is known for its pearls and diamonds. After the post-independence period, Hyderabad grew along the river Musi. With rapid urbanisation, the city has been divided into two parts- The old and the New cities. The old city is located on the southern bank of the river Musi and is home to many heritage centres, such as the Charminar monument. The city has 400 years of history with rich heritage importance. There is a special connection between the Charminar and the Musi River, which the locals value and cherish. Rapid urbanisation in the past decades left the old city behind for development.

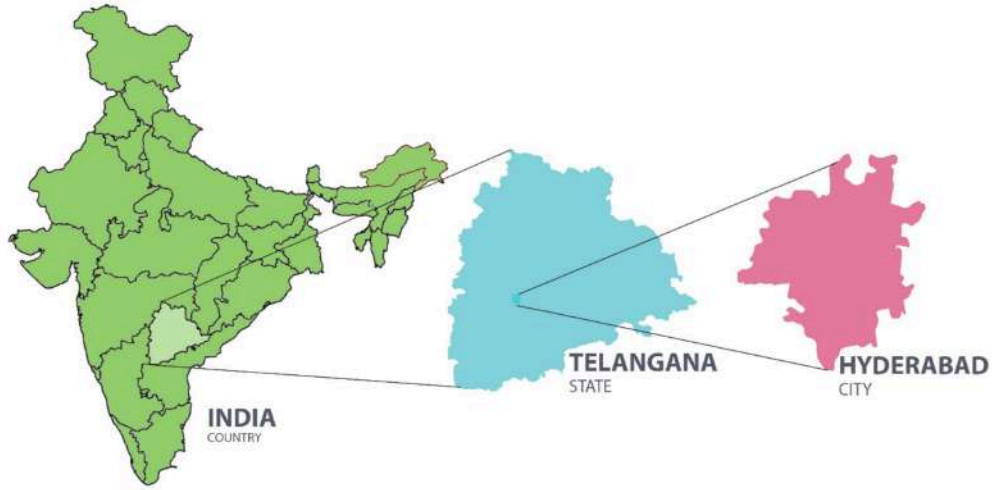


Figure 18: Location of Hyderabad city Source: Authors elaboration:

The city originated on Musi's banks (also currently its major river). Based on an average elevation of 542 m from the mean sea level, the region experiences a semi-arid climate (Koppen-Geiger classification) zone (Peel et al., 2007)(Srikanth, K., & Swain, D, 2022)

Demographics

Oldest Municipality: Hyderabad Municipal Corporation (established in 1869)
Population (Census, 2020): Approximately 10 million
Density (Persons/sq.kmCensus 2020): Approximately 18,480 persons/sq.km.
Decadal Growth (% from 2001 to 2020): 6.14%

Table 7: Census according to 2020

Census according to 2020	Country India	State Telangana	City Hyderabad
Population	1.4 billion	35 million	10 million
World rank	2	-	34
Surface area	3.287 million km^2	112,077 sq.Kms	650 sq. kms.
Urban population	35%	38.12%	-
Rural population	65%	61.88%	-

Source: Census data according to 2020

Table 8: Hyderabad Population and area

Hyderabad	Hyderabad (2020)	Hyderabad City(2031)
Population	10 million	18.5 million approx
Area	650 sq km	5965 sq. km approx
Rank	6 (India)	34 (world)

Source: Census data according to 2020

Hyderabad, the capital of Telangana state, is situated in the central region of South India. With a population of 10 million in 2020, Hyderabad's metropolitan area has emerged as India's sixth largest city, experiencing a staggering growth from 1 million residents in 1951. The city's built-up area has also expanded significantly from 56 km2 in 1989 to 240 km2 in 2020. According to HMDA 2011, the urban agglomeration is projected to house 10 million residents by 2020, while the wider urban area may witness a population surge to 13 million in 2021 and 18 million in 2031.

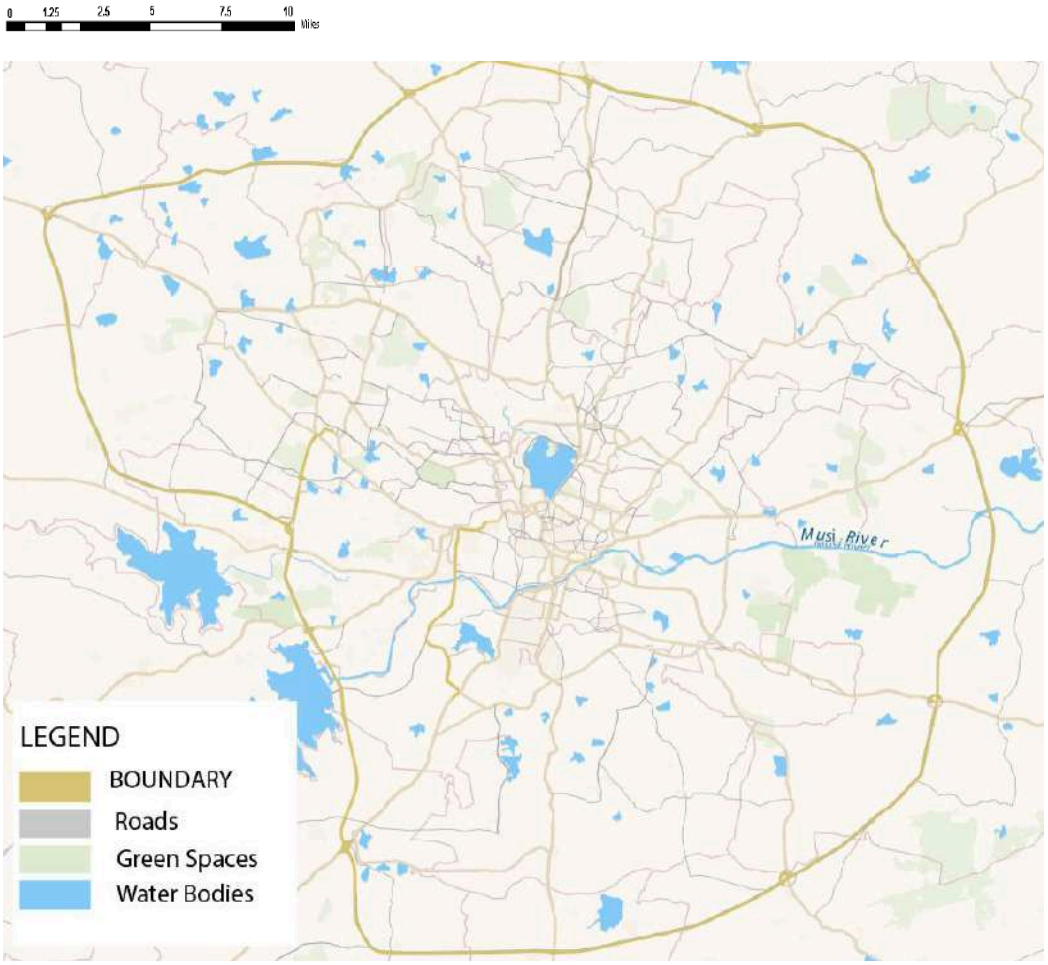


Figure 19: Map showing Green Spaces & Road network of Hyderabad
Source: Authors Elaboration

Hyderabad is the most liveable city in India in terms of climate, food and standard of living. After the state bifurcation in 2012, the city's population has almost doubled due to rapid urbanisation and migration from rural areas. The old city has mostly stayed the same from its inception. The city comes with innovative climate-resilient approaches to face flooding and heat challenges. However, it is very limited to a few developed areas, not prioritising its slums in its planning and policy-level designs. Programmes like Harita haram to plant trees have increased from 24% to 33 % of the total geographical area. Cool roof policy intervention has been made mandatory to be included in the building permission level for plot areas over 200 sq. yards. A flood relief programme and disaster risk management were established after facing the consequences of the 2020 floods. to combat heat challenges, Hyderabad has taken initial steps to adapt to these climate change effects in its action plan for 2020

3.2 Climate characteristics of Hyderabad city.

Hyderabad is distinguished by its tropical climate, witnessing hot and dry summers from March to June, with temperatures ranging from 35 -45°C (*figure 20*). The monsoon season, lasting from June to September, brings required rainfall, averaging around 800mm annually(*figure 21*), vital for replenishing water sources and supporting agriculture in and out of the city. Winters are mild, with an average of 15°C from November to February. Despite being located in a plateau region geographically, the city is prone to cyclone vulnerability, with its effect bringing occasional heavy rainfall and windy conditions. Humidity levels exceed more than 70% during monsoon season, contributing to overall moisture in the air. The city faces occasional flooding issues in low-lying areas due to heavy downpours. The recent flooding in 2020 was caused by unusual rainfall, leading to flash floods. Several low-lying areas, including slums and neighbourhoods with inadequate drainage systems, were affected by flooding. There was a massive stress on the city authorities. On the other hand, the city experiences the hottest temperatures in May, averaging up to 40°C and posing challenges for the inhabitants and the city's economy.

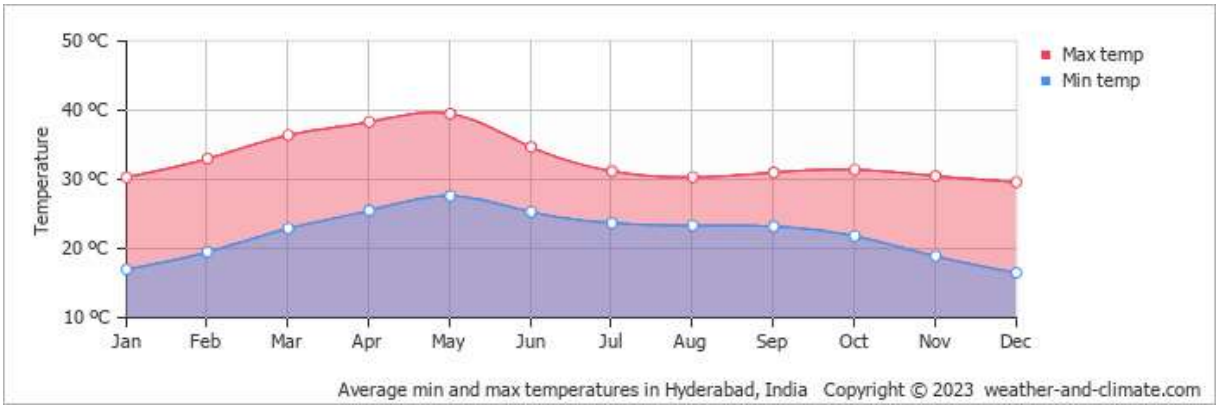


Figure 20: Average Temperature of Hyderabad

Source: World weather and climate information retrieved in 2023

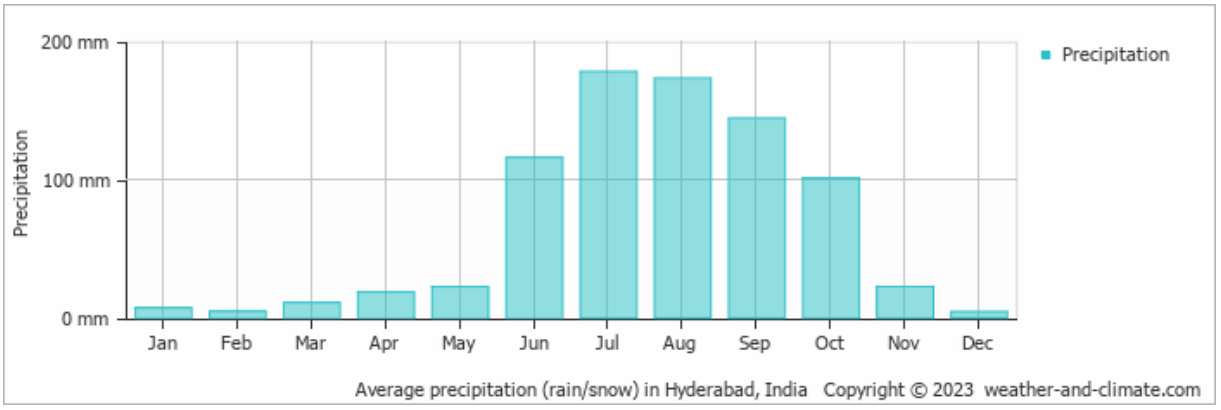


Figure 21: Average rainfall in Hyderabad
Source: World weather and climate information retrieved in 2023.

The most recent flood with 192mm of rainfall occurred in October 2020(*figure 22*), affecting up to 1,80,000 people over several weeks, causing an estimated loss of 5,000 crore.

Figure 22: The low-lying area of Indra Nagar was affected by floods in 2020.
Source: Google Images.

In recent years, Hyderabad city has experienced several extreme weather events. However, the most catastrophic of these occurrences occurred in 1908, flooding low-lying areas up to 3.3 meters and breaking the Musi river banks. Sadly, this calamity led to the loss of almost 15,000 lives and the destruction of over 19,000

homes. A flood management and drainage proposal for the city was made by Sir M Visvesvaraya, leading to the construction of two upstream storage reservoirs – Osman Sagar in 1920 and Himayat Sagar in 1927(Benjamin Cohen, 2011) In 2020 Greater Hyderabad Municipal Corporation (GHMC) allotted 10% of its total budget for adaptation to global warming and climate change, through a green budget initiative(GHMC, 2020).

Figure 23: People sleeping on rooftops to escape the heat trapped in their concrete compact homes. Source: Isha Ray

3.4 Informal Settlement/Slum Population Profile of Hyderabad.

GHMC covers an area of 650 square kilometres and has a population of 6,809,970. There are 1478 slums in Hyderabad, out of which 1179 are notified and 297 are non-notified. The total slum area is 80.45 Km2, which is 12% of the total GHMC area. The total Slum population is 19,51,207, which accounts for 28.65% of the total population of GHMC. The total number of households in the slums is 4.06 lakhs(Kumaraswamy, n.d, 2017).

Urban Population Distribution of Hyderabad

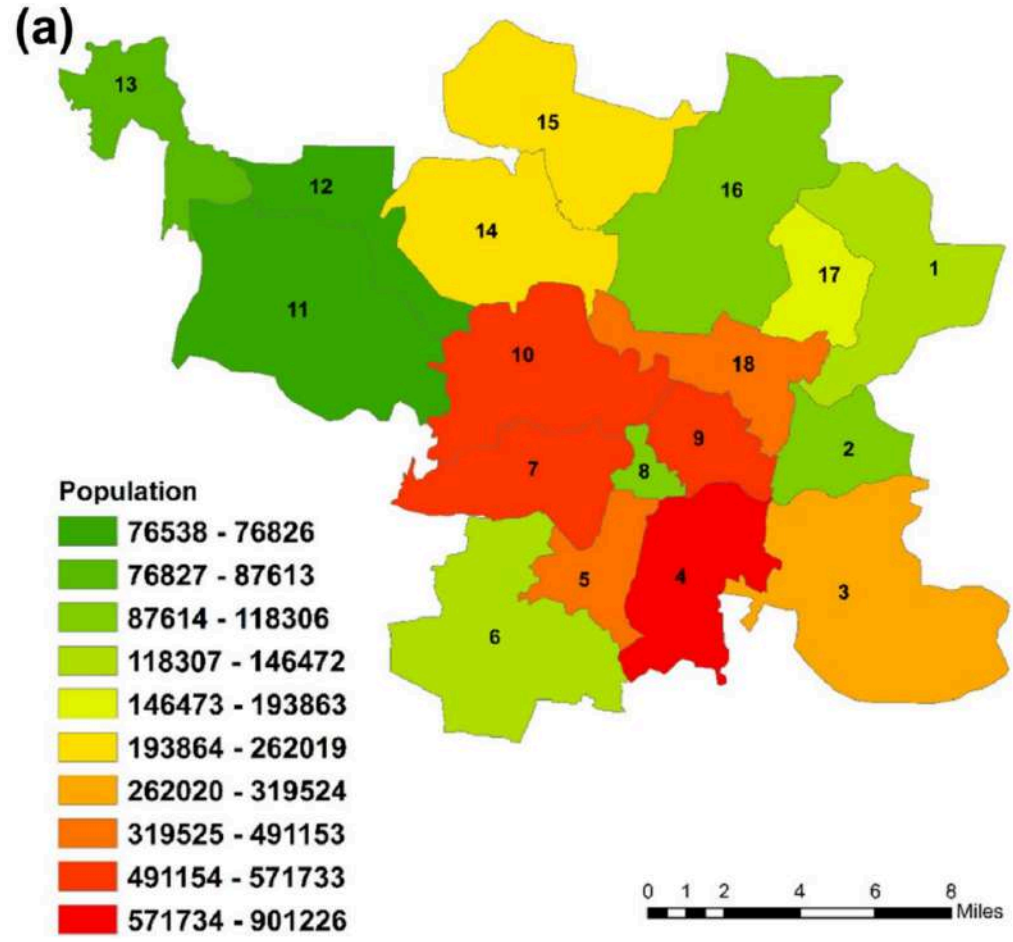


Figure 24: Map Showing Population Distribution of all circles in Hyderabad City
Source data: Census India 2011 & GHMC

Map 3.7 presents a clear picture of the population density distribution across Hyderabad's various circles, using the 2011 census data. Through a meticulous analysis of this map, it becomes apparent that Circles 4, 7, 9, and 10 are the areas with the highest urban population. These regions constitute the old city and serve as a critical hub for urban growth. The core area encompasses over 80 municipality wards, with a staggering 20,000 plus inhabitants per square kilometre. This data leaves no room for doubt that these regions are highly susceptible due to their dense population

Urban Population Density of Hyderabad

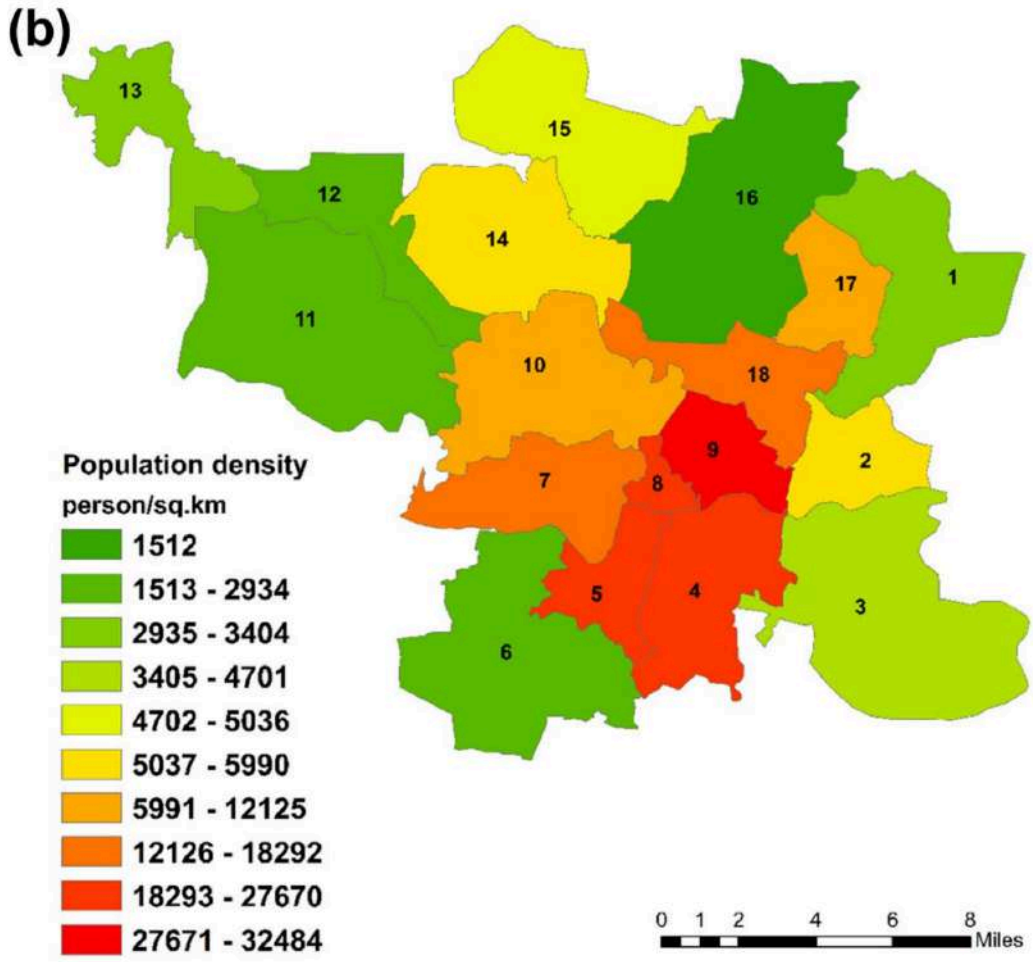


Figure 25: Map Showing Population density of all circles in Hyderabad City
Source data: Census India 2011 & GHMC

From the map, we can see the percentage of living per sq/km, which is the population density highest in the circles 4,5,8,9. The core old city fabric is very dense, consisting of a cluster of slums, as explained in (*figure 26)* below. These circles have had the least development progress over the past decades.

Urban Settlement Density of Hyderabad City

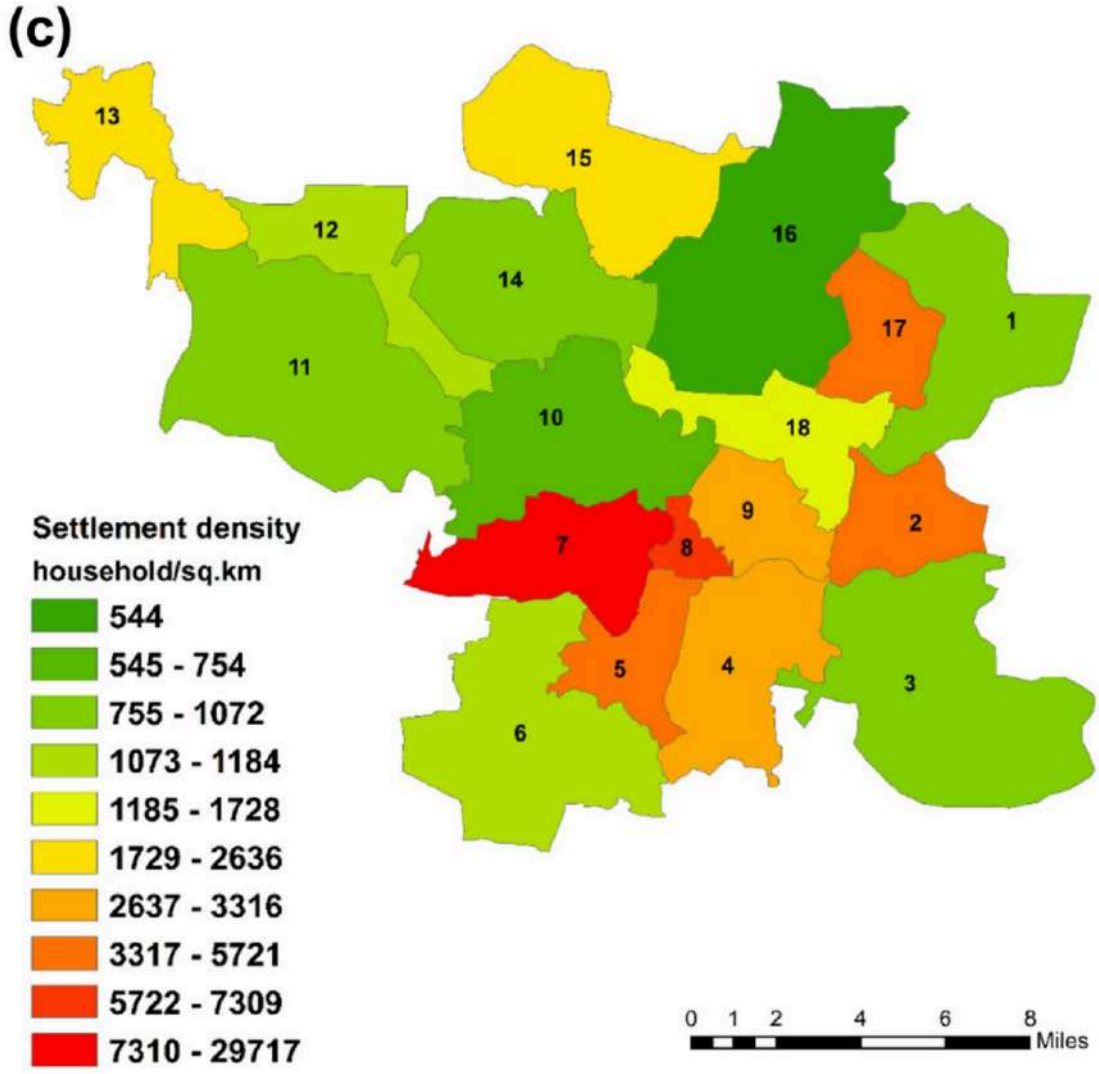


Figure 26: Map Showing settlement density of all circles in Hyderabad City
Source data: Census India 2011 & GHMC

Table 9: Table Summary Showing Population of slum in Hyderabad and Percentage of Slum Growth

Source: Hyderabad Concept Plan, Master plan by HUDA(Hyderabad Metropolitan Urban Authority 2003 & 2013; HMDA 2010; MCH 2005; Census of India 2011 & 2001

Year	slums	Slum population in thousands	City population In thousands	Total Population In %	Annual growth
1962	107	1201	1233	9.73	
1967	194	168			
1972	282	301	1731	17.37	9.5
1976	300				
1978	377				
1979	455				
1981	470	540	2251	23.99	6.75
1986	662	859			
1994	811	1258	3298	38.14	6.72
2001		601	3454	17.4	
2001	1142	1411	3633	38.83	
2011	1476				

**According to MCH(Greater Hyderabad Municipal Corporation0)*

+According to Government of India.

It is concerning to observe that a significant segment of Hyderabad's population resides in slums. Regrettably, the evaluation and surveillance of these slums are conducted inconsistently by different government entities. It should be kept in mind that once a slum is identified, the authorities have to furnish fundamental amenities. There is a political component to releasing slum statistics data and categorising them as notified or not notified. Residents of poor settlements, as well as former rural migrants, often lack political influence in receiving notifications due to political processes. Non-notified slums are those that are not recognised by the government. These slums do not benefit from legal rights, basic services and land tenure.

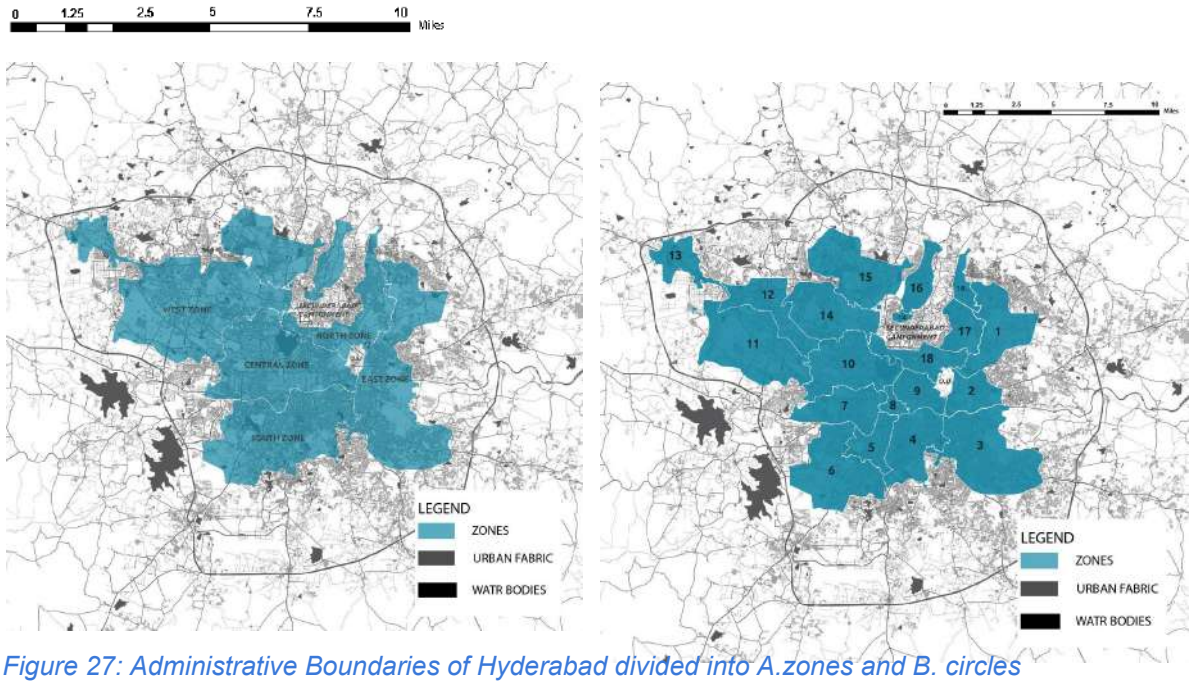


Figure 27: Administrative Boundaries of Hyderabad divided into A.zones and B. circles
Source: Authors Elaboration

The Hyderabad city is divided into six zones. Namely Charminar (Central Zone), L. B. Nagar(East Zone), Serilingampally(West Zone), Kukatpally(South Zone), and Secunderabad(Central Zone). Each Zone is divided into 30 circles, and each circle has 150 wards.

Table 10: Slums Population in Hyderabad in each circle

Circle /Zone	Area	No.of Slums Notified	No.of slums Non-notified	Total	Population	Households
1E	Kapra			51	1,59,179	
2E	Uppal	26	2	28	1,68,923	2,543
3E	Saroornagar	54	21	75	5,83,589	
4S	Bhavani Nagar Edi Bazar			211	2,87,000	58,670
5S	Chintalmet, Bahadurpura, Falaknuma, Jhanuma	93	1	94	1,17,165	
6S	Rajendra Nagar	38	7	45	64,532	16,133
7C	Khairatabad	115	32	147	1,48,850	
8C	Sultan Bazar	29	7	36		4,709
9C	Abids, Amberpet, Domalguda, Bagh Lingampally	143	40	183	14,22,573	33,009

10C	Khairatabad	145	12	157	2,15,850	43,209
11W	Serilingampally	24	6	30	58,220	14,555
12W	Hafizpet	10	22	32	1,73,800	11,718
13W	Patancheru / RC Puram			20	46,242	11,376
13W	RC Puram			26	70,622	17,031
14W	Kukatpally	26	42	68	85,052	20,228
15N	Qutbullapur			63	1,96,845	44,312
16N	Alwal	49	1	50	1,41,120	30,000
18N	Secunderabad	113	21	134	1,56,571	31,028
	Total	865	214	1450	39,20,748	3,38,521

Source: Data collected from Circle offices of GHMC

Urban Population Living in slums

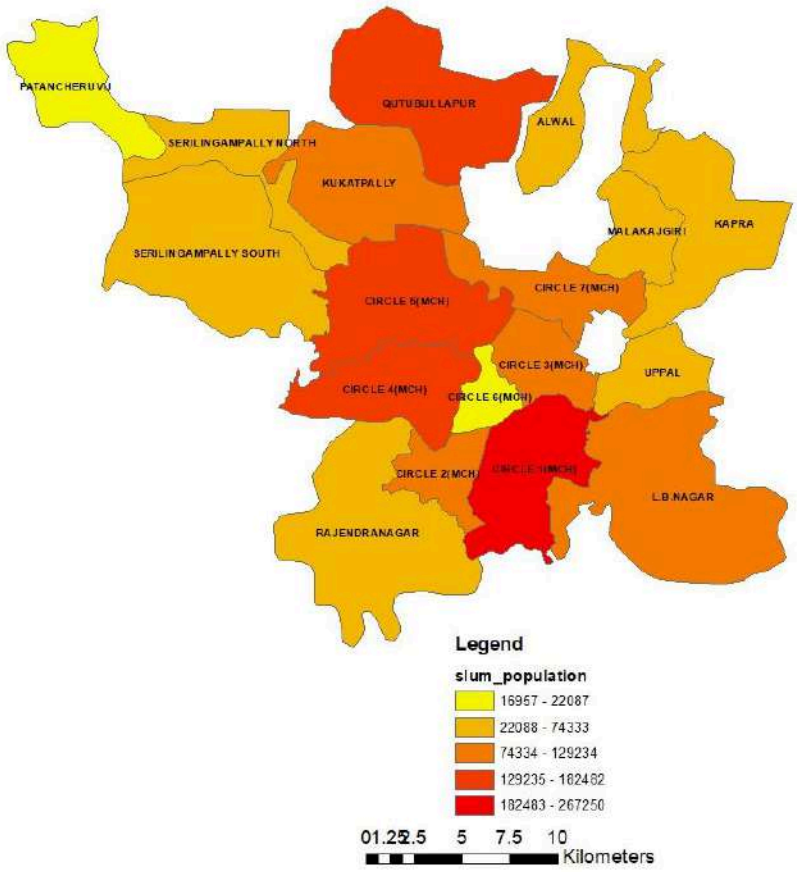


Figure 28: Map Showing Urban Population living in slums of all circles in Hyderabad City
Source data: Census India 2011 & GHMC

Change in Builtup over decades

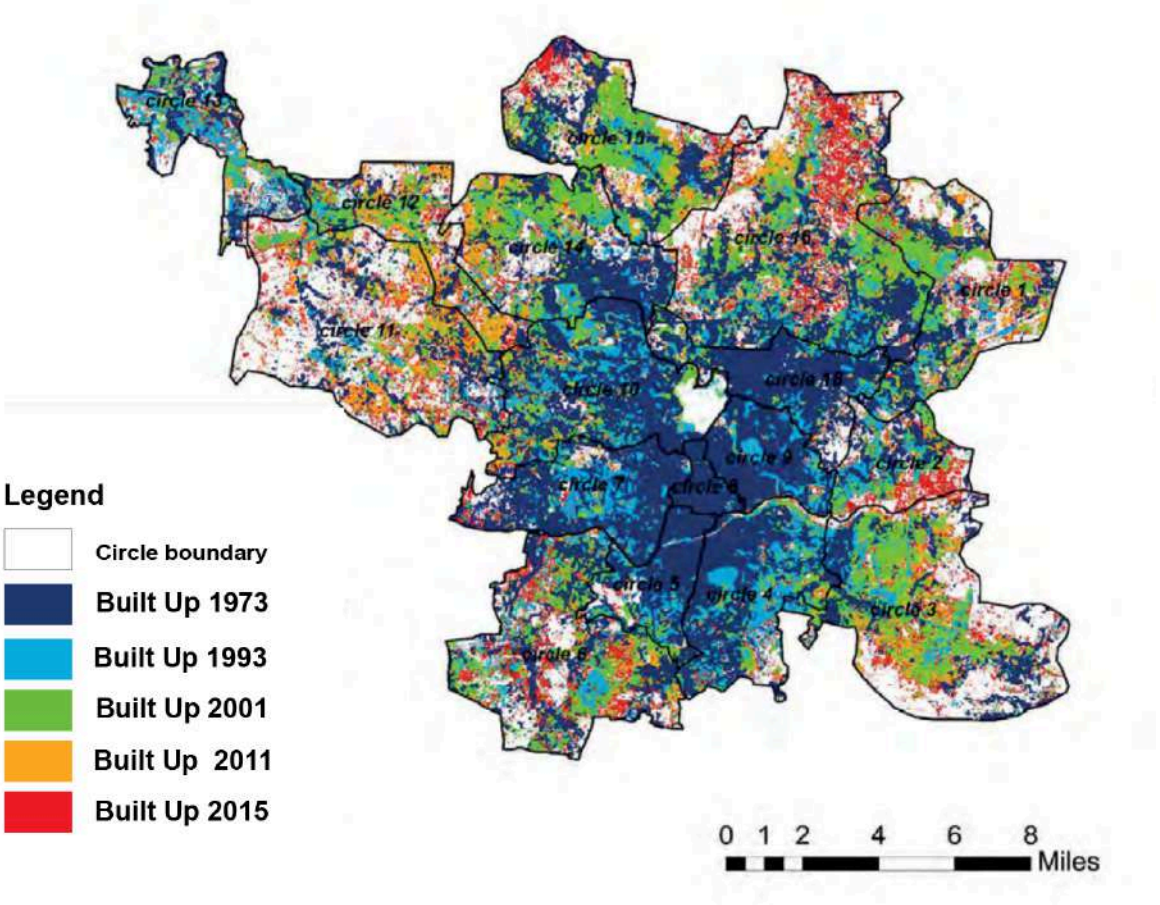
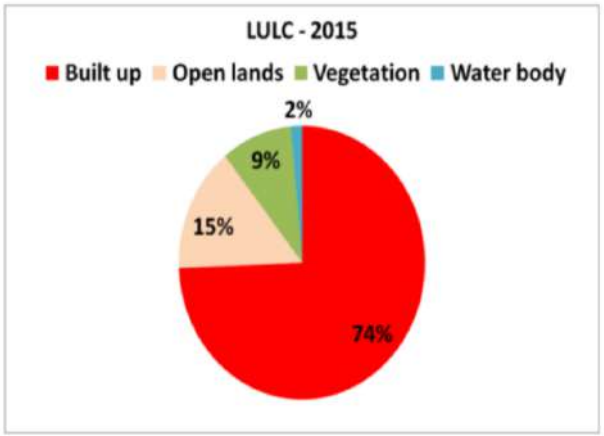


Figure 29: Land use land cover change of Hyderabad (1973-2015)
Source: map used from (Srikanth, 2017)



Urban Areas exhibit a marked contrast in their land use patterns and settlements, as compared to natural landscapes like forest and water bodies. Buildings, roads and other infrastructure tend to absorb and radiate more heat from the sun, leading to a difference between the older and newer parts of the city. According to Hyderabad Metropolitan Development Authority(HMDA) reports, 74% were built up with only 9% vegetation and 2% water bodies in 2015. State authorities estimate that the built-up area will increase by 2040.

Land Surface Temperature of Hyderabad city

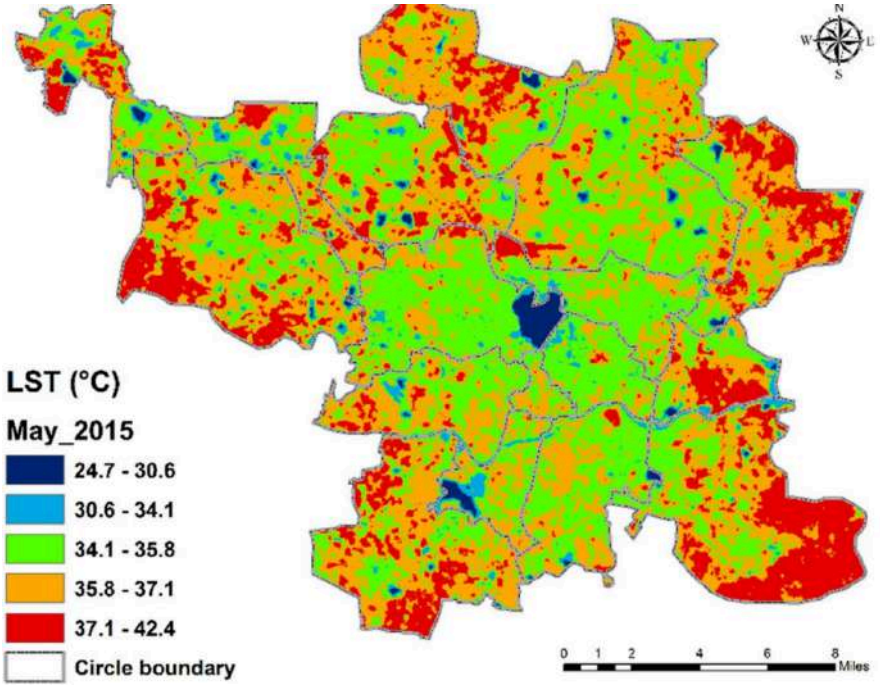


Figure 30: Land surface temperature of Hyderabad (2015)
Source: map used from (Srikanth, 2017)

Land Surface Temperature is the temperature of the earth's surface helps us to understand the profile of the land in interaction with water and energy with the atmosphere this map gives us the insight of how urban concrete plays a role. The average temperature of the land surface was around 34.1-36.0 in May 2015, which is the summertime of the year in Hyderabad.

UHI of Hyderabad City

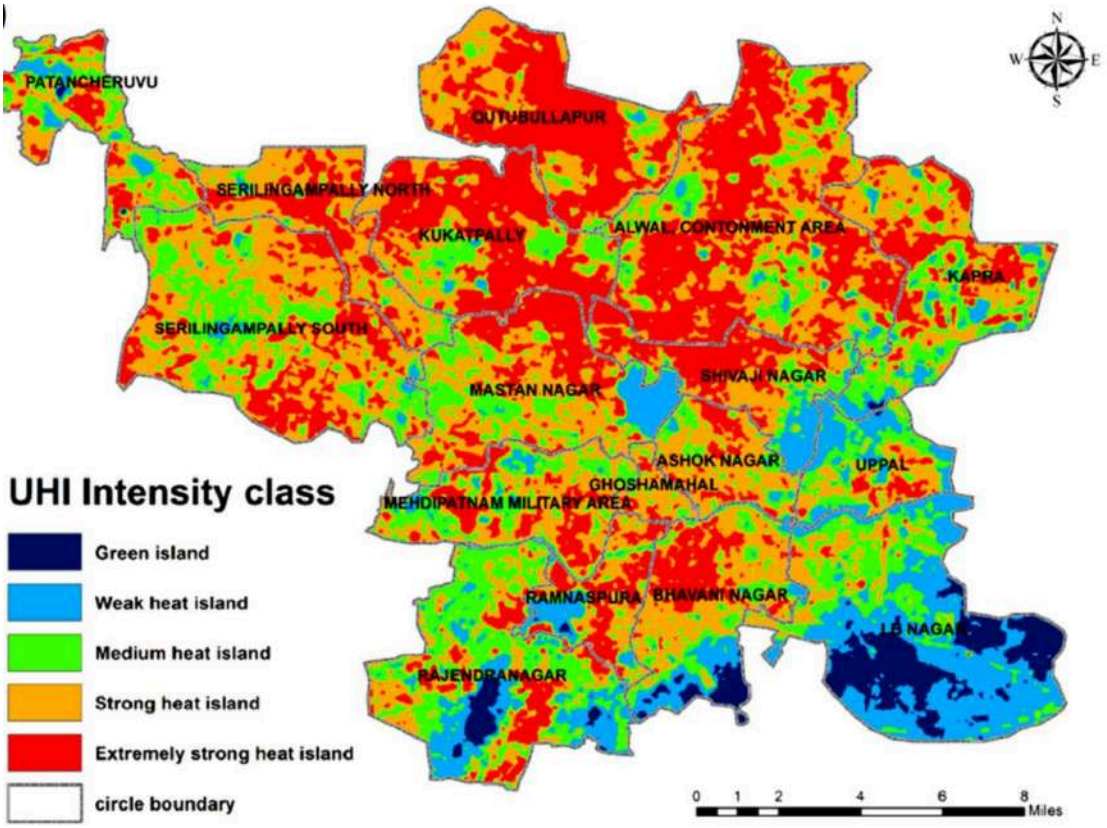


Figure 31: UHI of Hyderabad (2015)
Source: map used from (Srikanth, 2017)

The five distinct islands in UHI intense classes provide insights into the strong heat island effect. The southern and eastern parts are significantly cool because of water bodies and reserved sites. However, most of it ranges from extremely strong heat island to strong. In the southern part of the region of the old city where the site is identified shows an extremely strong heat island effect in the informal cluster of the Charminar area. The government of Hyderabad has identified the vulnerable areas and has been practising to address these consequences.

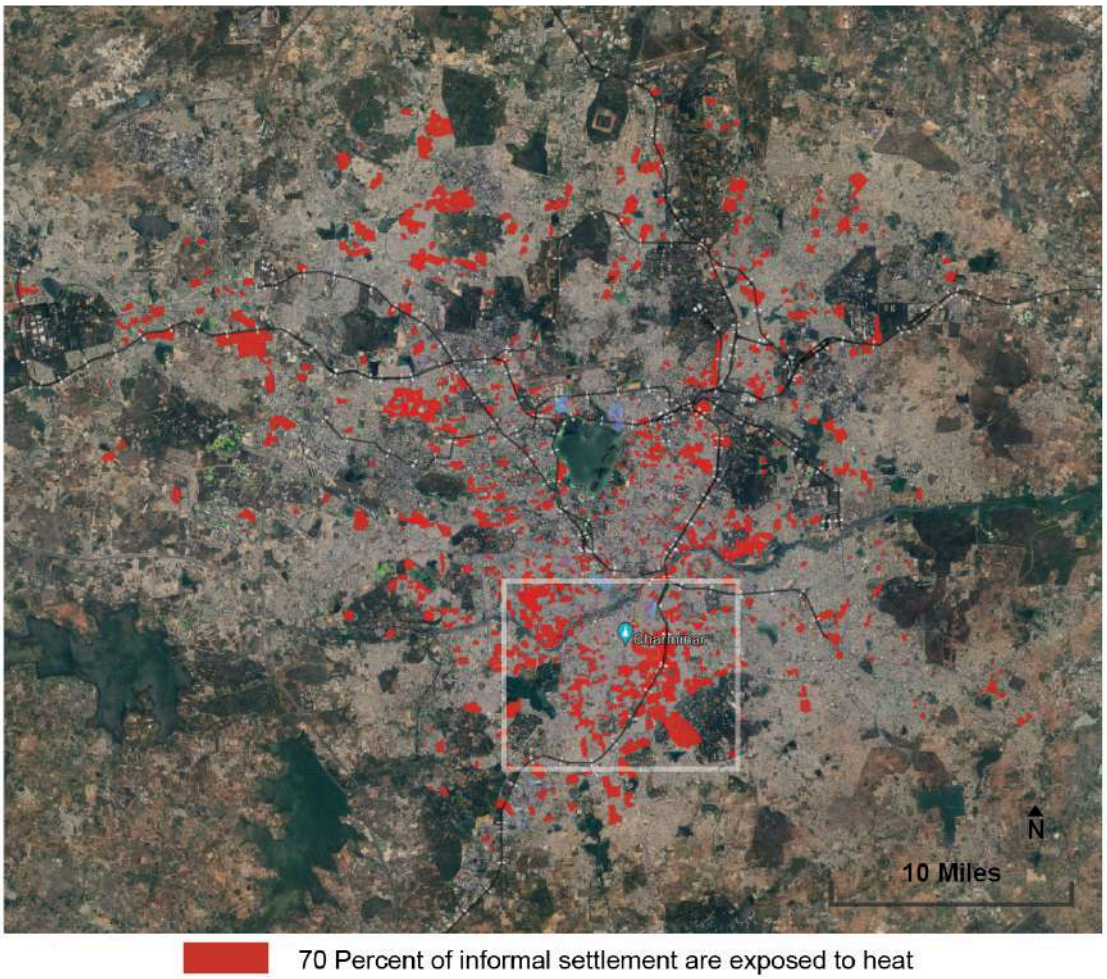


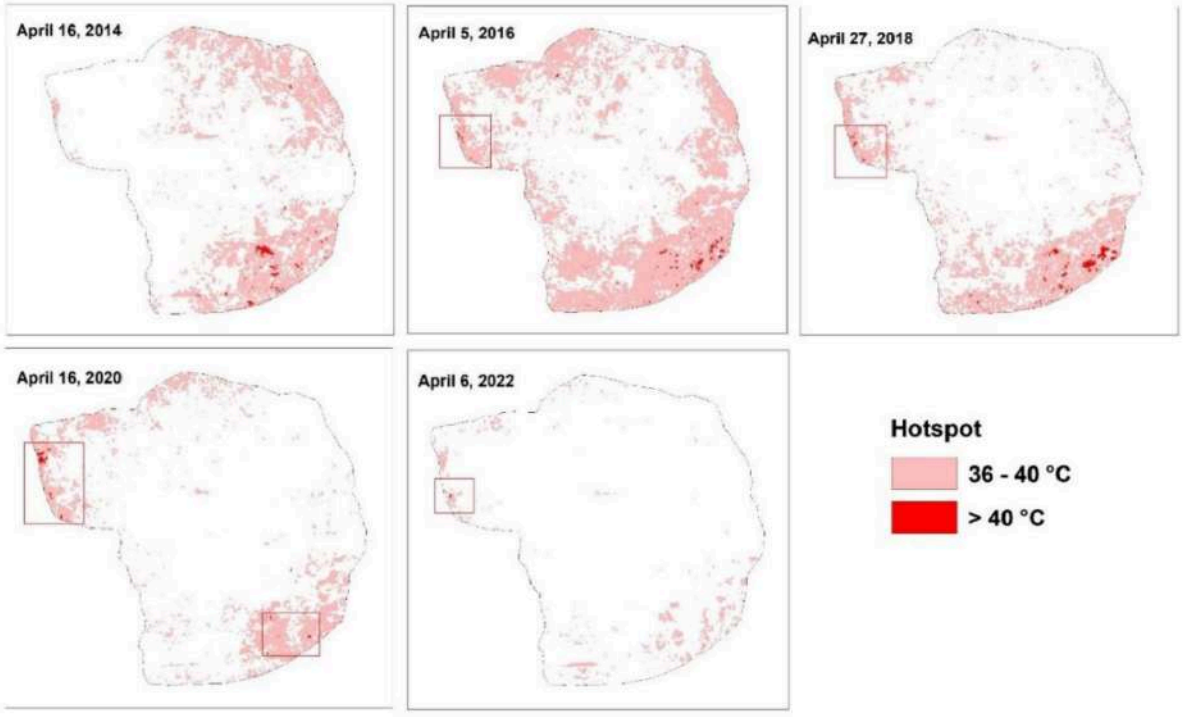
Figure 32: Map Showing Concentration of Slums Overlapped with Heat Hotspot.

By understanding through maps the prevalence of reported slums in regions such as Charminar, which has the greatest concentration of extreme heat waves, we can pinpoint the risk of informal settlements and rank them with the Charminar area.

Chapter 4: Results

4.1 The Vulnerability Maps

Heat Hotspots



Source: CSE analysis of Landsat 8 satellite image from USGS Earth Explorer website

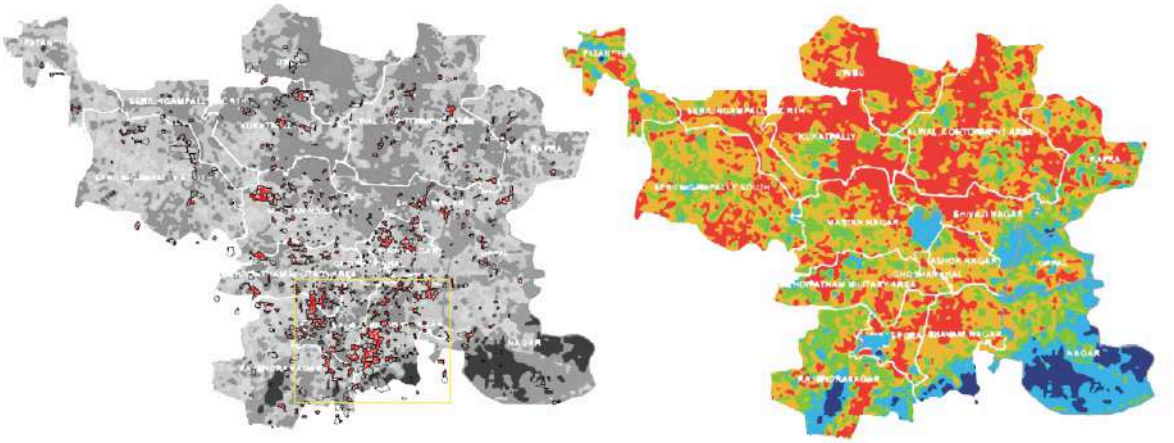


Figure 33:Hot spot Identification over Hyderabad on hot days in 2014,2016,2022
Source: retrieved from Case analysis

1) Ranking of zones UHI over Informal Settlements

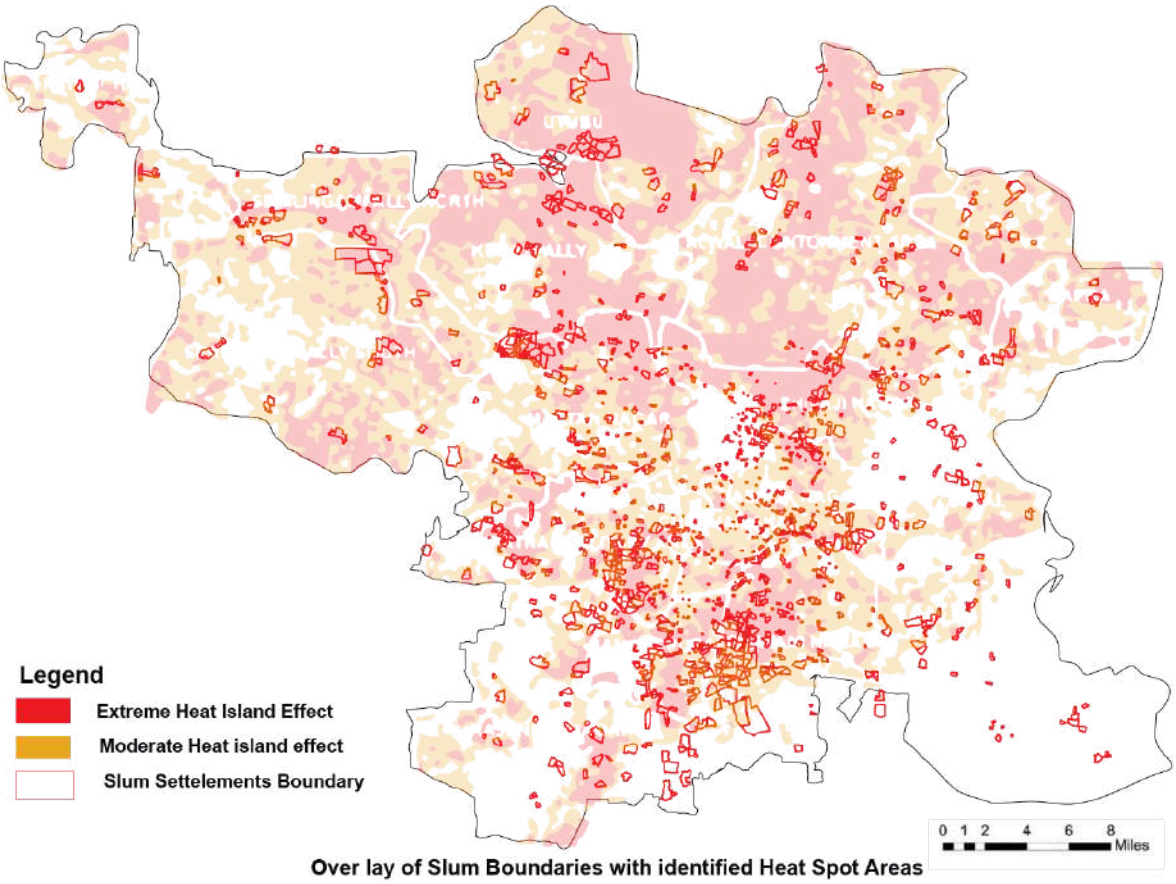


Figure 34:Vulnerability map of slums over UHI effect

The intention was to understand the heat profile of the city, its geographical features, its urban problems, and man-made and natural hazards. Figure 34: Urban Heat Island are classified as extremely strong heat Islands, strong Islands, or medium heat islands, and where there is green cover and water bodies are present, they are shown as green islands and weak heat islands. Upon that, the identified slums layer of the Hyderabad layer created in QGIS was overlaid. This helps us to identify the heat hotspot zones. This method helps us to prioritise the vulnerable areas to be assessed further. The settlements with a strong correlation with heat were identified, which helped us narrow it down further to the site. This method was adopted to get the maximum results and further implement solutions.

2) Ranked Zone for further local study

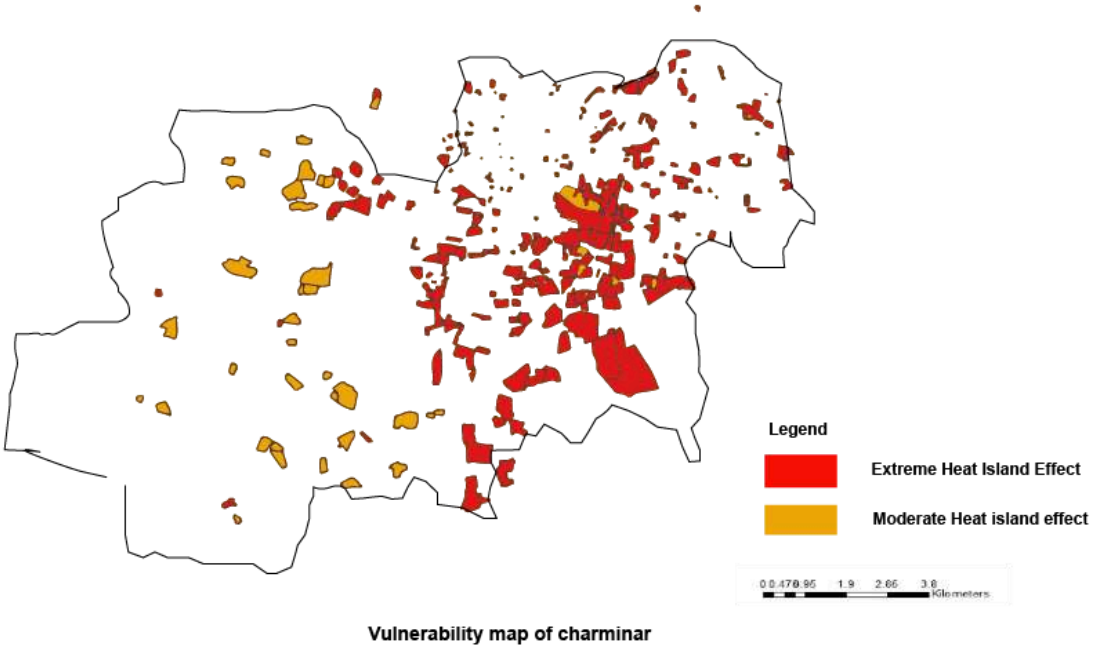


Figure 35: Identified High Vulnerable zone and the site

Site selection criteria

Step 1: Slums inside the urban fabric were identified using ward data of each circle to identify the slum cluster. Overlaying the UHI maps, it was observed that UHI impact is more in dense urban fabric with no green cover and a high degree of informality.

Step 2: In step two, the circle 9 Charminar area from *(figure 36)* below has a larger percentage of the slum population living in high-density slums. This was done to address the settlements that are more prone to problems to obtain maximum results and adaptive solutions.

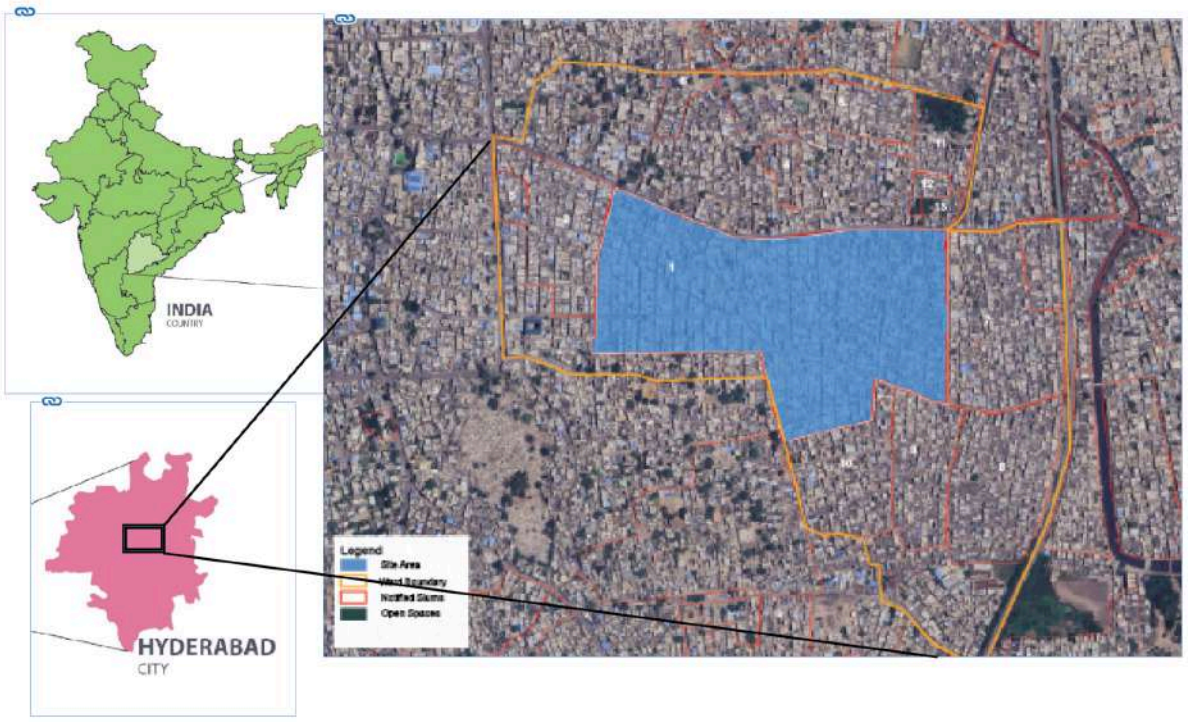


Figure 36 Site surrounding functional structure

Site Context & Analysis

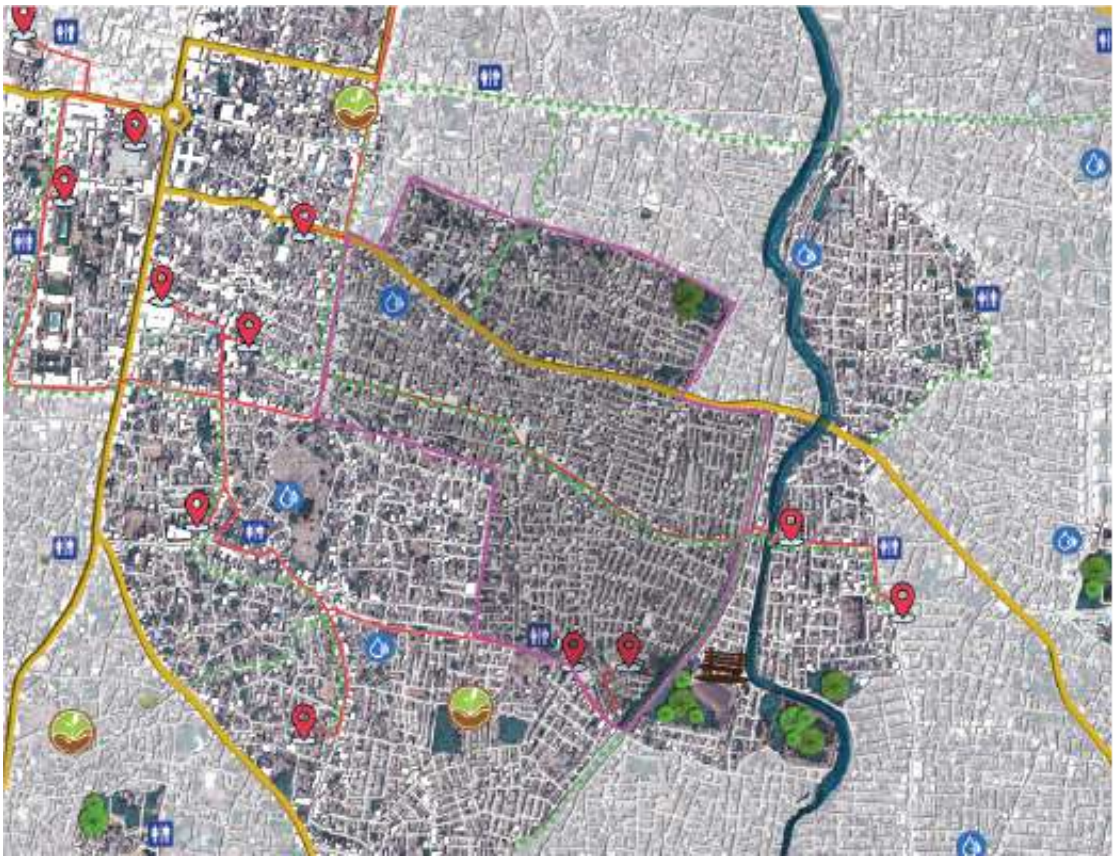


Figure 37: Map Showing neighbourhood with surrounding informal settlements

Figure 37 shows that the slums are overly dense, forming a high density of urban concrete jungle. We can see that the historic core that existed from Nizam's time has high Heritage value in terms of buildings, monuments, the heritage market, and the pathway. The slums that exist now have survived over the decades despite the people living in the slums falling below the poverty line. They need more basic infrastructure, poor drainage networks, less than 4% green cover, and poorly maintained roads. There is no solid waste management dump yard in the surroundings. Talab katta belongs to Ward 39, in which there are 13 notified slums and four unnoticed slums.it is essential to understand that the slum upgradation process involves a collective effort of the surrounding slums, which have almost the same problems as a whole.

The *figure38* below is the Moti Nala, the stream at the bund of the Talab katta - erstwhile Mir Jumla Tank and winds its way into another Nala that flows along the railway line to join the Musi River finally. Until the 70s, this nala actually brought clean, fresh water, but after the growth of residential and commercial areas and the death of the tank, this Nala became the carrier of large quantities of black water. It is now fenced off in some places, covered in some places, cuts across the road in some places and passes along or through the middle of the road in some stretches.

Figure 38: Moti nala line

4.2 Talab Katta informal settlement Case study

Site Conditions Talab Katta also known as Murad Mahal, was once farmland which helped the cultivation of crops during the Nizam rules. As times have changed, many immigrants in the form of urbanisation have entered the locality and created a very mixed culture. The lack of proper governance has caused a very compact form of lifestyle in these parts, which has become a breeding ground for many issues. Class conflicts are very common, where even the poor take big loans to build houses and become debt-ridden. Compactness has been a major limiting factor as it becomes tough to deploy any sort of development without public intervention or without hindering their day-to-day activities. The lack of public Toilets makes their Holy and religious Masjids turn into Sulabh complexes for all the shops and street vendors. Improper electricity supply causes voltage problems, thus creating security and functional issues, especially during night times or during business hours.

Figure 39: Settlement features of the area Source: Authors illustration

Field Study of Talab Katta Informal Settlement

The site study was a direct and empirical investigation of their living conditions carried out through visual surveys and interviews with the locals. An interview with the local municipal planner, Dr Rajender Reddy, helped strengthen the study's insights.

Street hierarchy Through the figure-ground analysis, the conclusion of gridiron and angular patterns are observed in the area. But, upon the site visit, there are multiple junctions where these patterns collide, creating spaces where up to 5 or sometimes even 6 different roads meet up. This creates extreme amounts of confusion and can also be a potential for accidents if not carefully manoeuvred. The Road widths vary from 4 to 6 meters, with the major spine running around 8 meters in width.	
Waste disposal Waste Disposal is the biggest issue here. Extreme levels of unhygienic practices are followed. The major junction of this area is riddled with a ton of waste from the entire locality. The municipality does come to clean every day, but even a slight delay can cause immovable levels of dumping in this area. Earlier, soldiers or police would	

accompany them weekly during the cleaning services a few years ago. Now, things have deteriorated, according to the local	
Health Conditions. The area is bugged with diseases such as typhoid and dengue. These are communicable diseases that spread from person to person. Two easily identifiable scenarios could be one where they come from people who live on the edges close to the drainage canal or the railway track and the second from the meat sellers and restaurant owners around the junction where the Garbage is dumped, especially during monsoon season where all the garbage would flow into the shops.	
Medical camps and facilities There are a few clinics in the area that can help by sending an ambulance during emergencies, but no specific hospital for any major surgeries that may be required in tight schedules, with the closest being 12km away. Medical camps are held once every 4-5 years, primarily during the time of elections.	

Paved/unpaved roads The concept of pavements is lacking in this area, and no proper hierarchy has been achieved in terms of urban mobility. Proper signage can improve the situation to an extent.	
Single-floor ***structures*** Despite infrastructural development in the area, a lot of the houses are still single- or double-storeyed, and they are not primarily connected to the central urban nodes.	
Development in terms of the sewerage lines is ongoing, but the biggest issue is the big Drainage Canal, which flows into the Musi River a few km further. This canal is filled with Garbage and is left completely open, adjoining a bunch of houses that shall later move in and around the locality.	
Trees are almost non-existent in this area, causing the most urban heatwave in these parts. The biggest trees would also not have branches wide enough to cover any part of the road. It is a sad state of affairs that the land that was used for cultivation is practically devoid of any natural elements now.	

Open spaces The Playground here is the biggest open space that can be identified in these parts. Other than that, a few empty spaces are observed under the pretext of either a dump yard for waste, vacant land or just space that is under construction.	
Old structures Mostly, the Old structures here include a few masjids or underdeveloped Houses. The primary attraction must be the proximity aspect to the iconic building of Charminar.	

Density among buildings

The concept of Compound walls or fencing is not reminiscent in these parts, especially those built much earlier. Henceforth, even middle-class families share a similar housing pattern, which lacks proper Boundaries, and share their walls with neighbours.

Figure 40: Narrow alley between settlement blocks Source: Author

The dwellings at talab katta are laid out in a gridiron pattern, but they are very closely packed. The brick units are one-storeyed and are separated by narrow alleys that also serve as stormwater drains. Windows of the units open out onto these small alleys. Water storage drums are placed in these alleys, and most of the washing and cleaning activity also takes place here. Unfortunately, most of the drains are in a damaged condition, and they are often strewn with garbage. This leads to clogging and the collection of contaminated water, resulting in unhygienic conditions that create a breeding ground for mosquitoes. Consequently, vector-borne diseases have become prevalent in the area.

Streetlights Ample amount of streetlighting is present on the primary Spine of Talab Katta and also on certain cross junctions of the secondary roads. But there are certain corners or dead ends that do not greet Boundariesighting during the nighttime.	
Shading areas: The area lacks shaded areas such as trees, bus stops, etc. The only possible shade attainable is by entering a street-facing shop or café.	

Parks The Locality Does not have an adequate number of trees, let alone Parks. This creates a very Poor Social Belongingness within this area. Proper Parks shall help people Socialize and share knowledge, information, and an opportunity to tackle their neighbourhood's problems in a more efficient manner	

Figure 41: Problems identified in Talabkatta in Hyderabad, India (Source: Authors illustration)

3.6 Synthesis of Case Study

Table 11: Synthesis of the case study

Levels	Indicators	Observation of Site
ENVIRONS	Location	Close to the highway. Major Roads, Railway stations, and Canal Along Musi River are prone to Seasonal Flooding, Steep slopes, marshy land, and previous Roads.
	Neighborhood characteristics	Poor -low-income status group; not close to any employment opportunities such as CBD;
SETTLEMENTS	Shape Density	Irregular, Unorganised & Scattered. Highly Dense Buildings(Roof coverage above 80%) Low Vegetation & Open spaces(Vegetation less than 10%)
OBJECT	Building Characteristics	Shape-Variable; Size-10-40m2; roof material -Corrugated iron sheets, tin, concrete, plastic; colour-Variable; Often regular orientation but clumped together.

4.2 UHI Report (Local Scale)

Methodology & analysis

The steps followed to evaluate this informal settlement were as follows:

1. A high-resolution Google Map was obtained for the entire area of the settlement.
2. A detailed 2D map of the settlement demarcating roads and pathways, built form on the ground and extensions to the first floors, tree canopies wherever present, open spaces wherever present, was created to scale.
3. A 3D model of the entire site was prepared, including the varying elevations of all the structures. Windows were not considered, as the site was built on a large scale. The undulating rooftop fabric was captured accurately to represent inter-shading patterns.
4. The settlement was then geo-located to represent the weather and climate data accurately for the simulation-based analysis - Golconda, Hyderabad, India, Asia.
5. To create a Solar Exposure heat map, The 3D model was run through a series of simulations using ShadeDat for Irradiance mapping, collecting the total solar exposure of all parts of the site. The following iterations were run:

A. Built form only.
B. Built form + Existing Trees
C. Built form + Existing Trees + Proposed Trees

6. Based on the inference gathered, zones were then divided into three types:

A. Critical
B. Warm
C. Safe

7. Critical and Warm zones were evaluated in terms of location and area and mapped out on a 2D drawing.
8. Additional interventions were then recommended for these zones as follows:

A. Warm - Cool Roof Insulation
B. Critical - PV Panels + Cool Roof Insulation

Data Acquiring

A high-resolution Google Map was obtained for the entire area of the settlement. A detailed 2D map of the settlement demarcating roads and pathways, built form on the ground and extensions to the first floors, tree canopies wherever present, open spaces wherever present, was created to

scale. A 3D model was prepared of the entire site including the varying elevations of all the structures. Windows were not considered, as the site was built on a large scale. The undulating rooftop fabric was captured accurately to represent inter-shading patterns.

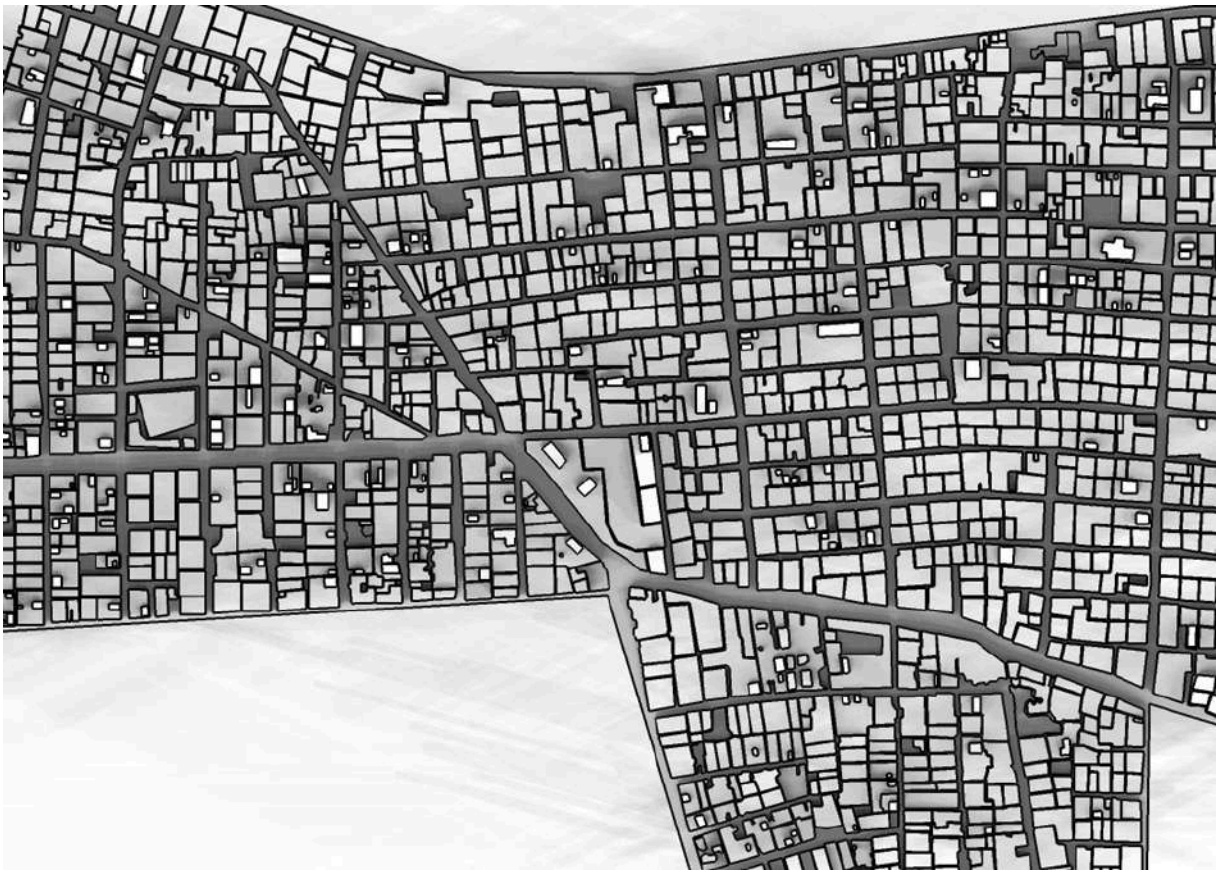


Figure 42: high-resolution image taken and drafted the roads and building layers

1. Climate Data

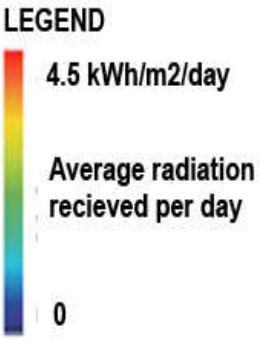
The settlement was then geo-located to represent the weather and climate data accurately for the simulation-based analysis - Golconda, Hyderabad, India.

1. Heat Maps of 3 Scenarios

The 3D model was run through a series of simulations using ShadeDat for Irradiance mapping, collecting the total solar exposure of all parts of the site, to create a Solar Exposure heat map. The following iterations were run:

A. Built form only

Figure 43: Simulation Map considering Built form only



Observations:

1. Predominant range is seen to be from Orange to Red, i.e., settlement built form receives high amounts of solar radiation.
2. Streets are seen to be yellow to blue, which is due to the high density of the built form, providing some relief through shade at the ground floor level.

b) Built form + Existing Trees

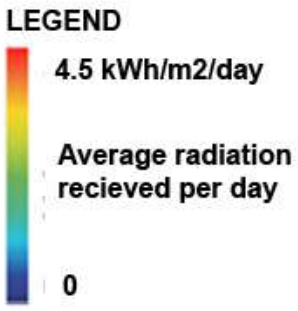
figure 44:Simulation Map with built form & Existing trees

Observations:

1. Predominant range is seen to be from Yellow to Orange, i.e., settlement built form is receiving high amounts of solar radiation, but it has reduced in many zones due to the tree presence. Relatively safe zones are now apparent due to diffusion by the tree cover.
2. Streets are seen to be Blue in most areas as there is shading in the tree clusters, which also cools surrounding roofs.
3. Zones with no trees existing are still in the range of Orange to Red, clearly identifying the most critical zones of the settlement.

C) Built form + Existing Trees + Proposed Trees

Figure 45: Simulation Map Built form with existing & proposed trees



there is a significant drop in the west side of the site where there is a cooling effect; where there are fewer trees planted, we could see how the behaviour of the particular area has a lower effect. Based on the result, the area is divided into three zones: critical, safe and warm zones. The chosen street layer has a more controlled outdoor cooling effect allows us to Understand and propose intervention further

4.3 Climate change adaption measures and their adaptation

Critical, Warm and Safe Zones Based on the inference gathered, zones were then divided into three types: A. CriticaL B. Warm C. Safe Additional Interventions are recommended for critical and warm zones as follows:

A. Warm - Cool Roof Insulation

B. Critical - PV Panels + Cool Roof insulation

C.Green Infrastructure

Cool Roof Installation

Installing a cool roof helps to gain thermal comfort during the day and significant temperature during the night. The best example is the cool roof policy by Ahmedabad City in India, which was incorporated into its action plan. It averages around 30 degrees and brings 3-5 degrees of difference. Implementing this policy in the wider neighbourhood community increases the benefits of affordable thermal comfort adapting to extreme heat.

Green Infrastructure

One of the most implemented and practised NBS is Green Infrastructure. They can mitigate heat stress and climate change impacts (Zölch & Teresa, 2016).

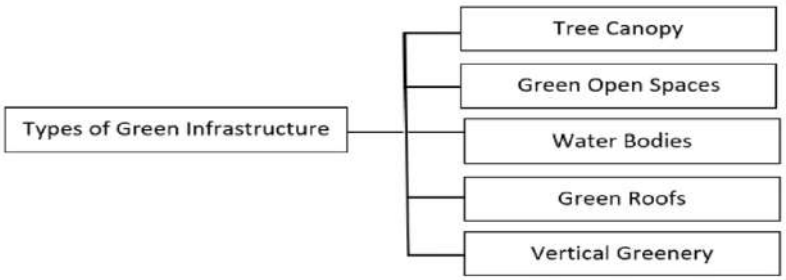


Figure 46: Green infrastructure benefits

Green infrastructure, especially the trees, act as temperature sinks and create cooling effects. Studies confirm that green spaces can extend their cooling effects to urban areas nearby, reducing the Urban Heat Island(UHI) effect. Proved by real-time implementation of Taipei's city green infrastructure. Urban trees can affect air temperature, moisture levels, wind speed, and air pollutants. Trees' characteristics determine their ability to mitigate solar radiation and influence air temperature and humidity(Abreu-Harbich et.al). Trees shade provide evapotranspiration cooling. Mango Tree, Tulip tree, Mirindiba, Malabar plum, and partridge wood are the most efficient tree species for mitigating urban heat island effect(Zolch et al.,2016).

Solar Panels:

Talab Katta informal settlement has potential for solar panels due to its low-rise flat roofs and high temperatures. Promoting solar energy can make the area energy-independent, safe and affordable. The energy load in the settlement helps them face future climate challenges. Modhira village in Gujarat, India, has solar panels on the rooftops of houses and becomes the first energy-independent settlement even at night. First, they utilise it themselves, and the extra electricity is sent to the grid electricity. Adaptation to these can be a reliable light source during blackouts or extreme events.

Solid waste management:

The neighbourhood of Talab Katta is poorly maintained in terms of waste management during the visual survey at the site, proposing adaptive measures to improve drainage clogging at Mulla Nala.

Hyderabad City Issues Identified in Study Areas

Table 12: Issues Identified in Study Area and Recommendations

Urban sector with Issues	**Recommendations**
Urban Planning	Conversion of impervious pavements to porous pavements can recharge water tables instead of runoff.
Albedo Factor	Implementing cool roofs made of high albedo material, and white concrete can help reduce the temperature of buildings and roads.
Anthropogenic heat	Encouraging low-power solar street lightings and panels saves for both individuals and businesses
Urban Vegetation and Forestry	Planting more trees and vegetation through plantation initiatives can help mitigate the effects of climate change and improve the quality of air
Sewerage system	A plan for an underground sewerage system for every house can help prevent water contamination and ensure proper sanitation.
Strom Water Management	Rainwater harvesting Stormwater management through rain gardens to recharge the decreasing groundwater levels., leading to more sustainable water usage

Proposed interventions

Table 13: Proposed adaptive measures and responsibility

Intervention Level	Proposed Strategies	government/ individual/ mix
House level	**Green walls** **Solar Panels** **Rainwater Harvesting pit** **Cool roofs**	mix
Neighbourhood level	**Green Street Scaping** **Solid waste management** **Solar Street LIghting**	government
Municipality level	**Increase public parks and water bodies** **Increase awareness &educate increase**	government

Figure 47: Green infrastructure as a solution in Talab Katta informal settlementsSource: illustration made by author

Figure 48: A neighbourhood Design proposal was proposed contextualising and understanding the need to adapt to heat waves in talab katta.

Chapter 5: Discussions

5.1 Vulnerable areas of Charminar and the GIS-based Analytical Process

The methodology was framed in two parts:

(1) **identifying priority zones** through heat stress vulnerability hotspot maps.

(2) **To propose NBS**(green infrastructure in particular) adaptation measures for the identified site talab katta based on the vulnerable ranking.

The methodology was initially used to identify the vulnerable hotspots for the city. This methodology was adopted and tested on the urban slum population. To rank and address the most vulnerable slums first, the LST map was taken from LANDSAT 8 and classified the land temperature above 42 degrees. Later, it overlapped with slum population data. The vulnerability maps were made based on the assumptions' factors: Sanitation, water, electricity, Health, transportation, housing structures, heat patterns, and population density (*Ellena et al., 2023)*. The data for factors were derived from the local municipality maps (HMDA, GHMC, HMWWS, TSPDCL) and population density manually inserted in GIS, and this was done because there was no readily available data.

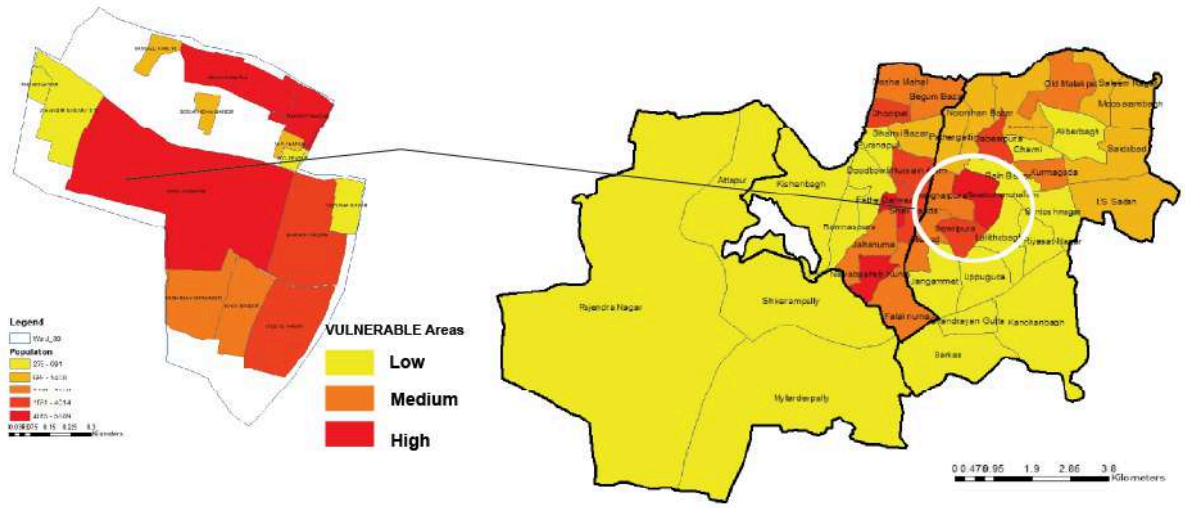


Figure 49: ***Vulnerable Zones Identified in Charminar***

The first step led to the identification of the slum that is talab katta. Firstly, site characteristics were studied through field survey interviews with the locals and GHMC officials. Then, the heat map methodology was created to identify critical, warm and safe zones. This helped to understand the behaviour of the site and propose solutions. Slum residents are exposed to the work conditions in the area.

Secondly, as discussed in the literature review, the benefits of the street-led slum upgrading concept have been realised. An attempt was made to incorporate green infrastructure along the street with a better road width and a space with more economic benefits. This creates a habitable outdoor environment that can be beneficial both ways. Sometimes, this is challenging because the results may look simple and easy. In the long run, the intent and awareness to implement strategically help adapt.

The first and most challenging part was the data collection. The slum ward shape file had notified and not notified slums in Hyderabad; not all were included. As discussed in the literature review, the slum dwellers lack ownership and basic identification. Even if they do, the urban government generally does not give importance much in the order of priority. The Charminar zone has a cluster of informal settlements that have existed for more than 100 years and are neglected as they are the old part of the city. The area is a whole of heritage sites with rich Mughal architecture and the iconic Charminar surrounded by slums. The Musi River once flourished with drinking water. Now, it is a drainage line, and most of the slums are located along the streams. The 2020 flood in Hyderabad was an example of how if we are not prepared for extreme climate conditions, there will be substantial economic loss, and the informal dwellers living in these areas will be the victims of climate change. Due to the least green coverage and very high population density, high temperatures and more hardcovers resulted in heat hotspot areas. This methodology attempted to answer the research question of whether informal settlement clusters with high built density and population density inside urban settings contribute to the UHI effect in the Charminar area. The methodology helped achieve this, yet it can be studied further by considering more in-depth investigation. This was strengthened by the state of infrastructure, including the condition of buildings, roads, and drainage systems. Poorly constructed infrastructure is more vulnerable.

5.2 Climate Adaptation Measures and their Effectiveness

An Approach to the Neighbourhood Upgrading to adapt to heat waves applying green infrastructure in the case study of informal settlement answering the research question

By Applying theory to practice helped to recommend best practices in similar conditions of adaptive measures around the world .desktop study gave insights to understand each slum situation is unique from others. These were designed to serve the community and deal with the problems of basic infrastructure and issues related to thermal comfort(building level), stormwater (street level) and Urban Heat Islands (Neighbourhood level) to withstand the climate change problems.

The research objectives revolve around understanding the heat behaviour around slums. Are they contributors to the effect or the victims of the effect of climate change? This thesis tries to find a way to understand the effects of climate change through the lens of a slum dweller's perspective in an urban environment. This framework offers a powerful solution to tackle the issue of exposure in various informal settlements effectively. We can strengthen policies by incorporating green infrastructure into policymaking, integrating the implementation strategy into heat action plans, and involving relevant stakeholders and local authorities actively involved in climate adaptation efforts. This will help settlements establish a green connection, thereby creating a livable outdoor environment and contributing to the overall adaptive capacity of the city in the face of climate change.

5.3 Green Infrastructure Adaptive Measures & Sustainable Development Goals(SDG)

Role of Green Infrastructure Adaptive measures in informal settlements contribute to reaching the global Sustainable development goals for sustainable cities and communities

Table 14 This table illustrates how specific adaptive measures for Green infrastructure in informal settlements support Sustainable Development Goals for sustainable cities.

Sustainable Development Goal (SDG)	Connection	BGI Contribution to Informal Settlements
	Creating Sustainable Urban Environments. Informal settlements play a significant role in achieving this.	Blue-green enhances Sustainability and increases community engagement Green spaces promote environmental sustainability. The climate adaptive measures enhance resilience.
	Amis to Promote Sustainable Water Management.	Blue-green infrastructure components, such as green roofs and water retention areas, help to optimise water usage and mitigate water-related issues.
 3:	Better and healthier living conditions.	Blue-green infrastructure promotes overall well-being in informal settlements by providing green spaces. Improving air quality and mitigating heat stress.

	Climate Change impacts take urgent action to combat climate change and its impacts.	Implementing climate adaptive measures in informal settlements enhances the community's resilience. Blue, green infrastructure can also mitigate climate effects and reduce vulnerability.
	Affordable and energy-independent in low-income countries,	Increasing energy efficiency is achieved by integrating green roofs and solar panels in housing, which leads to reduced energy costs for residents
	Emphasizes collaborative efforts and partnerships for sustainable development.	Blue-green infrastructure collaboration involves local communities, governments and international partners, aligning with collaboration
	Implement equitable distribution of green spaces in each settlement	Implement equitable distribution of green pockets and basic amenities, and enhance interaction and cohesion.
	End poverty in developing countries	Upgrading in informal settlements helps people generate economic opportunities along the improved streets, and vegetative gardens create opportunity.

Conclusions:

The thesis findings shed light on the relationship between climate change, urban informality, and heat vulnerability in Hyderabad. It has faced multiple climate change issues over the decades, like higher temperatures and changes in rainfall. Due to its geographical situation, the city experiences flooding and heat waves. The problems are even more serious for people living in urban informal settlements. These communities are experiencing extra heat, making them vulnerable to extreme weather. The specific focus on informal settlements allows us to identify areas that experience extreme heat waves compared to other informal settlements in urban scenarios. Looking closely, it was found that people in informal settlements deal with significant extreme urban island problems in some areas with higher temperatures, making heat stress even worse. This means we must focus and prioritise these places to find effective solutions by understanding the most vulnerable areas. The correlation identified between Urban Heat island effects and the location of these settlements highlights the need for targeted strategies that consider the unique environmental context of each community.

The idea of using green infrastructure upgradation like planting more trees and creating more green space at house level, street level, and neighbourhood level is crucial in dealing with climate change problems in informal settlements For the settlements in India, most of them lack open spaces due to high urban density, in these situations, streets can be identified and develop them. UN-Habitat states that the concept acts as a node for green infrastructure and economic opportunities. These upgrades cool down the areas and bring other benefits like cleaner air and more livable conditions. These sustainable interventions align with the socio-economic context and promote inclusivity and community participation in adaptation.

As Cities continue to urbanise and climate change impacts intensify, understanding, analysing and designing appropriate strategies becomes increasingly important. The comprehensive nature of this research aims to guide policymakers, urban planners and community stakeholders in developing context-specific interventions that address the overlapping challenges of climate change and informality. We can make a positive impact by directing our efforts toward building adaptive infrastructure in urban slums, fostering community participation, and considering the distinct characteristics

of cities in developing countries. These actions will help promote and implement adaptive measures in informal settlements, ultimately contributing to achieving global sustainable development goals for sustainable cities and communities.

1) Working together for stronger informal communities

By involving every informal dweller in decision-making, offering training, creating awareness, and involving community leaders, stakeholders, NGOs and the local government, ensuring effective and sustainable efforts to deal with climate change.

2) Smart ideas for better Homes in informal Areas:

Government and organisations should explore innovative solutions for informal settlements by using green materials and low-cost technologies and promoting energy independence. Also, exploring micro-financing and community-driven initiatives to overcome financial constraints.

3) Road map for SDGs in Making Informal Settlements in Urban Areas for a Better Future

Develop government policies aligning with relevant SDGs focusing only on informal settlements for the climate change challenges. Mobilising resources through partnerships between local authorities, businesses and civic society.incorporating SDGs into local Urban Planning Authorities for holistic development, ensuring economic, social and environmental sustainability in informal settlements.

4) Climate Resilient Centre for Informal Settlements

A climate-resilient centre for informal settlements could be a vital physical infrastructure linking local municipalities, local governments and the central government, each holding equal power in the development and management process. This centre would be a collaborative hub, promoting unity and joint decision-making to enhance adaptation to climate change challenges in informal settlements. It could address and manage climate change-related problems directly. It can also facilitate urban planning, infrastructure development, and disaster response, ensuring that policies and initiatives align with the situation of informal settlements. This promotes a more inclusive and effective approach to climate resilience, fostering sustainable development and community well-being.

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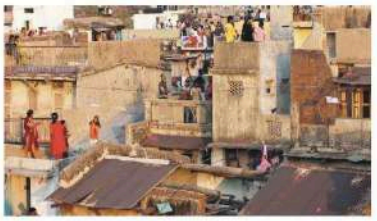
Annexure : CASE STUDIES

Cool Roofs Jodhpur,INDIA In Jodhpur, India, heat mitigation programs provide poorer residents with special reflective white paint to cool their roofs. as part of its HAP. The project, which was supported by NRDC and the Mahila Housing Trust, a local women's group, has had encouraging results. One assessment found that homes with painted tin roofs were at least 1°C cooler than nonpainted ones, and more expensive roofing technologies produced cooling of up to 4.5°C.	
Urban Agriculture Quito,Equador The project aims to tackle climate change, poverty and food provision, by supporting urban gardens on public or private land with community participation. The aims being food security and sovereignty, environmental management, employment and income improvement, social inclusion, sustainability and resilience.Increase amount of green open spaces for residents.Changing image of the urban environment. Urban regeneration. Social justice and social cohesion. Increase wellbeing. Increase awareness of NBS solution & their effectiveness and co-benefits.	
Running water & wastewater management (Kayole Estate) **Nairobi,Kenya** Run by community volunteers and funded with small grants from the localgovernment, Kayole Mtaa Safi has since carried the project forward,removing garbage, planting trees, and setting up playground structureswith the goal of creating a fun and open space for people of all ages,especially children. Sometimes, neighbours donate their time and toolsfor maintenance work	

Cooling Effect: "Green Canopy Initiative" in Rio de Janeiro, Brazil. The successful implementation of green roofs in a slum of Rio de Janeiro, especially in the warm tropics, represents a significant improvement in well-being. The temperature decreases by about 20°C, improving thermal comfort and even making the difference between being exposed to a temperature above or below thresholds of mortality risks. Considering the current scenario of global warming and expansion of slums worldwide, it is clear that well-planned and designed green roofs may represent a feasible solution for improving the well-being of the most vulnerable urban populations.	 - Vegetation and Green Spaces: Planting trees and creating green spaces can help absorb and deflect sunlight, reducing overall temperatures and providing a cooling effect
2. Heat Island Mitigation: "CoolRoof Project" in Los Angeles, USA Green Roofs and Walls: Implementing green roofs and walls on buildings helps mitigate the urban heat island effect by providing insulation and reducing heat absorption.	
3. Shade Provision: "TreeVista Project" in Tokyo, Japan. Urban Forests: Planting trees strategically can provide shade, reducing surface temperatures and making outdoor spaces more comfortable during extreme heat events.	
4. **Water Management:** "RainHarvest Village" in Chennai, India. - Rainwater Harvesting: Harvesting rainwater not only addresses water scarcity but also contributes to cooling through the evaporation process, particularly in green areas.	

Solar Household

Ruimsiq community,SA

With assistance from the South African Federation, 75 households had solar home systems installed in their shacks to provide energy for lighting, radio, TV, and cell phone charging. Once implemented in every home, this program will guarantee cleaner indoor air quality and help reduce the risk of fire in the settlement. In addition to providing low-emission energy poverty alleviation, solar household systems train and employ local technicians to install and maintain the solar panels.

Learnings :
Solar panels help to be energy independant and maintain indoor temperture in control .maintain clean air insideair inside

Cool Roofing for Reducing Heat Stress

Delhi Slums,INDIA

540 households have been covered by this intervention, which may work well in Delhi during the summer. Slum dwellers' lives will be slightly more comfortable as indoor temperatures drop, and the neighborhood will also become more climate change resilient.

Learnings :
The temperature can be lowered by 5–6 degrees Celsius with modular roofs.

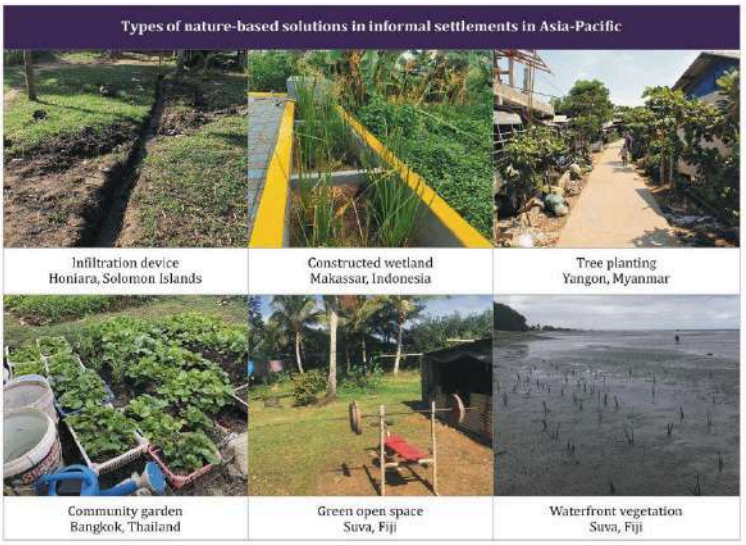


Fig. 1. Examples of NbS identified in informal settlements in Southeast Asian and Pacific Countries.