CLIMATE RISK ASSESSMENT AND ADAPTATION PLAN OF TAMIL NADU

SUSTAINABLE HABITAT

Under

CLIMATE STUDIO

REPORT

2024

Supported by
Department of Environment and Climate Change
Government of Tamil Nadu

Prepared by
Centre for Climate Change and Disaster Management
Department of Civil Engineering
Anna University, Chennai

Dr.P.Senthilkumar, I.A.S.,
Principal Secretary to Government
Environment Climate Change and Forests Department
Government of Tamil Nadu
Secretariat
Chennai – 600 009

PREFACE

The impacts of climate change are being felt across the globe and Tamil Nadu is no exception. As we continue to witness these changes unfold, it becomes imperative that our urban habitats are prepared and resilient in the face of evolving climate challenges. This report, "Climate Risk Assessment and Adaptation Plan for Sustainable Habitat in Tamil Nadu" is a crucial step towards addressing these concerns head-on offering a roadmap for the future of sustainable urban development in our state.

Tamil Nadu, with its rich heritage and dynamic urban growth, holds great potential to become a leader in climate-resilient urban planning. This document is a comprehensive reflection of our commitment to safeguarding our cities and communities from the adverse impacts of climate change. By identifying vulnerabilities, risks and opportunities, it enables us to craft effective strategies for adaptation and sustainable development, which are essential for the well-being of future generations.

The collaborative efforts reflected in this report underscore the strength of partnerships between government departments, academic institutions, and experts. Together, we have not only outlined the challenges but also proposed innovative solutions, from integrating green infrastructure to promoting community-based resilience initiatives. These strategies represent resolve to build sustainable urban environments

Together, let us work towards a sustainable, resilient and climate-adapted future for Tamil Nadu.

(P.Senthilkumar)

Thiru.A.R. Rahul Nadh I.A.S.,
Director
Department of Environment and Climate Change
Government of Tamil Nadu
Chennai – 600 015

FOREWORD

Tamil Nadu is rich in cultural heritage and vibrant urban centers, which faces unique risks and opportunities in the face of climate change. As we stand on the precipice of a rapidly changing climate landscape, it becomes increasingly evident that our urban habitats must evolve to withstand and adapt to these environmental challenges.

The Climate Risk Assessment and Adaptation Plan for Sustainable Habitat in Tamil Nadu is presented in this document will be a milestone in our journey towards building a climate- resilient future for Tamil Nadu in the Sustainable Habitat sector. This comprehensive report not only serves as a testament to the proactive stance of Tamil Nadu in confronting climate change but also provides a blueprint for sustainable urban development in the region. By delving into the intricate interplay between climate variables and urban infrastructure, this document offers invaluable insights into the vulnerabilities and resilience of our cities.

The Adaptation Strategies outlined in this plan offer green infrastructure initiatives to community-based resilience programs and these a multifaceted approach in building climate resilience. By integrating nature-based solutions and technological innovations, we can forge a path towards sustainable urban development that benefits both present and future generations.

As we embark on this collective endeavour to safeguard Tamil Nadu's sustainable urban habitat, let us remember that the task at hand is not merely about mitigating risk but also about building resilience, fostering equity, and preserving the essence of our communities. This report serves as a guiding light in our pursuit of a more sustainable and resilient future for Tamil Nadu.

I extend my sincere gratitude to Dr.P.Senthilkumar, I.A.S., Principal Secretary to the Government, Environment, Climate Change and Forests Department for his

valuable guidance and unwavering support in the successful operationalization of the Climate Studio.

I appreciate the efforts of Dr. Kurian Joseph, Professor & Director, Centre for Climate Change and Disaster Management, Dr. A. Ramachandran, Emeritus Professor, Centre for Climate Change and Disaster Management and research team of Climate Studio for collecting, collating and analyzing scientific information from various sectors and compiling the report in the present form.

I would like to extend my appreciation to all the Government line Departments and Institutions for their valuable contributions by providing essential data and information, which played a crucial role in the successful operationalization of the Climate Studio project.

(A.R. Rahul Nadh)

TEAM – CLIMATE STUDIO

PRINCIPAL INVESTIGATORS	:	Dr. Kurian Joseph, Professor & Director, CCCDM
		Dr. A. Ramachandran, Emeritus Professor, CCCDM & Member, Chief Minister's Governing Council on Climate Change
		RESEARCH TEAM
CLIMATE MODELING	:	Dr. R. Geetha, Project Scientist
		Ms. K. Sathyapriya, Project Associate
WATER RESOURCES	:	Dr. L. Balaji, Project Scientist
		Dr. R. Malarvizhi, Project Associate
SUSTAINABLE AGRICULTURE:		Dr. S. Pavithrapriya, Project Scientist
		Mr. P. Praveenkumar, Project Associate
FOREST ECOSYSTEM	:	Dr. S. Hariharan, Project Scientist
		Dr. M. Mithilasri, Project Associate
COASTAL ECOSYSTEM	:	Dr. Madavi Venkatesh, Project Scientist
		Ms. S. Nivetha, Project Associate
SUSTAINABLE HABITAT	:	Dr. Divya Subash Kumar, Project Scientist
		Mr. S. N. Ahamed Ibrahim, Project Associate
GEOSPATIAL INFORMATION	:	Dr. M. Mathan, Project Scientist
WEB PORTAL	:	Mr. K. Asan Basheer, Project Associate
ADMINISTRATION TEAM	:	Mr. D. Murali, Superintendent
		Ms. H. Janani, Project Assistant
		Mr. S. T. Udhayachandran, Project Assistant

ACKNOWLEDGMENT

We sincerely acknowledge the support and encouragement by Dr. P. Senthilkumar, I.A.S., Principal Secretary to the Government, Environment, Climate Change and Forests Department. We express our sincere gratitude to Tmt. Supriya Sahu IAS., former Additional Chief Secretary to Government, Department of Environment, Climate Change and Forests, Government of Tamil Nadu, Thiru. A.R. Rahul Nadh IAS., Director, Department of Environment and Climate Change, Government of Tamil Nadu and Thiru. Deepak Bilgi IFS., Chief Mission Director, Tamil Nadu Coastal Restoration Mission, for the successful execution of the project "Operationalisation of Climate Studio" and in completion of the Climate Risk Assessment and Adaptation Plan for the key sectors of Tamil Nadu.

We humbly acknowledge Prof. Dr. R. Velraj, the former Honourable Vice Chancellor, Anna University, Prof. Dr. K.P. Jaya, Head of the Department, Department of Civil Engineering, Dr. K. Palanivelu, Professor, CCCDM, Dr. R. Saravanan, Professor and Director, CWR and the adjunct faculty of CCCDM, Anna University for their valuable inputs and expertise. Further, we acknowledge the support from the following departments for providing the necessary data for the completion of the Climate Risk Assessment and Adaptation Plan for the key sectors of Tamil Nadu:

- Department of Environment, Climate Change and Forests (DoE&CC), Government of Tamil Nadu
- Indian Meteorological Department (IMD), Ministry of Earth Sciences, Government of India
- Central Ground Water Board (CGWB), SECR, Ministry of Jal Shakthi, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India
- State Planning Commission (SPC), Government of Tamil Nadu
- Tamil Nadu Agricultural University (TNAU)
- Department of Agriculture, Government of Tamil Nadu
- Department of Animal Husbandry, Government of Tamil Nadu
- Department of Fisheries and Fishermen Welfare, Government of Tamil Nadu
- Department of Statistics and Economics, Government of Tamil Nadu
- Department of Water Resources, Government of Tamil Nadu
- National Centre for Coastal Research (NCCR), Government of India
- Tamil Nadu Pollution Control Board (TNPCB), Government of Tamil Nadu
- Institute of Water Studies (IWS), Tharamani
- Institute of Remote Sensing (IRS), Anna University

We sincerely thank other project staff and administrative staff of CCCDM for their continuous support towards the successful execution of the project.

EXECUTIVE SUMMARY

Anthropogenic climate change stands as a formidable barrier to achieving sustainable development, exacerbating the severity and frequency of extreme weather events. These events unleash cascading effects, both direct and indirect, impacting millions of lives and wreaking havoc on natural resources. The repercussions reverberate across key socio-economic sectors such as water resources, agriculture, forestry, biodiversity conservation, coastal ecosystems, and urban habitat sustainability. This sobering reality necessitates a critical evaluation of comprehensive climate change risks across sectors, employing scientific methodologies to formulate effective adaptation strategies. Crafting adaptation strategies tailored to specific sectors demands the active involvement of key stakeholders including government departments, communities, and individuals. Collaborative efforts are essential to implement science-based action plans at all levels, ensuring the availability of water resources, enhancing food security, safeguarding public health, preserving biodiversity, maintaining ecosystem services, and fostering equitable and inclusive socio-economic development. Successful adaptation measures not only alleviate climate risks but also contribute to achieving the Sustainable Development Goals, particularly in eradicating extreme poverty and hunger (SDG 1,2), and reducing risks to ecosystems, water, food systems (SDG 3,6,15), human settlements (SDG 11), and overall well-being complementing Climate Actions (SDG 13).

Climate Studio at CCCDM

Embracing its commitment to the Nationally Determined Contribution (NDC), Tamil Nadu has emerged as a pioneer in formulating and implementing the adaptation and mitigation strategies across the key sectors. Utilizing the acclaimed IPCC framework on "Climate Change Risk Assessment," the Government of Tamil Nadu has established the 'Climate Studio' at the Centre for Climate Change and Disaster Management (CCCDM), Department of Civil Engineering, Anna University. This state-of-the-art facility, supported by GIZ, Germany which is with equipped with high - performance computational resources and digital learning tools

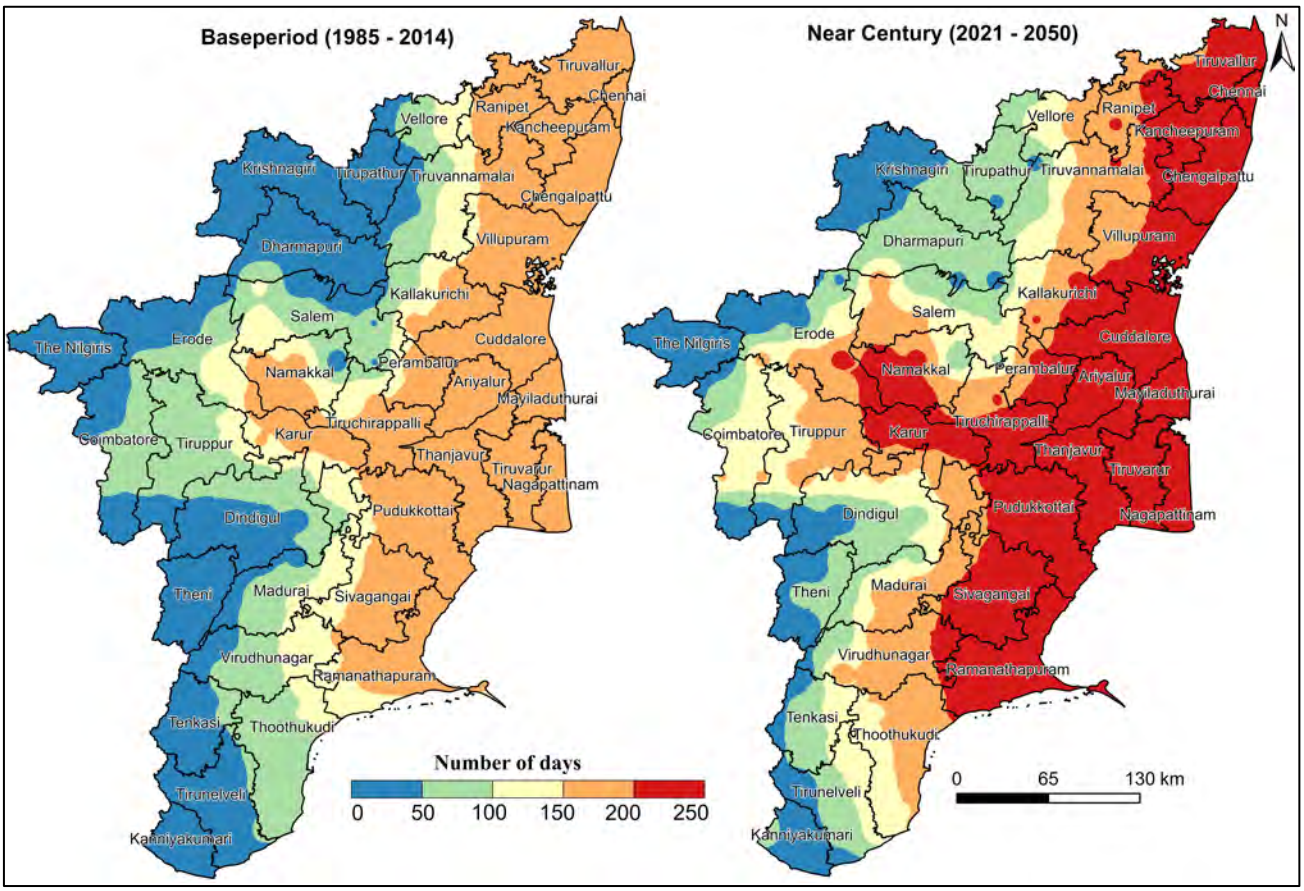
and operationalized by the Government of Tamil Nadu with the amount of Rs. 3.8 crores, to analyse climate impact on key natural resources. The Climate Studio aims to provide updated high-resolution regional climate scenarios, assess climate change impacts on natural resources, develop multi-sectoral spatial risk information, and train stakeholders through capacity-building programs and workshops. Over 250 sectoral officials and thousands of participants have been trained and sensitized, fostering a climate-resilient future for Tamil Nadu.

Climate Change and Sustainable Habitat

Climate change poses significant challenges to creating sustainable habitats as per the IPCC agenda. Sustainable habitat initiatives as envisaged in Sustainable Development Goals (SDGs) such as 6,7, 11 and 13, *inter alia* UN New Urban Agenda (2020) are the primordial components for the micro-level study of urbanization. In line with the international protocols, India's priority towards climate change and sustainable habitat lies in fostering low-carbon, resilient urban development through the National Mission on Sustainable Habitat and NDC. The state of Tamil Nadu through its ambitious Tamil Nadu State Action Plan on Climate Change (TNSAPCC) emphasizes promoting measures such as green infrastructure development, efficient waste management systems, renewable energy adoption, and climate-resilient urban planning to mitigate climate change impacts and enhance urban sustainability. The present study analyse the extent of climate risk on the urban habitat of Tamil Nadu with key indicative parameters influencing the city climate risk. Adequate pre warning system and forecasting system are highly requiring for the risk management, preparedness and recovery.

Thermal Discomfort

The assessment for Sustainable Urban Habitat in Tamil Nadu reveals critical insights into the climate vulnerabilities and resilience strategies across its urban landscape. From 1985 to 2014, escalating thermal discomfort conditions, particularly in the northern coastal regions, have significantly impacted urban areas. Comparing to the 150 days of discomfort days in baseline period, projections indicate a concerning trend of increasing thermal discomfort days, reaching up to 250 days per year by the Near Century. Spatiotemporal analysis of Urban Heat Intensity and assessment of urban green cover reveal alarming trends, with Chennai exhibiting the least extent of green cover.



City Climate Risk assessment

City Climate Risk assessment highlight that cities in the northern coastal regions viz. Greater Chennai Corporation and the surrounding areas of Avadi, Tambaram are having high level of climate hazards and exposure. The cities viz. Tirunelveli, Trichy, Thanjavur, Kumbakonam, Madurai, Sivakasi, Dindigul, Nagercoil, Kancheepuram, Thoothukudi, Cuddalore and Salem are cities with moderate risk to climate change, while Karur, Tiruppur, Hosur, Coimbatore, Erode and Vellore face low risk.

TN Climate Smart Cities assessment

The analysis focused on the following five thematic sectors:

- *Urban Green Cover and Biodiversity:* Coimbatore city performs fairly well in terms of urban planning.
- *Energy Efficiency and Green Building:* There is a need for extensive data to be prepared and resilient to climate change impacts.
- *Mobility and Air Quality*: Coimbatore city has taken up most strategies towards the maintenance of air quality.

- *Water Management*: Madurai city has relatively fared well with respect to water management strategies.
- *Waste Management:* Chennai has performed better than other cities overall.

Adaptation Strategies

The Chennai being the most populous capital city of the state and high level of exposure to climate hazards resulted in initiation of more number of actions and strategies done by the government local bodies and hence emerges as a leader in climate readiness, yet the prevalence of grey infrastructure solutions is predominant, and there is a need for nature-based approaches for long-term benefits. The study warrants an urgent need for climate-smart actions, especially in Greater Chennai, on the line SDG Goals and the Paris Agreement (2015). Capacity-building initiatives have raised awareness among policymakers and officials, empowering them to address climate risks and formulate City Climate Action Plans.

Key priorities include heat mitigation, flood risk reduction, waste management, urban greening, energy efficiency, and sustainable transportation, which are the prime agenda to take forward.

Moving forward, it is imperative to embark on Climate Smart City Assessments across all 21 cities and 138 municipalities, ensuring comprehensive evaluations of vulnerabilities and opportunities. Simultaneously, an exclusive focus on intra-Chennai (zone-level) risk assessments is essential to pinpoint localized challenges and devise targeted resilience strategies. By embracing these initiatives, we pave the way for informed decision-making, sustainable urban development, and effective climate adaptation measures, thereby fostering resilient and livable communities for generations to come.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ADB	Asian Development Bank	LEED	Leadership in Energy & Environmental Design
AMRUT	Atal Mission for Rejuvenation and Urban Transformation	LST	Land Surface Temperature
AR	Assessment Report	MFI	Modified Fournier Index
ARRP	Adyar River Restoration Project	MTC	Metropolitan Transport Corporation
BEE	Bureau of Energy Efficiency	NDMA	National Disaster Management Authority
CAAP	Clean Air Action Plans	NMT	Non-Motorized Transport
CAP	Climate Action Plan	NRW	Non-Revenue Water
CMIP	Coupled Model Intercomparison Project	NUHM	National Urban Health Mission
CNG	Compressed Natural Gas	PTU	Public Transport Unit
CRRT	Chennai Rivers Restoration Trust	RCP	Representative Concentration Pathways
CSCAF	Climate Smart Cities Assessment Framework	RRC	Resource Recovery Centres
DHI	Drought Hazard Index	SDI	Streamflow Drought Index
FHI	Flood Hazard Index	SDM	Statistical Downscaling model
GCC	Greater Chennai Corporation	SMIF	Sustainable Municipal Infrastructure Financing
GDCR	General Development Control Regulations	SPEI	Standardised Precipitation Evapotranspiration Index
GEM	Green and Eco-friendly Movement	SSP	Shared Socio-economic Pathways
GHG	Greenhouse Gas	TANGEDCO	Tamil Nadu Generation and Distribution Corporation
GIS	Geographical Information System	TNCRUDP	Tamil Nadu Climate Resilient Urban Development Project
GRIHA	Green Rating for Integrated Habitat Assessment	TNIPP	TN Investment Promotion Programme
MoHUA	Ministry of Housing and Urban Affairs	TNSAPCC	Tamil Nadu State Action Plan on Climate Change
ICRERP	Integrated Cooum River EcoRestoration Project	TNSUDP	Tamil Nadu Sustainable Urban Development Project
IDF	Intensity-Duration-Frequency	TNUFIP	Tamil Nadu Urban Flagship Investment Programme
IGBC	Indian Green Building Council	TNUIFSL	Tamil Nadu Urban Infrastructure Financial Services Limited
IMD	Indian Meteorological Department	ULB	Urban Local Bodies
IPCC	Intergovernmental Panel on Climate Change	WGII	Working Group II

1. INTRODUCTION

The National Mission on Sustainable Habitat (NMSH) of the Ministry of Urban Development, Government of India, delineates that *Sustainable habitat would mean achieving a balance between the economic and social development of human habitats together with the protection of the environment, equity in employment, shelter, basic services, social infrastructure, and transportation.* With the growing consensus on the impact of climate change, there is a realization to reduce the harm to nature caused by rapid urbanisation. The main objective of the Mission is 1) to enhance urban planning and management 2) to ensure sustainable use of resources like land, water, and energy, 3) promote eco-friendly construction methods and materials to reduce environmental impact, 4) improve infrastructure for basic services like water supply, sanitation, and transportation in urban areas, 5) encourage the adoption of green building standards and energy-efficient technologies and 6) address the issues of urban poverty, slum rehabilitation, and inclusive urban development and foster public awareness and participation in sustainable urban development initiatives. With these objectives, the Mission aims to create cities that are environmentally sustainable, socially inclusive, economically vibrant, and resilient to future challenges. In line with the NMSH, the Tamil Nadu State Action Plan on Climate Change (TNSAPCC) envisages the importance of mitigation and adaptation actions to address the climate change challenges in urban areas.

Tamil Nadu is one of the most urbanized states in India. Census 2011 estimates that 48.45% of the total population of the state resides in cities with a fast growth rate at (27% during 2001-11) clearly outpacing the rural population growth of 6%, during the same period (2001-2011). Population projections have estimated that by 2036, 60% of the population of the state will be settled in urban. Tamil Nadu has the highest number of statutory towns in India with the dispersed pattern of urbanization of 21 municipal corporations (as in 2023), 138 municipalities and 490 town panchayats. As envisaged in TN Vision 2023, population growth, rapid urbanization, changing lifestyles, and the development goals act as drivers to exert pressure on the environment in Tamil Nadu.

Urban habitats in Tamil Nadu are particularly vulnerable to the impacts of climate change, as they face challenges such as population growth, urbanization, and a lack of infrastructure and services. One of the most significant impacts of climate change on urban habitats in Tamil Nadu is on the water sector. The state faces water scarcity due to the over-extraction of groundwater, and climate change is expected to exacerbate this problem. Sea level rise is also expected to contaminate coastal aquifers and increase the

salinity of drinking water leading to water insecurity, and making it difficult for urban inhabitants to access clean and safe water.

The cities of Tamil Nadu are confronted with issues of congestion, traffic, and pollution which are expected to be exacerbated by climate change. Extreme weather events such as floods and cyclones can also damage transportation infrastructure, making it difficult for people to access essential services. This will affect the mobility of urban inhabitants, and make it difficult for them to access work, education, and healthcare. In the present study, the climate-mediated hazards, vulnerability, exposure, and risk are assessed for the baseline period and the future period.

In this context, it is imperative to study the impacts of climate change on the urban habitation of Tamil Nadu. An attempt has been made to understand the Urban Habitat in the following context:

- Evaluate Thermal Discomfort levels throughout Tamil Nadu during the baseline period and projected for SSP2-4.5 scenario.
- Monitor the temporal changes in Urban Heat Intensity across 21 cities in Tamil Nadu.
- Analyze Urban Green Cover and Land Use patterns within each city to identify areas for improvement and conservation.
- Assess climate risks faced by the 21 cities of Tamil Nadu to develop targeted adaptation strategies and resilience measures.
- Evaluate the climate smartness of Tamil Nadu cities to identify areas where innovative solutions and policies can be implemented to mitigate climate change impacts and promote sustainability.

2. TAMIL NADU CLIMATE PROFILE

Climate Change is “a change in the State of the climate that can be identified by changes in the mean and/ or the variability of its properties and that persists for an extended period, typically decades or longer” (IPCC 2014). Anthropogenic climate change has been defined as “a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere (e.g.

increase in greenhouse gases (GHG) due to fossil fuel emissions) or surface characteristics (e.g. deforestation) and which is in addition to natural climate variability observed over comparable periods".

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes (IPCC 2021). It is reported that, in India, the mean annual temperature has increased by 0.6°C over the last century; the monsoon rainfall has declined over the last three decades of the 20th century in many parts of the country, while some parts have shown an increasing trend in the observed frequency of heavy precipitation events.

The climate of Tamil Nadu is strikingly different from the country's general climate. Due to its topographical features and geographical area, the climate of Tamil Nadu is referred to as semi-arid and tropical monsoon. The long coastal stretch in the east, hills on the western rim, and a flat interior significantly influence the climate of the State, which is tropical with only little seasonal variation in summer and winter temperatures. Apart from a brief break during the monsoon season, the State experiences hot temperatures throughout the remaining months. Due to the proximity to the sea, the humidity remains relatively high. The summer is hot, with temperatures rising to 43°C and extending from April to June. November to February is the coolest winter period, with temperatures around 18°C.

The State receives most of its annual rainfall during October, November, and December (northeast monsoon). It is contrary to the rest of the country, where the rainy season comprises the months of June, July, August, and September. The State is frequently subjected to extreme weather conditions, such as flooding in the coastal districts and severe droughts in the interior due to monsoon failure. This has an adverse effect on agricultural production. Drought, water depletion, soil erosion, seawater incursion, forest fire, species extinction and thermal discomfort are major manifestations of climate change. Monsoon rains play a crucial role in replenishing groundwater levels, thereby aiding in groundwater recharge and irrigation, establishing essential connections with the agricultural sector.

Since the last decade, the State has been facing a noticeably higher incidence of cyclonic events (Vardah 2016, Ockhi 2017 and Gaja 2018) and severe floods (2005, 2015 and 2017, 2023). This warrants immediate action to analyse and understand the current and future climate trends of the State. This Chapter

dwells upon Tamil Nadu's historical climatic trends based on India Meteorological Data (IMD) data for 1985 – 2014 and future projections about the climate and related uncertainties.

The high resolution (0.25°x0.25° latitude and longitude) daily gridded rainfall datasets for 184 precipitation grids for a period of 30 years (1985– 2014) and 1.0°x1.0° latitude and longitude daily gridded temperature datasets for 23 temperature grids, spanning over 30 years (1985-2014) for maximum and minimum temperatures provided by IMD (https://www.imdpune.gov.in/lrfindex.php) have been used to calculate the spatial variability in precipitation and temperature respectively.

2.1 Temperature

An examination of Tamil Nadu's climatic conditions reveals significant variations in both maximum and minimum temperatures across its districts. With a mean annual maximum temperature of 32.5°C, ranging from 29.5°C to 33.4°C, certain districts such as Chennai, Kancheepuram, Chengalpattu, Thiruvallur, Tiruvarur, and Cuddalore experience higher temperatures compared to others. Conversely, the Nilgiris district stands out with the lowest annual maximum temperature. Similarly, the mean annual minimum temperature, averaging at 22.6°C and ranging from 19.4°C to 24.1°C, showcases variations across districts, with Tiruvarur recording the highest values followed by Cuddalore, Mayiladuthurai, and Nagapattinam. Conversely, the Nilgiris district, situated in the Hilly Zone, consistently registers the lowest minimum temperatures. These temperature dynamics are further illustrated in Figure 1, depicting the spatial variation of annual average maximum and minimum temperatures across Tamil Nadu during the baseline period of 1985-2014. The anomanly change shows that the average temperature change is increased closed to 1°C (Figure 2)

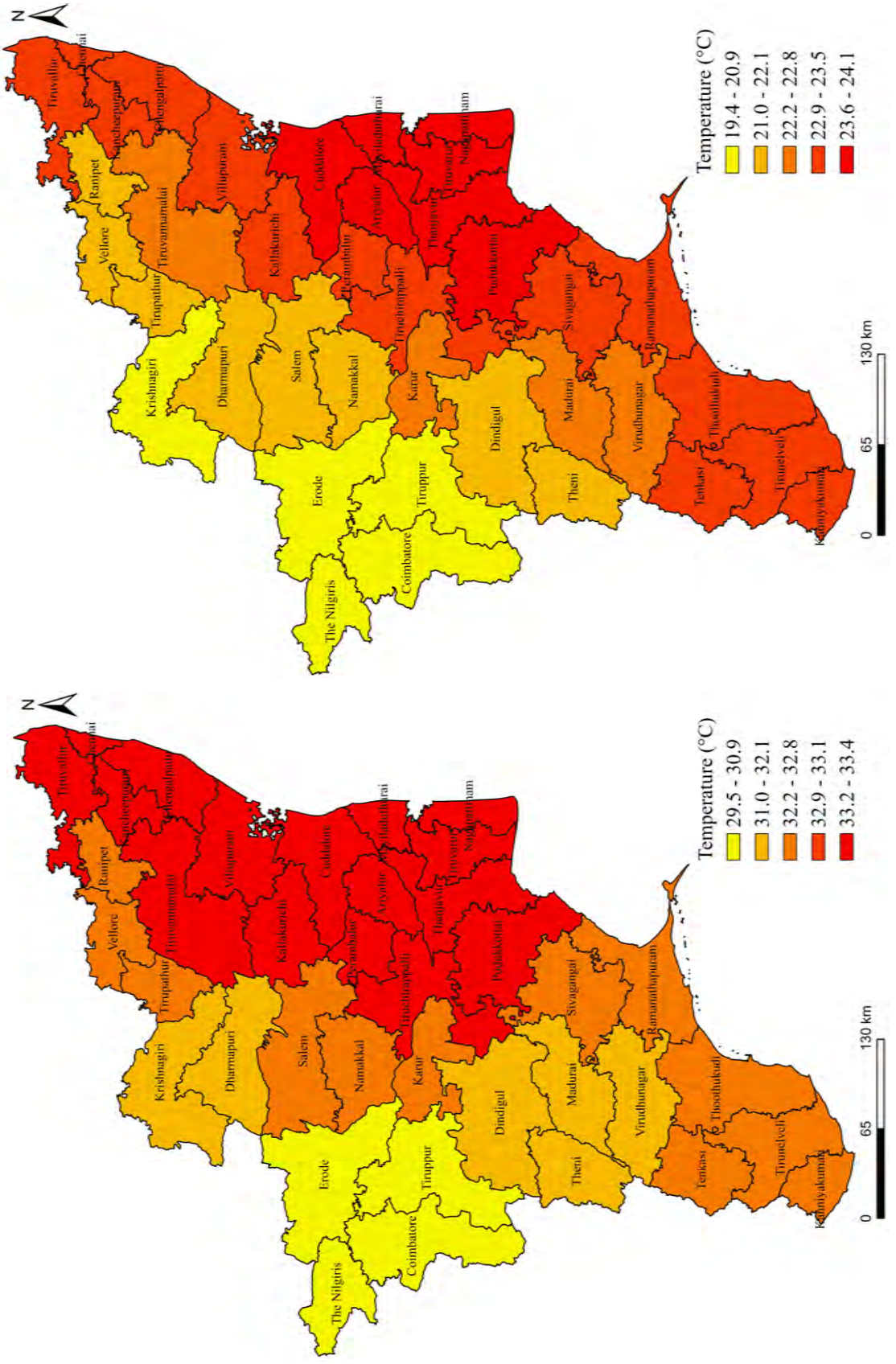


Figure 1 Observed Annual Max and Min Temp. of Tamil Nadu (1985-2014)

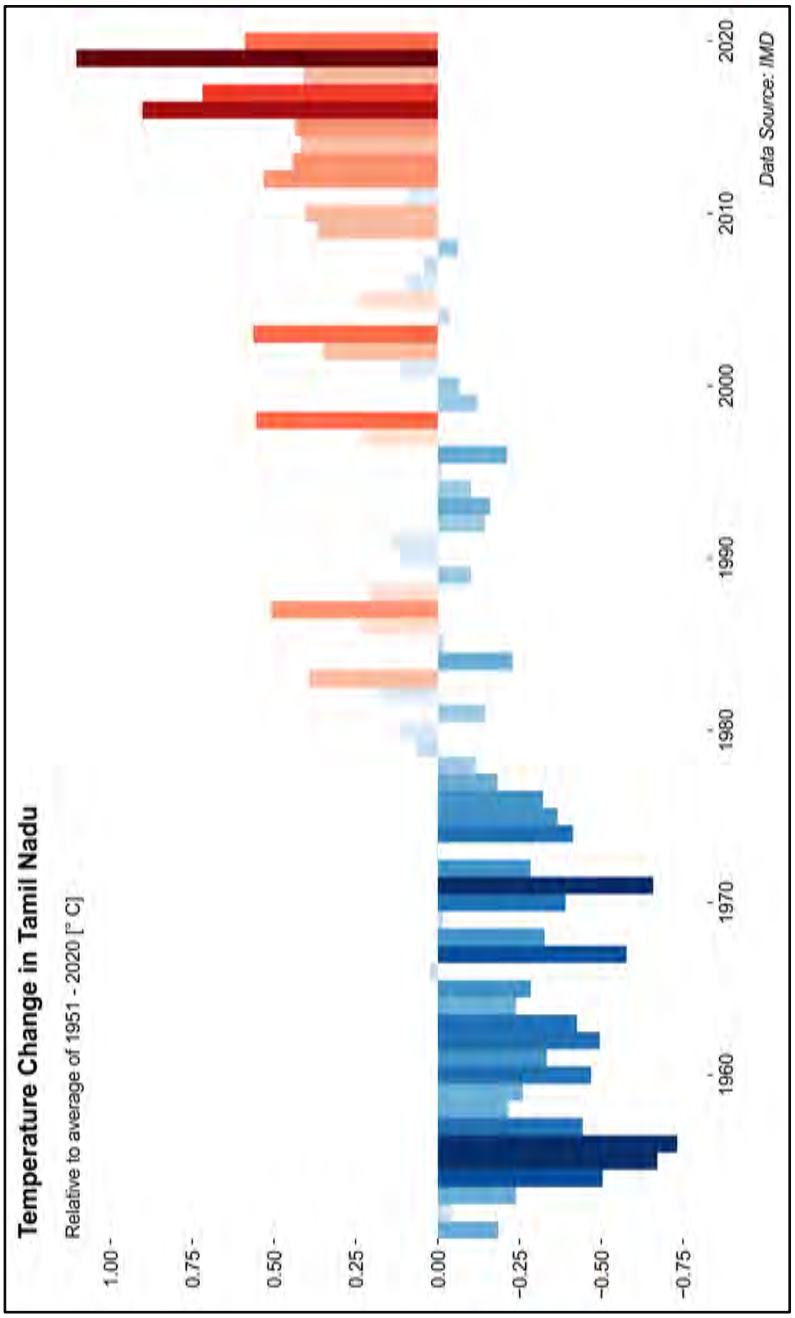


Figure 2 Temperature Change in Tamil Nadu since 1951

2.2 Rainfall

The average annual rainfall of Tamil Nadu is 989 mm within the district values ranging from 763 mm to 1432 mm over 30 years (1985-2014). As depicted in Figure 2, among all districts The Nilgiris, Thiruvallur, Chennai, Kancheepuram, Chengalpattu, Cuddalore, Tiruvarur, Mayiladuthurai and Nagapattinam receive the maximum average annual rainfall. In contrast, Erode, Tiruppur, Karur, and Thoothukudi receives the lowest annual average rainfall.

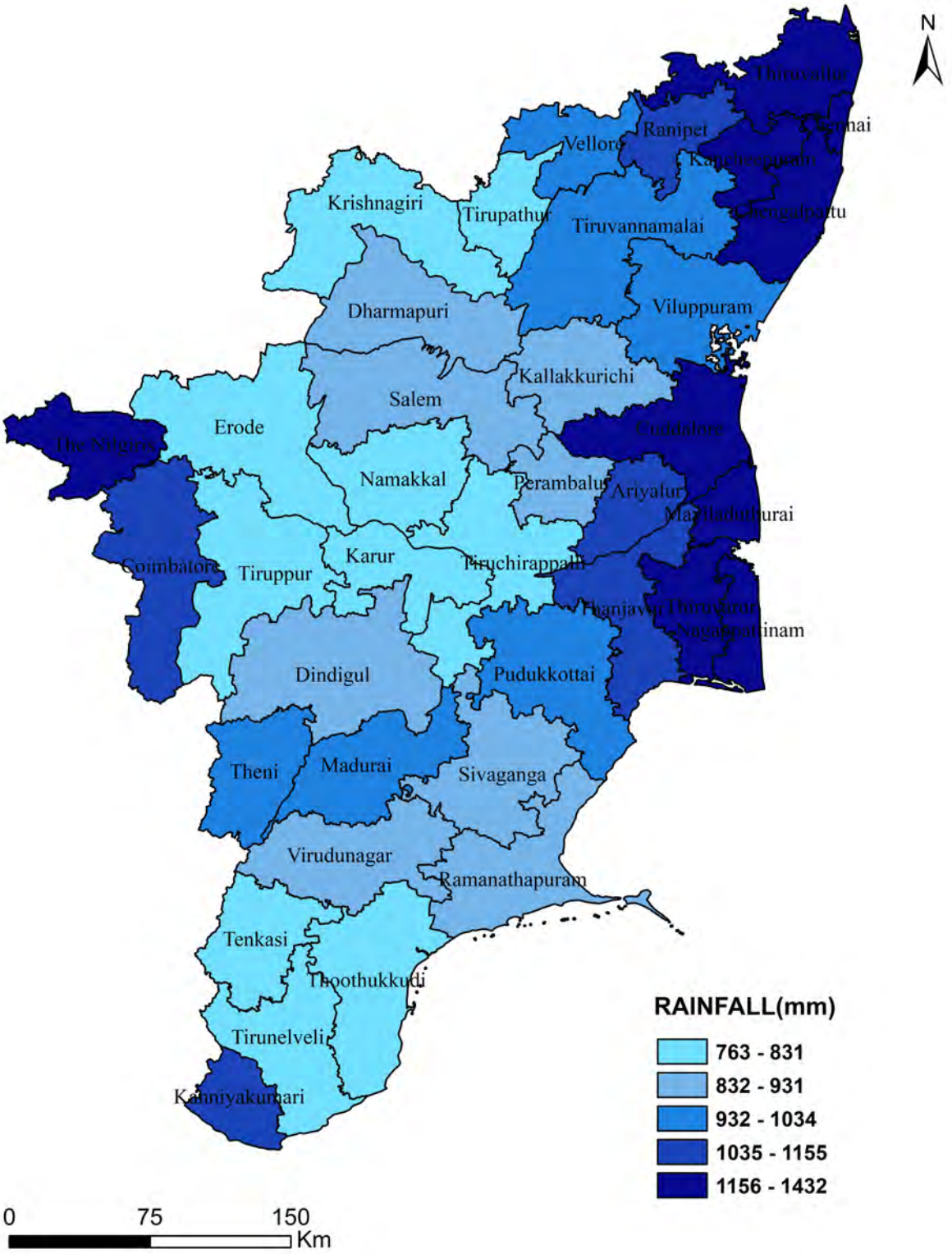


Figure 3 Observed Annual Rainfall of Tamil Nadu (1985-2014)

2.3. Climate Change Projections and Scenarios

Climate change projections and scenarios provide insights into future climate conditions. Climate models simulate the Earth's climate, considering factors such as GHG emissions, atmospheric composition, solar radiation, and land surface characteristics. The recently released Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) incorporates the SSPs to explore different socio-economic development pathways and their associated climate change consequences. These scenarios enhance our understanding of the complex interactions between human activities and climate change, guiding decision-making processes for climate mitigation and adaptation. These models generate projections of future climate conditions. Scenarios like the Shared Socio-economic Pathways (SSPs) explore different future trajectories based on socio-economic factors (Figure 4).

Figure 4 SSPs mapped in the challenges to mitigation/adaptation space

The SSPs categorize scenarios into SSP 1 - sustainability, SSP 2 - middle-of-the-road, SSP 3 - regional rivalry, SSP 4 - inequality, and SSP 5 - fossil-fuelled development, representing different socio-economic and emission pathways. Figure 4 shows an SSP matrix that defines five possible SSPs in terms of different degrees of "challenges to adaptation" (or ability to deal with climate change that has already occurred) and "challenges to mitigation" (or ability to restrain the extent to which climate change will occur) as well as other features of socio-economic development.

The EC-Earth3 model is statistically downscaled using PyClim-SDM (Statistical Downscaling Model) from 100×100 km to 25×25 km spatial resolution for Tamil Nadu for the Shared Socio-economic Pathway scenario SSP2-4.5 (Mid Pathways) and SSP5-8.5 (Business as Usual) of IPCC AR6 and are projected for temperature and precipitation from 2021-2100. Figures 5 and 6 indicate the projected changes in annual maximum temperature by near, mid and end term under SSP2-4.5 and SSP5-8.5, respectively. Table 1 shows the change in annual maximum temperature with reference to the baseline (1985-2014) in both the scenarios.

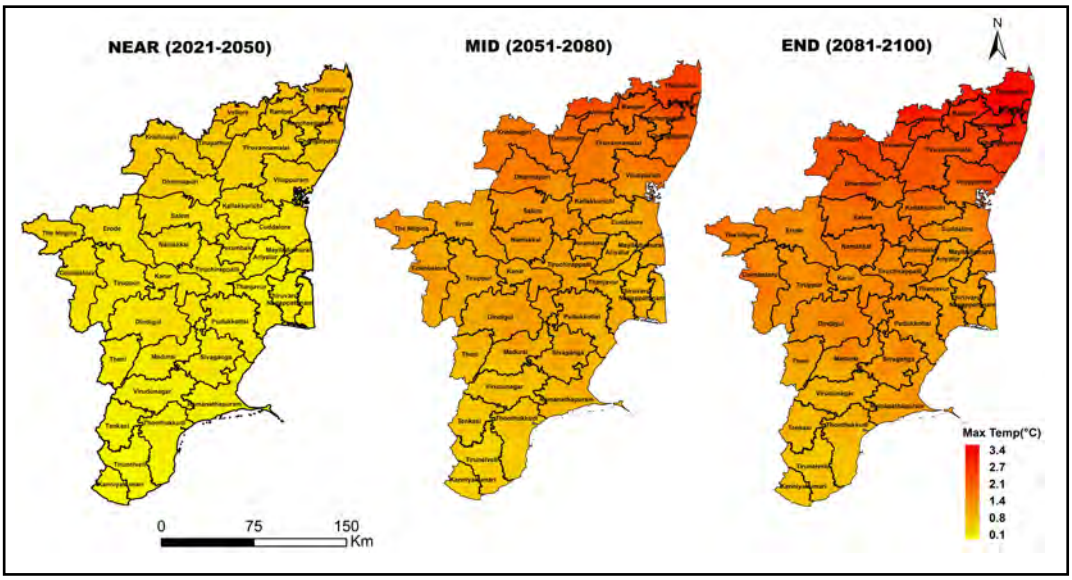


Figure 5 Projected Changes in Annual Maximum Temperature under SSP2-4.5

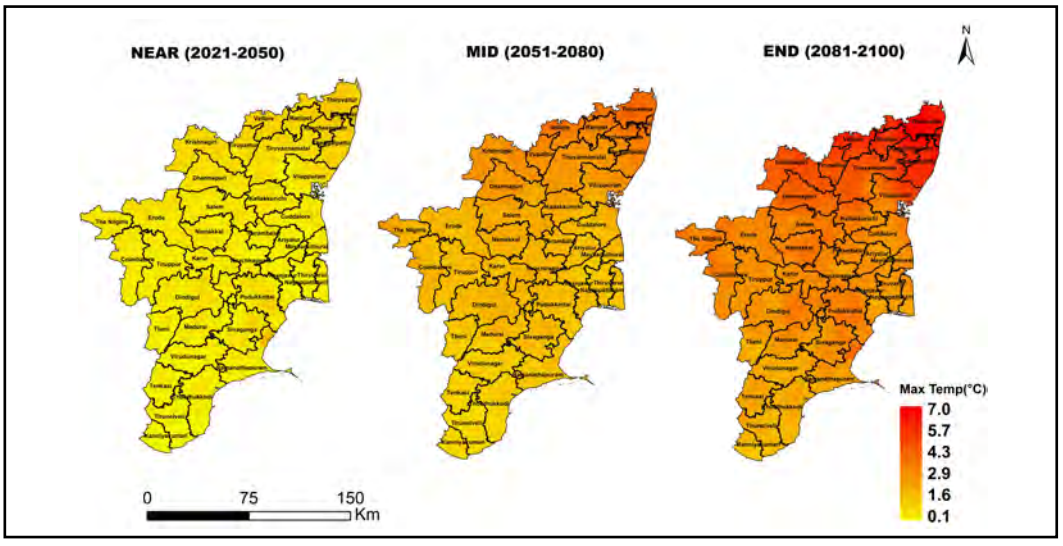


Figure 6 Projected Changes in Annual Maximum Temperature under SSP5-8.5

Table 1 Change in Annual Average Maximum Temperature

Projection Period	Increase in Annual Maximum Temperature with reference to baseline (°C)	
	SSP2-4.5 Scenario	SSP5-8.5 Scenario
Near Century (2021-2050)	0.4	0.6
Mid Century (2051-2080)	1.3	1.7
End Century (2081-2100)	1.7	3.5

Table 1 indicates that the annual mean maximum temperature in the State may rise by up to 0.4 °C, 1.3°C and 1.7°C in near-century, mid-century and end-century respectively under SSP2-4.5 scenario. Under the SSP5-8.5 scenario, the maximum temperature may rise by 0.6°C, 1.7°C and 3.5°C by near-century, mid-century, and end-century respectively. The northern districts such as Chennai, Nagapattinam, Kanyakumari, and Mayiladuthurai are projected to have a maximum increase in temperature by the end of the century.

Table 2 indicates that the average rainfall in Tamil Nadu State may increase marginally, by 4% towards the near century, 11% by the mid-century, and about 16% towards the end-century under the SSP2-4.5 scenario (Figure 7). Under the SSP5-8.5 scenario, the increase in rainfall is by 7% towards the near century, 18% in the mid-century, and 26% towards the end century (Figure 8).

Table 2 Projected Change Percentage in Annual Average Rainfall

Projection Period	Increase in Annual Rainfall (%)	
	SSP2-4.5 Scenario	SSP5-8.5 Scenario
Near Century (2021-2050)	4	7
Mid Century (2051-2080)	11	18
End Century (2081-2100)	16	26

The coastal districts such as Cuddalore, Nagapattinam, and Mayiladuthurai are projected to have a maximum increase in rainfall by the end of the century.

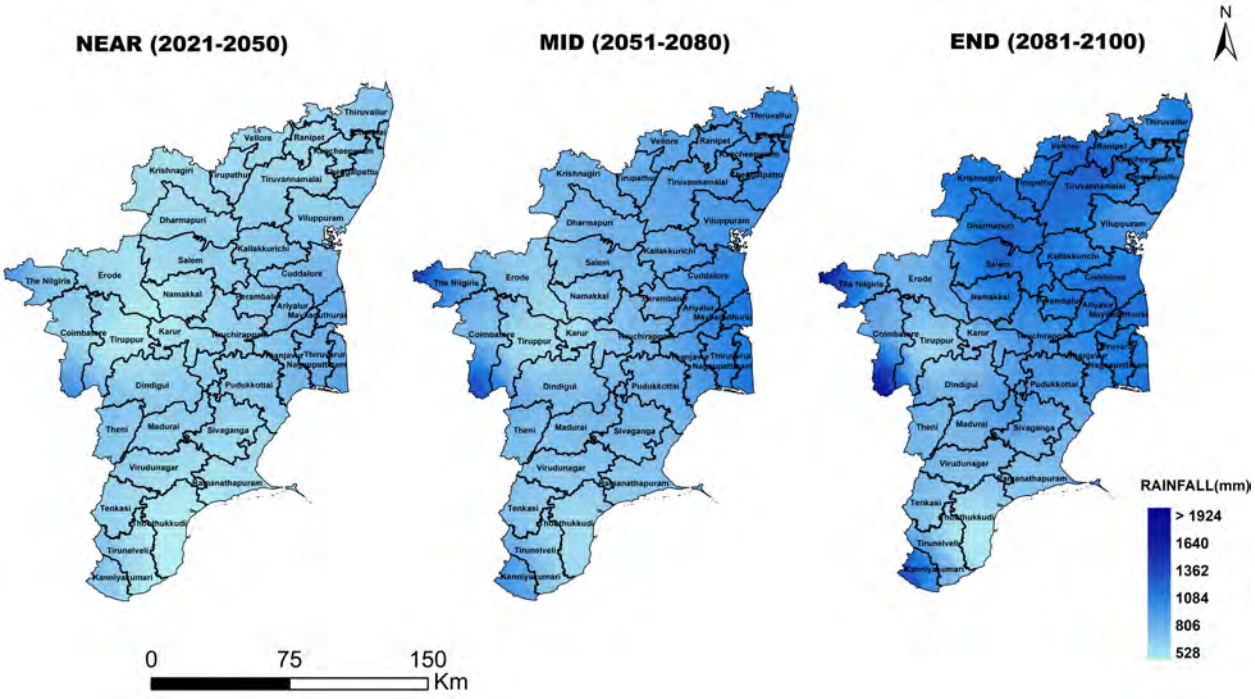


Figure 7 Projected Average Annual Rainfall under SSP2-4.5

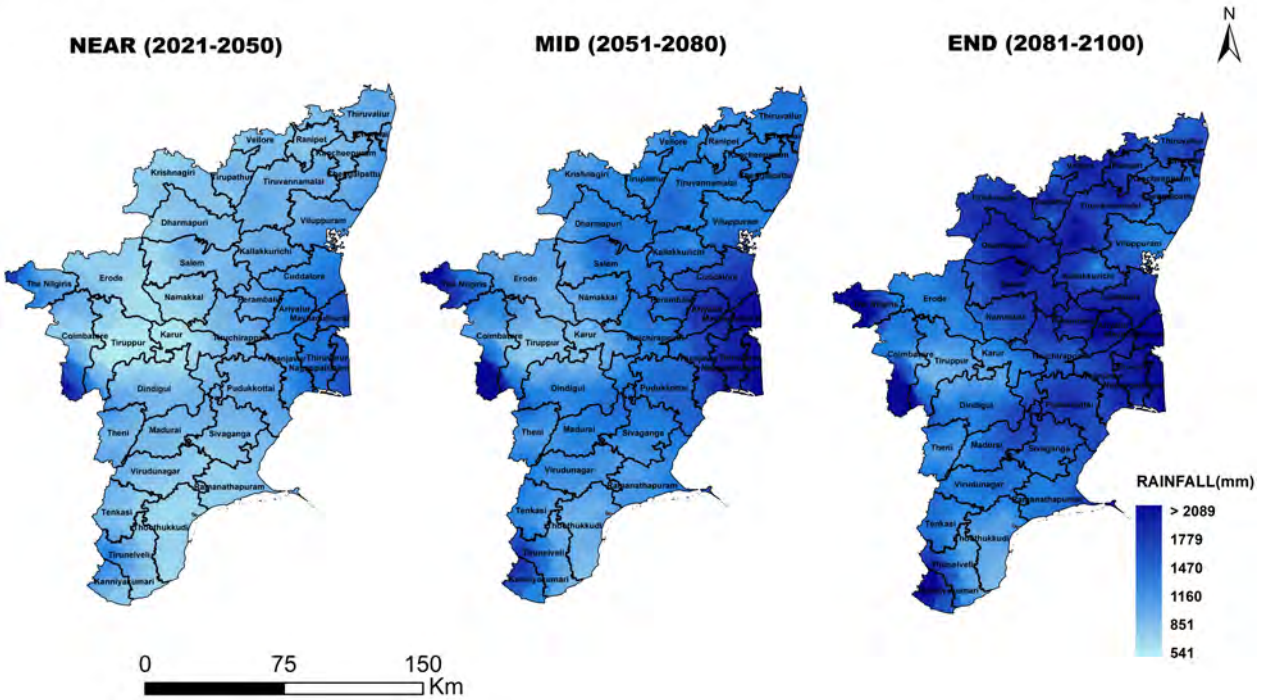


Figure 8 Projected Average Annual Rainfall under SSP5-8.5

3. PROFILE OF SUSTAINABLE URBAN HABITAT IN TAMIL NADU

Cities and Urban areas are centres of economic growth and development. Tamil Nadu is one of the most urbanised states of the country and it is projected that at a pace of rapid urbanisation, projections suggest that nearly 70% of the State's population will reside in urban areas by the year 2047. Expanding urbanisation necessitates initiatives like smart city development, increased economic activities, job creation, and enhanced infrastructure connectivity. In the pursuit of creating a sustainable urban habitat, Tamil Nadu recognizes the critical importance of climate vulnerability assessment and adaptation planning. As one of India's most urbanized states, Tamil Nadu faces unique challenges and opportunities in its urban landscape. Understanding the state's vulnerability to climate change and devising comprehensive adaptation plans is integral to ensuring the resilience and well-being of its urban population. This initiative seeks to safeguard the state's urban areas against the impacts of climate change, promote sustainable development, and create cities that thrive amidst environmental challenges.

Till the year 2021, there were 15 Municipal corporations and during the Demand for Grant for the year 2021-22, the Government announced that the Municipalities of Kancheepuram, Kumbakonam, Karur, Cuddalore and Sivakasi and adjoining urbanised areas will be merged to form respective municipal corporation. It was also announced that, the Tambaram Municipality and the adjoining municipalities, town panchayats and village panchayats be merged to form a municipal corporation. At present there are 21 Municipal Corporations in Tamil Nadu which are considered for the present study, 7 cities are located in coastal districts, while others are inland cities (Table 3 and Figure 9).

Regarding the per capita water supply in urban local bodies, 6 ULBs provide 135 litres per day, 4 ULBs offer between 110 to 134 litres, and 10 ULBs provide 70-109 litres per capita per day. Additionally, there are 164 water bodies in corporations and 425 in Municipalities across Tamil Nadu. Among the 20 corporations, the implementation of Under-Ground Sewerage Schemes (UGSS) is underway in 18 corporations. As of now, the scheme has been completed and put to use in 16 corporations. The Greater Chennai Corporation (GCC) manages a storm water drain network spanning 2,071 kilometers, comprising 8,835 storm water drain structures.

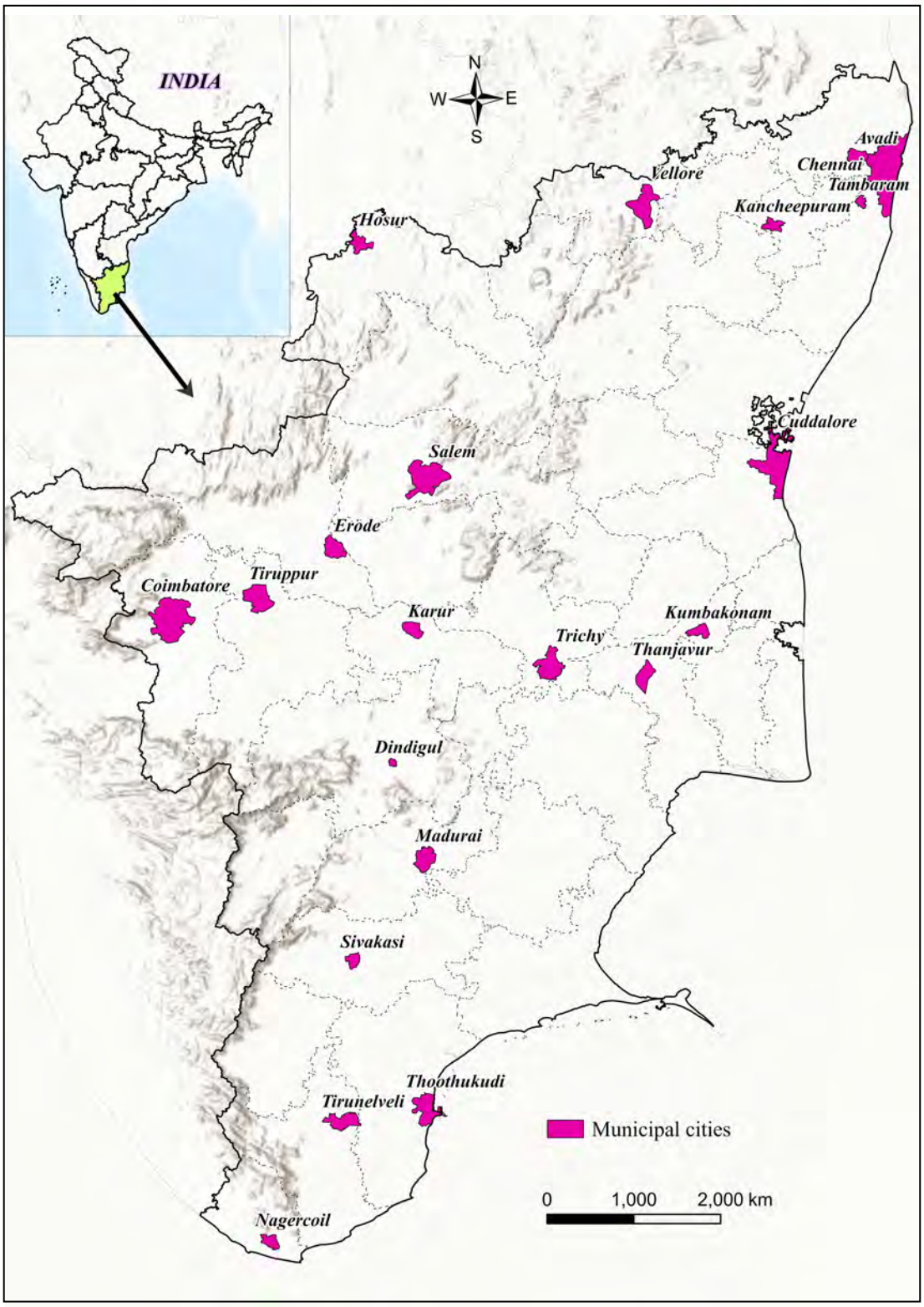


Figure 9 Municipal Corporations of Tamil Nadu

Table 3 Details of Cities (Municipal Corporations) in Tamil Nadu

City	District	Area (in sq.km)	Total Population	Population Density
Avadi	Thiruvallur	65	3,45,996	5,323
Chennai	Chennai	426	46,46,732	42,428
Coimbatore	Coimbatore	257.04	10,50,721	2,466
Cuddalore	Cuddalore	27.69	1,73,636	676
Dindigul	Dindigul	14.01	2,07,327	7,487
Erode	Erode	109.52	1,57,101	11,213
Hosur	Krishnagiri	72.41	1,16,821	1,613
Kancheepuram	Kancheepuram	36.14	1,64,384	4,549
Karur	Karur	53.26	70,980	1,333
Kumbakonam	Thanjavur	14.68	1,40,156	9,547
Madurai	Madurai	148.00	10,17,865	6,877
Nagercoil	Kanyakumari	49.10	2,24,849	4,579
Salem	Salem	91.34	8,29,267	9,079
Sivakasi	Virudhunagar	19.89	71,040	3,572
Tambaram	Chengalpattu	87.64	1,74,787	1,994
Thanjavur	Thanjavur	36.33	2,22,943	6,137
Thoothukudi	Thoothukudi	90.66	2,37,830	2,623
Tirunelveli	Tirunelveli	108.65	4,73,637	2,972
Tiruppur	Tiruppur	159.35	4,44,352	2,657
Trichy	Tiruchirappalli	167.23	8,47,387	7,799
Vellore	Vellore	87.915	1,85,803	2,113

Source: Census of India, 2011

According to the Government of Tamil Nadu Policy Note 2023-2024 of the Department of Municipal Administration and Water Supply (MAWS), Tamil Nadu cities generate about 17,000 MT/day and about 10,856 MT/day of municipal solid waste are disposed of through open dumping. The GCC alone generates 7,600 MT/day and other 20 corporations and 138 municipalities generating over 5,200 MT/day. Out of this, nearly 52% is wet waste and 48% is dry waste. The wet waste is scientifically processed and converted into manure. Out of 21 corporations, a bio-mining process to eradicate legacy waste has been taken up in 12 corporations and 86 municipalities. At present, there are 256 wet waste processing facilities, such as micro composting centers, windrow composting centers, biogas plants, bio-methanation plants, and bio-CNG plants, having 1,217 tonnes per day (TPD) capacity in the GCC. From the wet waste processing units, presently, 400 MT of manure is produced every month. Currently only about 6,155 tonnes are processed through dry waste recycling, micro composting and bio-methanation in the ULBs of Tamil Nadu. The methane emission from disposal facility in Tamil Nadu is about 55,000 MT/year and GCC contributes more than 52%.

In total, 287 hospitals and 302 Urban Primary Health Centers (UPHCs) are maintained by various corporations and municipalities. The GCC provides health care services through a network of 140 UPHC, 16 Urban Community Health Centres (UCHC) and 3 Emergency Obstetric Centres (EOC). The National Urban Health Mission (NUHM) supports 280 UPHCs, 140 UPHCs in GCC.

A total number of 8.62 lakhs streetlights are available in 20 Corporations (other than GCC) and 138 municipalities. The Greater Chennai Corporation has 2.90 lakhs streetlights installed. The corporations and municipalities maintain a total 25,814 km of roads. This include 5,399 km of cement concrete (CC) roads, 15,911 km of black top (BT) roads, 169 km of water bound macadam (WBM) roads, 2,890 km of earthen roads and 1,445 km of other type of roads like paver block roads etc. The GCC maintains 5,657 km of roads including 4317.05 km of bituminous roads,1273.88 km concrete roads and 65.81 km of other types of roads. A total of 166 bus stands are under the maintenance of various corporations and municipalities, GCC maintains 1,416 bus shelters built under various schemes, including 637 bus shelters set up under a Build Operate and Transfer (BOT) model. Further, it maintains 128 traffic islands and 173 centre medians.

4. CLIMATE CHANGE RISK ON SUSTAINABLE URBAN HABITAT

Tamil Nadu's history is marked by cyclones, storms, and floods, impacting urban areas. The Andhra Pradesh cyclone (1997) and Chennai floods (2015) caused significant damage. Chennai faces frequent flooding due to intense rainfall, with notable instances in 1918, 1985, 2005, 2015, and 2021. The city experiences flooding five to six times during monsoon months, affecting low-lying areas. The Storm-Water Department identified 562 water stagnation areas affecting 16.7% of the city and 20% of its population. Around 36% of slums fall within these flood-prone areas and exacerbating health risks. Rapid urbanization, concretization, and encroachment worsen flooding and water stagnation. Despite efforts like rainwater harvesting, enforcement and adoption of policies remain challenging. Chennai's densification has led to decrease in floodplains, lakes, and wetlands since 1991. Addressing these challenges requires holistic approaches to urban planning and conservation.

While Chennai city's vulnerability due to flood has been very well documented, other cities have also borne the brunt of extreme weather in the recent past. For instance, Cuddalore, Villuppuram, Sivaganga, Ramanathapuram and Karaikal received red alerts during the 2021 South India floods caused by depression in the Bay of Bengal and a low-pressure system. Over 11,000 people were displaced due to heavy rainfall. Kanyakumari and Thoothukudi were overwhelmed by unprecedented rainfall, resulting in deaths and losses during 2021. Thoothukudi, Tirunelveli, Tenkasi, and Kanyakumari faced historic rains and flooding during December 2023.

Chennai faced severe water scarcity, reaching "Day Zero" in 2019 when reservoirs dried up due to deficient monsoons. Over-extraction of groundwater and reduced recharge from rainfall led to deteriorating water quality and depletion of water tables. Chennai witnessed a threefold increase in built-up areas from 1991 to 2021. Similarly, cities viz. Thoothukudi face challenges of water scarcity due to salt water intrusion. Water crisis impacts slum dwellers severely, increasing financial burden and health risks, with women disproportionately affected. Chennai witnessed a threefold increase in built-up area from 1991 to 2021,

accompanied by a decline in vegetation and water bodies. Cities along the coast of Tamil Nadu, like Chennai and Nagapattinam, face heightened susceptibility to rising sea levels.

In this context of vulnerability of cities of Tamil Nadu, it is understood that a comprehensive study to assess all the cities from the climate perspective is needed and attempted in the present study. The impacts, vulnerability and risks of climate change on sustainable urban habitat involved the assessment of thermal discomfort, the Urban Heat Intensity of cities, the extent of urban green cover, the land use land cover of cities, climate risk, and readiness of cities to handle climate challenges and suggest adaptation actions for Tamil Nadu.

The Thermal discomfort of the region was evaluated using Thom's discomfort index, which considers air temperature and humidity to gauge human comfort levels. This provided a baseline understanding of the prevailing conditions. Further, projections were made for the near-century (2021-2050) to understand the spatial and the temporal changes to the discomfort level in line with the increase in temperature. The Urban Heat Intensity (UHI) of the 21 cities were assessed for the years 2012 and 2022, to understand the temporal changes in Land Surface Temperature as an indication of the UHI over a decade. Simultaneously the Urban Green Cover and Land Use / Land Cover of 21 cities were assessed for the current period. Since these assessments have not been done comprehensively for all the 21 cities, this assessment becomes the primary data input for the hazard, vulnerability and risk assessment subsequently.

A detailed climate risk assessment was conducted for 21 cities in Tamil Nadu, aligning with the IPCC framework. This involves identifying various climate hazards like heat waves, floods, sea-level rise assessing vulnerability and exposure indicators such as urban green cover, infrastructure resilience, and population density. Geospatial technology aided in mapping these parameters to facilitate a holistic understanding of climate risks across the region. The projections of bioclimatic variables on urban environment was assessed so as to understand the influence at the micro climate level.

4.1 Thermal Discomfort

The Discomfort Index (DI) is a metric for assessing thermal comfort by considering both temperature and humidity levels. Daily mean temperature and relative humidity from the regionally downscaled climate data was used to compute the discomfort indices across Tamil Nadu for the baseline period (1985-2014) and projected for the Near Century (2021-2050) under SPP 2-4.5. Throughout these computations, Thom's formula [Thom 1959; Yousif and Tahir 2013] was applied, and formulated as follows:

$$DI = T - (0.55 - 0.0055RH) (T - 14.5)$$

Here:

DI represents the Discomfort Index in degree Celsius.

T denotes the mean monthly temperature (in degrees Celsius).

RH signifies the mean monthly relative humidity of the air (as a percentage).

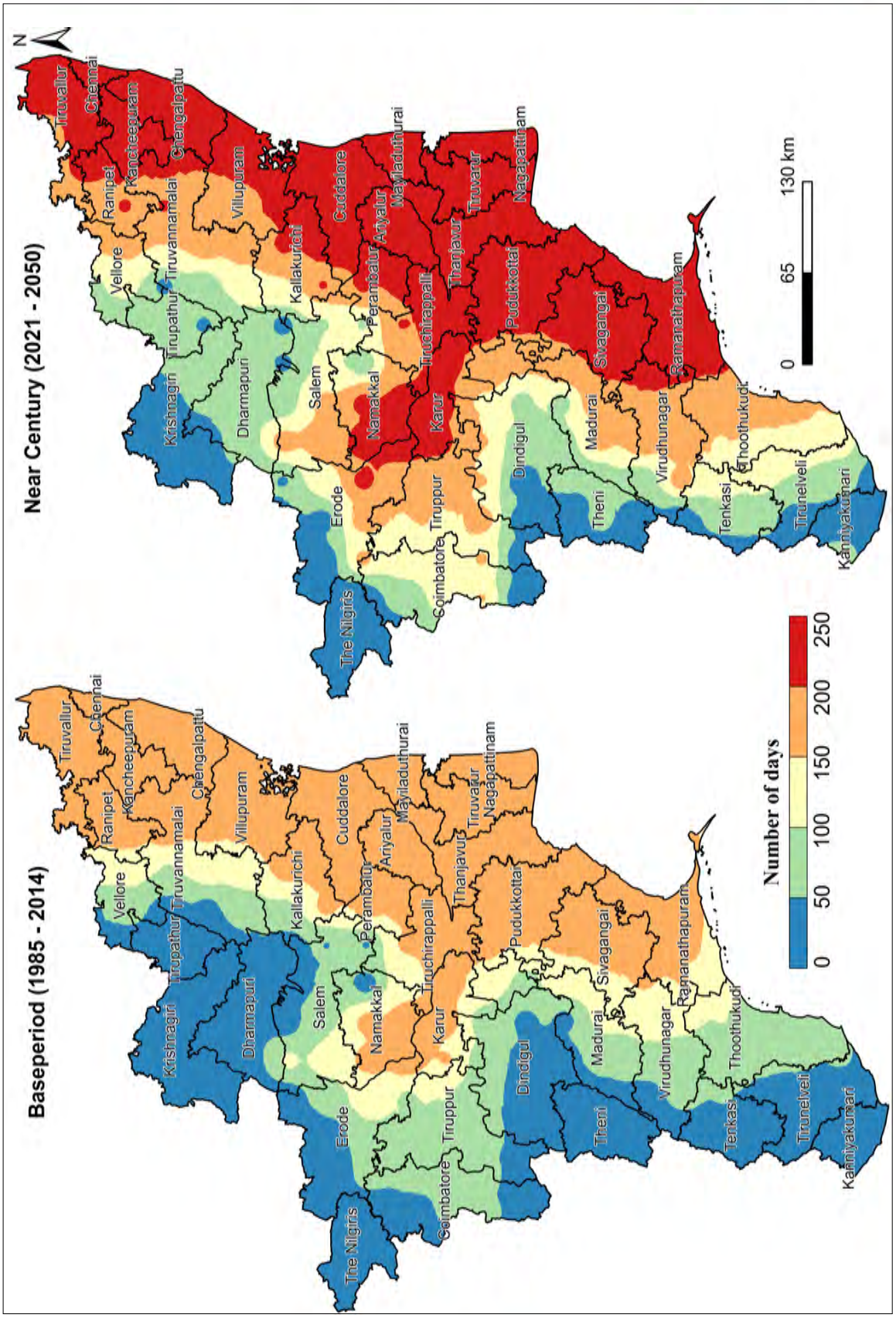


Figure 10 Annual Average Number of Days with Discomfort Condition

The discomfort conditions and its trend are essential for the major cities in Tamil Nadu since it has been associated with a greater risk of morbidity and mortality along with the increased electricity consumption. The Discomfort Index (DI) is analysed based on the daily average temperature and relative humidity. Figure 10 illustrates the Annual Average days of the discomfort conditions (DI 27-29) which were experienced by most of the people in Tamil Nadu in the baseline period (1985-2014) and projected near century (2021-2050).

It is observed that the trend of the discomfort days is increasing across the northern coastal regions of Tamil Nadu to more than the range of 100-125 days every year, especially during the summer and southwest monsoon season. The number of thermal discomfort days is projected to increase to 200-250 days in the near century.

4.2 Temporal Changes in the Urban Heat Intensity of Tamil Nadu Cities

The Urban Heat Intensity (UHI) can be detected by using the Land Surface Temperature (LST). LST is a measure of the earth's surface temperature experienced through contact in a particular location. From a satellite's point of view, the "surface" is whatever is visible when seen through the atmosphere. It could be the grass on a lawn, the roof of a building, or the leaves in the canopy of a forest. LST is mapped using the remote sensing method.

The Landsat 5 Thematic Mapper (TM) and 8 Operational Land Imager (OLI) satellite imagery was pre-processed to remove noise using cloud masking, atmospheric correction, and image calibration. The thermal bands of the satellite imagery were used to calculate Brightness Temperature (BT). This process typically involves converting digital numbers to radiance and subsequently calculating the surface temperature using the radiative transfer equation. The brightness temperature was converted to LST using suitable methods.

The temporal analysis (decadal variation between 2012-2022) of LST for all 21 cities was conducted as an indicator for the Urban Heat Intensity. The drastic temporal changes in selected cities is depicted in Figure 11. It is observed that the cities have undergone transformation due to urban sprawl during the past decade that is evidently seen with the increase in spatial extent of maximum LST.

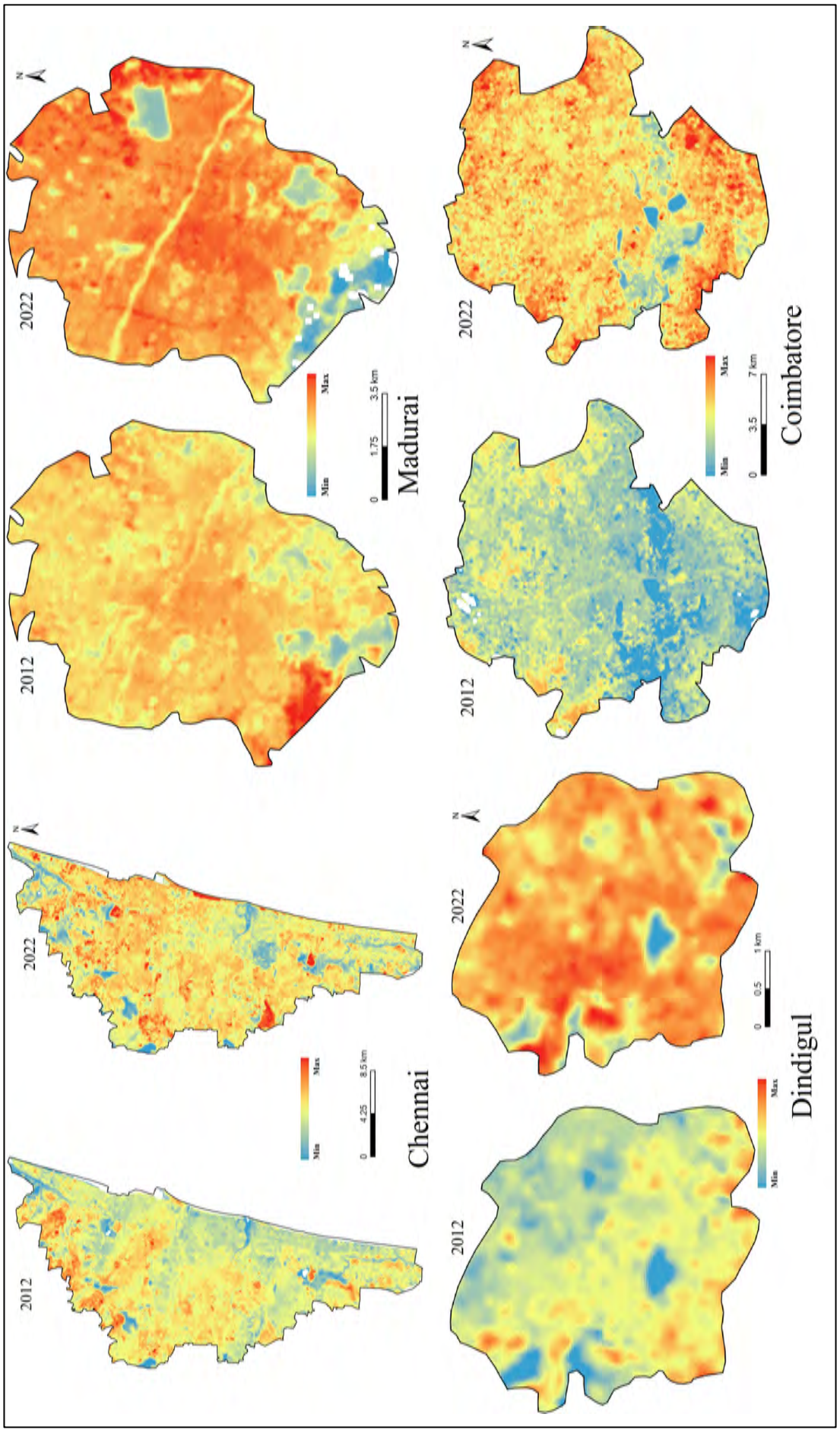


Figure 11 Cities with Highest Temporal change in LST between 2012 and 2022

4.3 Urban Green Cover and Land Use Pattern in Tamil Nadu Cities

For conducting the urban green cover assessment, the Normalised Difference Vegetation Index (NDVI) is employed. Landsat 8 (OLI) satellite images of 30m resolution for the year 2021 across all the 21 municipal corporations of Tamil Nadu was retrieved using Google Earth Engine (GEE). The classification of NDVI index has been implemented through the range from -1 to + 1 which refers to vegetation intensity based on spectral reflections.

Land Use / Land Cover (LULC) mapped using the Sentinel 2 (10m resolution) data were used to assess the urban sprawl in 21 cities of Tamil Nadu. The LULC was classified and validated by using the Ground Control Points (GCPs) and Google Maps. Also accuracy assessment and Kappa Coefficient was calculated for the LULC analysis.

The proportion of urban green cover was assessed in 21 municipal corporations of Tamil Nadu. The spatial spread of green cover for the cities with the least green cover proportion and highest green cover proportion are portrayed in Figures 12 and 13 respectively. It is observed that most of the cities in Tamil Nadu have very less green cover, with Chennai city recording the least extent of green cover of 2% and Nagercoil city has the highest proportion (20%) of urban green cover. The assessment of LULC for all cities was also conducted and it was observed that the cities with the least proportion green cover had the highest extent of built-up area (Figure 14).

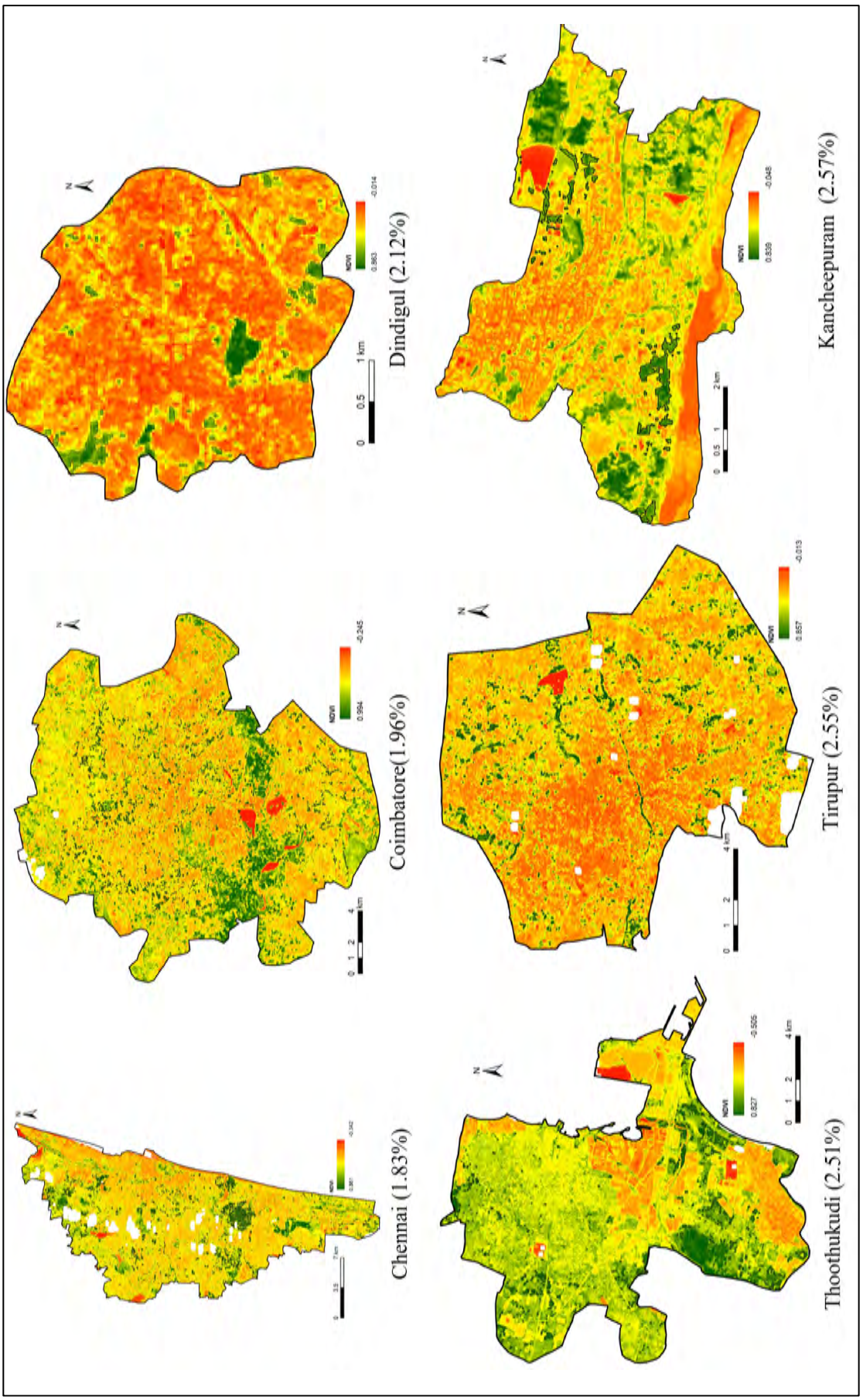


Figure 12 TN Cities with Least Proportion of Urban Green Cover

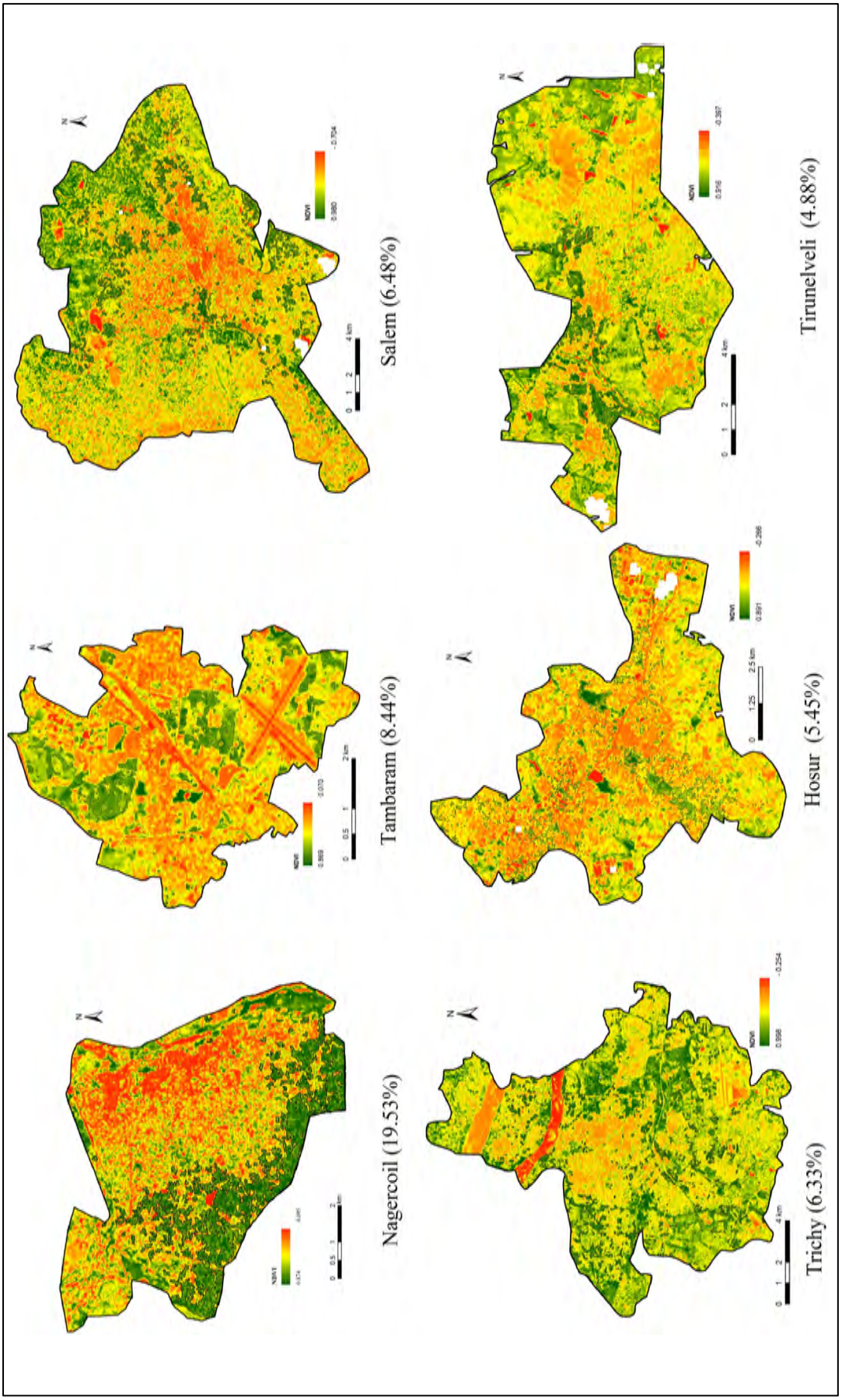


Figure 13 Cities with Highest Proportion of Urban Green Cover

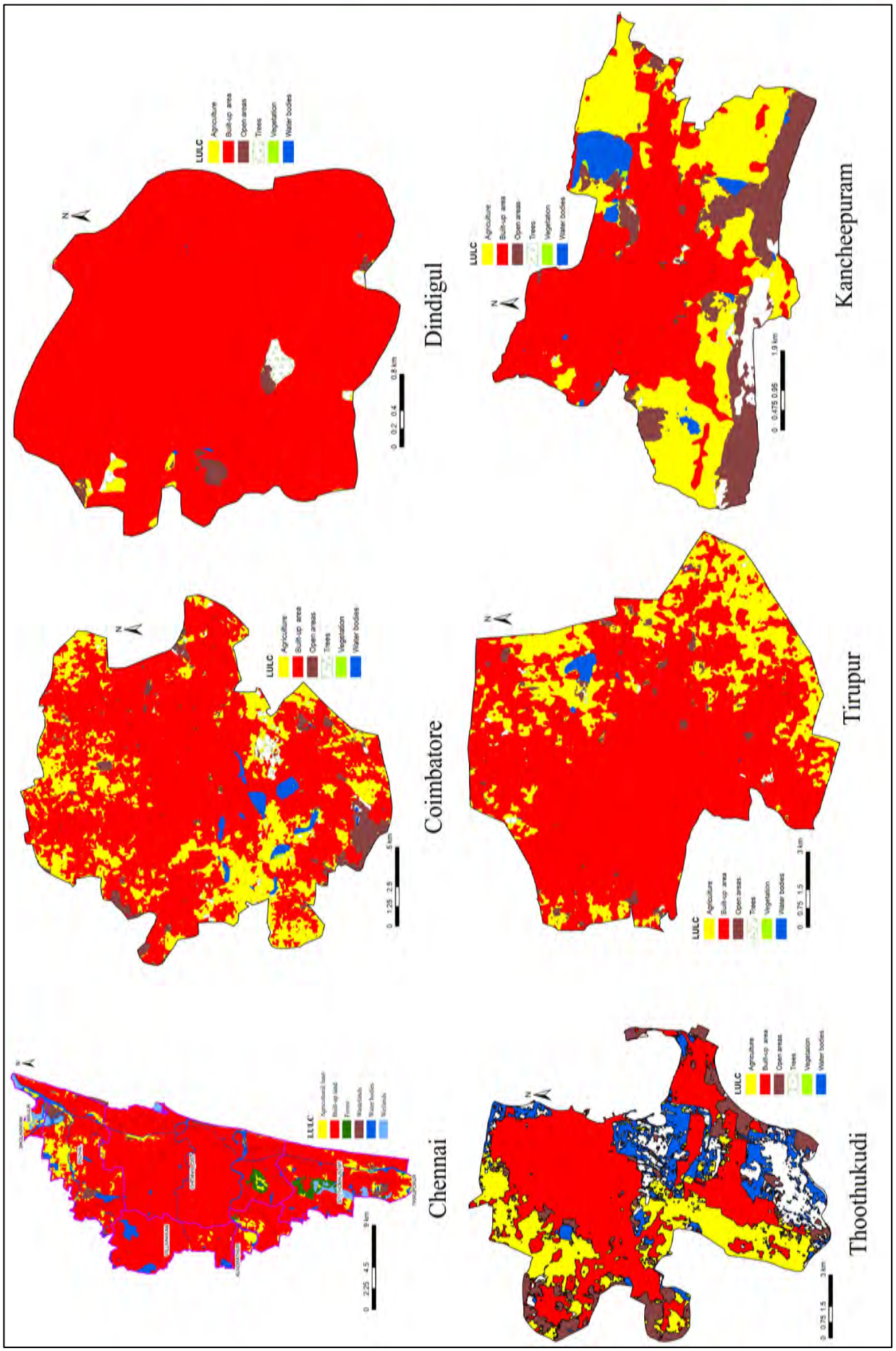


Figure 14 Cities with least proportion of green cover

As per the urban greening guidelines 2014, the Ministry of Urban Development recommends that the proportion of recreational areas (including parks, spaces, water bodies, etc.) to the total developed area in medium towns and large cities should be from 18 to 20% in medium towns and large cities; and 20-25% in metropolitan cities (MoUHD, 2014). From the analysis of the proportion of urban green cover, it is observed that only Nagercoil has 20% of urban green cover, while all the other cities are below it. This could be attributed to the location of the city in the high rainfall zone, which receives rainfall during two monsoon seasons that is the South West Monsoon during the June, July, August and September (JJAS) and the North East monsoon during the October, November and December (OND). Out of 21 cities, the majority of the cities (16 cities) have less extent of green cover which don't meet the minimal requirement of the Ministry of Urban Development.

The World Health Organisation (WHO) recommends a minimum of 9 sq.m of green space per capita in urban areas and also suggests that an ideal amount of 50 sq.m per person of urban green space may be provided (Ministry of Health and Family Welfare, 2019). The per capita green space availability was evaluated based on the population projection in urban Tamil Nadu (Nagendra et al., 2013). It is projected that the population of urban areas of Tamil Nadu will increase by 18% by 2023 from 2011. This percentage increase is applied to project the city population. The evaluation of the per capita green space based on the projected population in 21 cities of Tamil Nadu is depicted in Table 4. It is observed that 11 cities (Avadi, Chennai, Coimbatore, Dindigul, Kancheepuram, Madurai, Tambaram, Thanjavur, Tirunelveli, and Tiruppur) out of the 21 cities do not meet the minimum recommendation of the World Health Organisation of 9 sq m per person, and is a critical point of consideration. Cities with more than 9 sq m per person of urban green cover are Nagercoil, Cuddalore, Erode, Hosur, Karur, Kumbakonam, Salem, Sivakasi, Thoothukudi, and Vellore.

Table 4 Extent of green space needed to meet the Urban Greening Guidelines, 2014

CITY	Total City Area	Recommended Green Cover (sq.km)	Existing green cover (sq.km)	Additional Green Cover Needed (sq.km)	Potential area for additional green cover (sq. km.)
1. Chennai	438.95	79	8	71	9
2. Coimbatore	332.25	60	7	53	13
3. Tiruppur	143.22	26	4	22	2
4. Cuddalore	353.95	55	17	38	22
5. Vellore	160.70	29	5	24	12
6. Trichy	143.38	26	9	17	4
7. Madurai	96.05	17	4	14	2
8. Salem	243.87	44	16	28	18
9. Erode	85.38	15	3	13	2
10. Thoothukudi	140.72	24	4	21	14
11. Kumbakonam	50.23	9	2	7	0
12. Tirunelveli	101.71	18	5	13	8
13. Sivakasi	39.08	7	2	5	1
14. Hosur	67.43	12	4	8	4
15. Avadi	60.035	11	2	9	4
16. Karur	59.92	11	2	9	4
17. Dindigul	12.31	2	0	2	0
18. Thanjavur	79.63	14	2	12	10
19. Nagercoil	46.95	8	9	-1	1
20. Kancheepuram	47.01	8	1	7	8
21. Tambaram	22.43	4	2	2	2

In this situation it is vital to enhance the green cover in the cities with the lowest per capita green spaces. The cities with more than the recommended green cover must be preserved without further degradation owing to the ever-growing population in urban areas in the future. Though urban forestry is man-made, the results inferred that more attention must be given to urban forestry management.

4.4 Climate Risk Assessment of Cities of Tamil Nadu

The consequences of climate change are explained as a function of various evolving components since the IPCC First Assessment Report. Assessing the impact of climate change has been delineated through risk reduction and the latest Assessment Report of IPCC Working Group II. The concept of risk provides a framework for understanding the gradual but severe, interrelated and often unalterable impacts of climate change on ecosystems, biodiversity, and human systems. In this context, the exact definitions from the IPCC AR6 Report are provided and real-time examples are provided to explain each concept.

The potential occurrence of a natural or human-induced physical event or trend may cause loss of life, injury or other health impacts, damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. Climate-related risks are created by a range of hazards. Some are slow in their onset, while others happen more suddenly. The slow onset hazards include changes in temperature and precipitation leading to droughts, agricultural losses and sudden onsets such as tropical storms and floods.

Vulnerability refers to the degree to which a system or population is susceptible and unable to cope with the adverse effects of climate change, including climate variability and extremes. It encompasses the characteristics and circumstances that make individuals, communities, or ecosystems more prone to harm or disruption from climate-related hazards. Various factors, including social, economic, and environmental conditions influence vulnerability. These can include poverty, inequality, limited access to resources and services, inadequate infrastructure, and lack of institutional capacity.

Exposure can be understood as the presence or susceptibility of human and natural systems to the impacts and risks associated with climate change. Based on the IPCC report, exposure often refers to the condition of being in areas or settings that are vulnerable to the adverse effects of climate change. This includes factors such as geographic location, population density, socio-economic characteristics, and ecological sensitivity. Exposure encompasses the potential for harm or disruption to livelihoods, infrastructure, ecosystems, species, and socio-economic systems as a result of climate-related hazards and

changes. Based on the AR6 assessment, risk is assessed as a function of the interaction of climate hazards, vulnerability, exposure and response. The risk conceptualization framework is shown in Figure 15.

The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from the potential impacts of climate change and human responses to climate change. "In the context of climate change impacts, risks result from dynamic interactions between climate related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards". Hazards, exposure and vulnerability may each be subject to uncertainty in magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making. Understanding the climate change risk is to understand the sub-components that contribute to it (IPCC, 2022).

Figure 15 Conceptualization of Risk Framework - IPCC AR6

(Source: IPCC AR6 Report, WGII)

The Climate Risk Assessment of cities establishes a tangible foundation for comprehending the climate-associated hazards a city might face. The following steps were employed to conduct the climate risk

assessment there needs a qualitative outline of pertinent climate-related perils, encompassing historical patterns as well as future projections, a list of prioritized effects across various sectors within the city to enumerate the vulnerability of cities and a concise overview of exposed population affecting diverse sectors in the city.

4.4.1 Climate Hazards for Tamil Nadu Cities

Climate hazards considered for the assessment of Tamil Nadu cities include heat waves, flood hazard, drought and sea level rise.

The intensified urban heat island effect and temperature extremes place urban areas at risk. This includes the vulnerability of settlements and infrastructure to elevated temperatures, potentially leading to health issues, disruptions in daily life, and increased energy demand. The Indian Meteorological Department defines heat wave, is a condition of air temperature which becomes fatal to the human body when exposed. Quantitatively, it is defined based on the temperature thresholds over a region in terms of actual temperature or its departure from normal. In certain countries it is defined in terms of the heat index based on temperature and humidity or based on extreme percentile of the temperatures.

In the present study the number of days exceeding 90th percentile of Maximum temperature with reference to base period (1985 to 2014) has been analysed. The comparison of the Tamil Nadu cities based on the above criteria for the current period and for the near future is depicted in Table 5. It is observed that the coastal cities of Chennai, Nagercoil, Thanjavur and Thoothukudi have experienced more than 40 heat wave days when compared to the other cities during the base period. The number of heat wave days is projected to double during the near-century (2050s).

Table 5 Annual Days exceeding 90th percentile of MaxT with reference to baseperiod

S.No.	Cities	Days exceeding 90th percentile of MaxT	
		Base Period (1985-2014)	Near Century (2021-2050)
1	Avadi	43	80
2	Chennai	42	81
3	Coimbatore	24	44
4	Cuddalore	26	52
5	Dindigul	20	42
6	Erode	31	51
7	Hosur	44	67
8	Kancheepuram	39	74
9	Karur	29	50
10	Kumbakonam	22	43
11	Madurai	13	31
12	Nagercoil	2	7
13	Salem	32	54
14	Sivakasi	3	11
15	Tambaram	42	78
16	Thanjavur	21	42
17	Thoothukudi	4	12
18	Tirunelveli	1	6
19	Tiruppur	28	48
20	Trichy	22	44
21	Vellore	43	73

Flood Hazard

The IPCC AR6 report defines flood hazard as the potential occurrence of extreme precipitation or river flow that can cause flooding and lead to negative consequences. Flood hazards can be influenced by various factors, such as climate change, land-use change, and water management practices (IPCC, 2022). Flood hazard assessment is an essential component of flood risk management, and it involves estimating the probability and magnitude of flood events (Hirabayashi et al., 2013). Hydrological models are mathematical formulations that can determine the volume of runoff leaving a watershed from the rainfall received by the watershed. A flood hazard model can be developed to incorporate all effective criteria for identifying flood hazard areas. Proxy indices namely runoff coefficient, Modified Fournier Index (MFI), Rx1day (maximum 1-day rainfall amount) and R25mm (number of heavy rainfall days above 25 mm) are the effective, dynamic and influencing parameters in determining the frequency and magnitude of flood events. The Flood Hazard Index (FHI) calculated helps demarcate the severity and extent of flood events on spatio-temporal scales. It is observed that the overall flood index shall increase in the near future (2021-2050) when compared to the baseline period (1985-2014) in all the cities of Tamil Nadu (Figure 16).

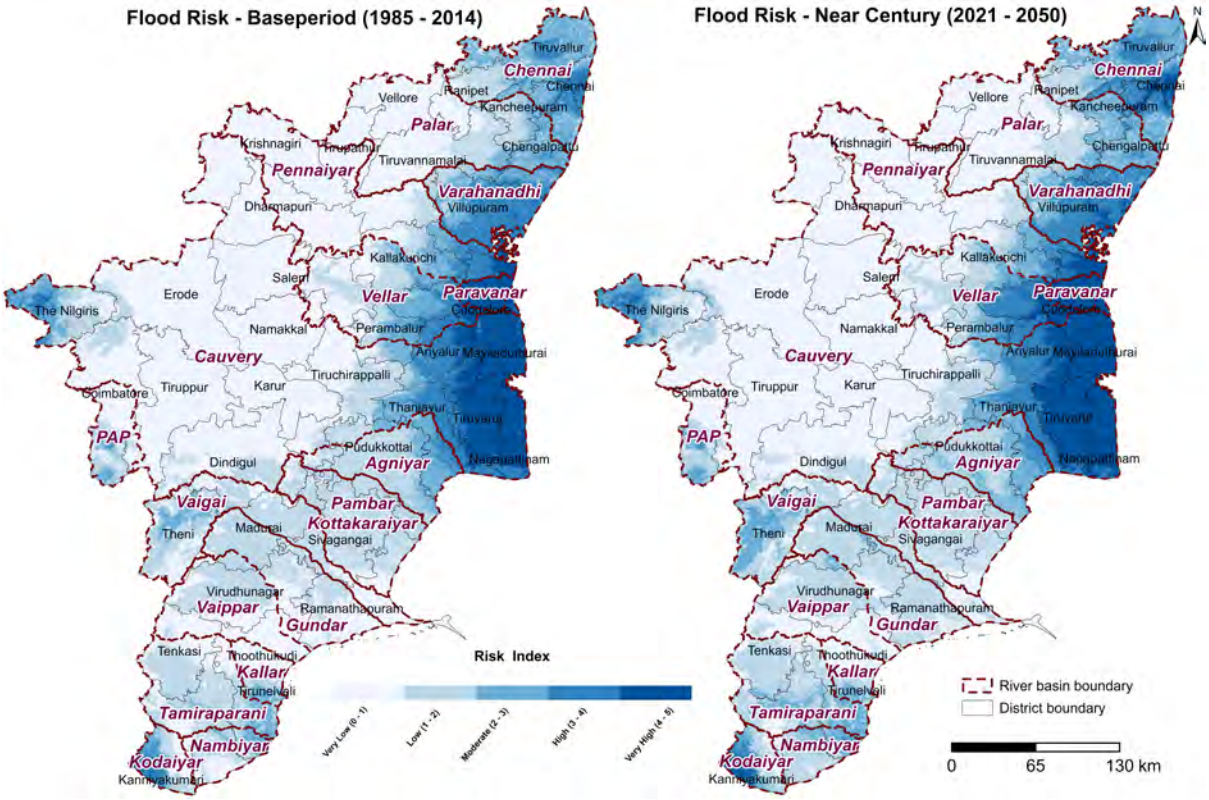


Figure 16 Flood Map of Tamil Nadu

Flood events, compounded by sea level rise, threaten the stability of cities and settlements. The inundation of areas can cause damage to infrastructure, disrupt communities, and exacerbate existing vulnerabilities, particularly in coastal regions. Table 6 indicates the flood hazard index of 21 cities for the base period and the near century period.

Table 6 Flood hazard index of 21 cities during base period and near century.

S.No.	Cities	Flood Hazard Index	
		Base Period (1985-2014)	Near Century (2021-2050)
1	Avadi	3.64	3.89
2	Chennai	3.99	4.35
3	Coimbatore	1.62	1.62
4	Cuddalore	4.66	5.17
5	Dindigul	1.95	1.95
6	Erode	1.26	1.26
7	Hosur	1.25	1.5
8	Kancheepuram	2.11	2.83
9	Karur	1.27	1.27
10	Kumbakonam	4.11	4.23
11	Madurai	1.91	2.16
12	Nagercoil	2.3	2.55
13	Salem	1.25	1.25
14	Sivakasi	2.08	2.33
15	Tambaram	3.52	4.02
16	Thanjavur	3.27	3.27
17	Thoothukudi	2.85	2.85
18	Tirunelveli	2.47	2.72
19	Tiruppur	1.35	1.35
20	Trichy	2.09	2.09
21	Vellore	1.45	1.45

Drought and Water Scarcity

Drought is a naturally occurring event characterised as an extended period of dryness over a prolonged period and a broad region. Droughts pose a significant hazard to health, agriculture, economies, energy, and the ecosystem. The IPCC AR6 report projects that drought risk is expected to increase across many world regions in the coming decades, especially in areas already vulnerable to droughts. According to the report, it is highly likely that some regions, including the Mediterranean, Western North America, and Southern Africa, will experience an increase in the frequency and intensity of droughts.These projections highlight the urgent need for effective drought management and adaptation strategies to minimise the impacts of droughts on people, economies, and ecosystems. Drought is categorised into four major types, meteorological drought (rainfall below normal level), agricultural drought (soil moisture below threshold), hydrological drought (departure in storage and runoff) and socio-economic drought (economic shortfall in the water supply) (Eslamian, 2017).Drought Indices, such as Standardised Precipitation Evapotranspiration Index (SPEI), and Streamflow Drought Index (SDI), help to evaluate the frequency and intensity of drought events. The Drought Hazard Index (DHI) has emerged as a reliable tool to provide quantitative information

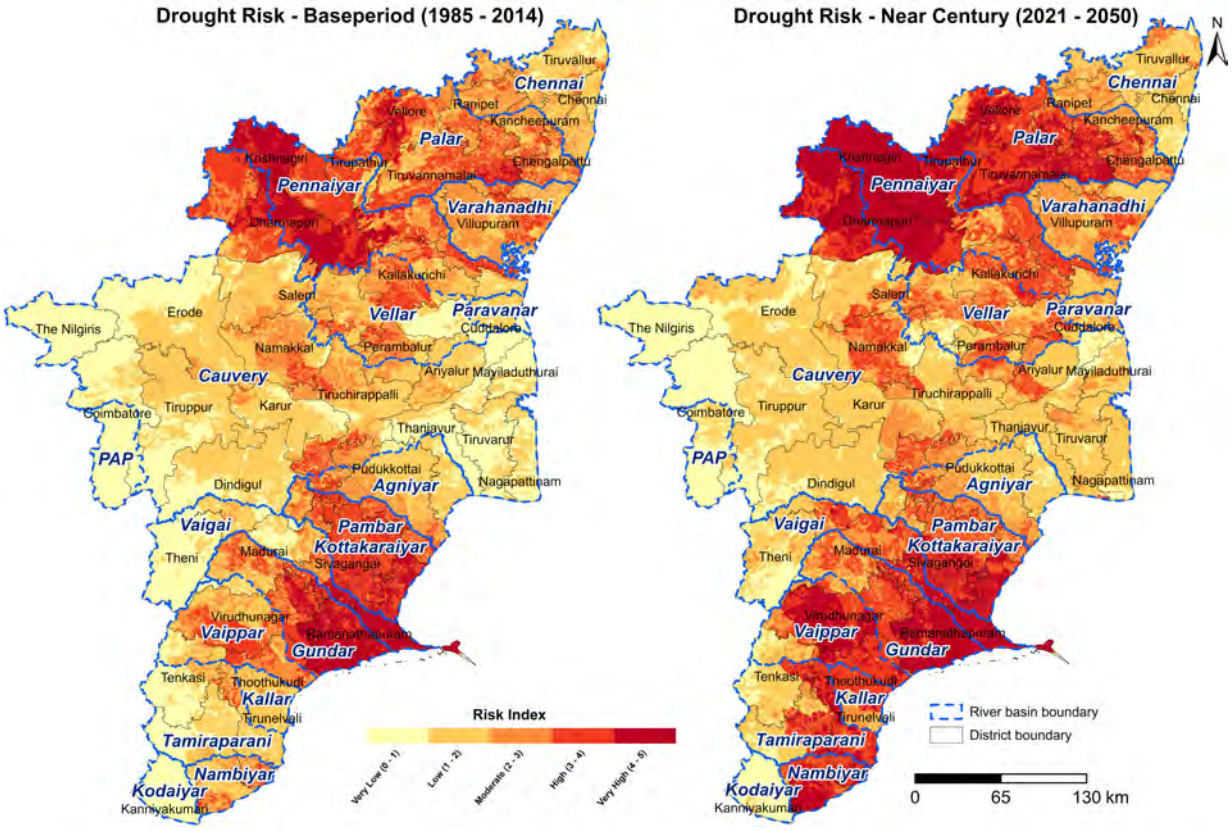


Figure 17 Drought Map of Tamil Nadu

about an area's vulnerability to drought, it is observed that there is a mixed prediction with respect to drought risk in the near future period (2021-2050) with reference to baseline period (1985-2014) (Figure 17). It is observed that Madurai city will face severe drought when compared to other cities of Tamil Nadu. Cities viz. Tirunelveli, Thoothukudi, Thanjavur, Sivakasi, Salem, Kumbakonam, Cuddalore, Nagercoil and Kancheepuram will face drought risk in the near future. The simulated hydrological features are further used to compute the Drought Hazard Index for the cities for the current and future periods (Table 7).

Table 7 Droughthazard indexof 21 cities during thebase period and nearcentury.

S.No.	Cities	Drought Hazard Index	
		Base-period (1985-2014)	Near Century (2021-2050)
1	Avadi	3.25	3
2	Chennai	3	3
3	Coimbatore	2.75	2.25
4	Cuddalore	2.75	3.25
5	Dindigul	2.25	2.5
6	Erode	2.5	2.5
7	Hosur	4	4
8	Kancheepuram	3	3.25
9	Karur	2.25	2.5
10	Kumbakonam	2.25	2.5
11	Madurai	2.25	3.75
12	Nagercoil	1.75	2.5
13	Salem	2.75	3
14	Sivakasi	3.25	3.75
15	Tambaram	3	2.75
16	Thanjavur	2	2.75

S.No.	Cities	Drought Hazard Index	
		Base-period (1985-2014)	Near Century (2021-2050)
17	Thoothukudi	2.5	3
18	Tirunelveli	2.5	4
19	Tiruppur	2.75	2.25
20	Trichy	3	3
21	Vellore	3	3.5

Sea level Rise

Sea level rise has significant impacts on coastal cities around the world. As global temperatures increase due to climate change, ice sheets and glaciers melt, and thermal expansion causes the ocean to expand, resulting in higher sea levels. This phenomenon poses several challenges and impacts for coastal cities. There are three coastal cities in Tamil Nadu viz. Chennai, Cuddalore and Thoothukudi. The projected sea level rise for the coastal cities are provided in Table 8.

Table 8 Projected Sea Level of Coastal Cities of Tamil Nadu during Near Century

S.No.	Tamil Nadu Cities	Sea Level Rise (cm) – SSP2-4.5
1	Chennai	19.9
2	Cuddalore	20.26
3	Thoothukudi	20.13

IMPACT OF BIOCLIMATIC VARIABLES ON SUSTIANABLE URBAN HABITAT

The Bioclimatic Index (BioClim) is a set of 19 bioclimatic variables derived from temperature and precipitation data. These variables provide insights into the climatic conditions experienced by living organisms and are widely used in ecological and biogeographical studies. For city sustainable habitat planning, some of the key Bioclim variables to consider include Mean Temperature of Warmest Quarter, Mean Temperature of Coldest Quarter, Temperature Annual Range, Annual Precipitation, Precipitation of

Wettest Month, Precipitation of Driest Month, Precipitation Seasonality, Mean Diurnal Range, Isothermality and Temperature Seasonality. The change in the mean values of these bioclimatic variables was assessed for the 21 cities of Tamil Nadu for the Baseline period (1985-2014) and the Near Century (2021-2050) under SSP2- 4.5 scenario. The mean Diurnal Range represents the average difference between daily maximum and minimum temperatures, influencing thermal comfort and energy demand for heating and cooling. It is observed that the diurnal range has minimised during the near century across all the cities of Tamil Nadu. A long-term decline in the Diurnal Temperature Range (DTR) due to faster-increasing rates in night-time than in daytime air temperature is a global phenomenon with profound ecological impacts. Warmer nights and reduced DTR may affect humans, different plant species, and urban green cover.

Isothermality is the fraction of mean Diurnal Range over the Temperature Annual Range, which indicates the degree of temperature uniformity throughout the year, influencing plant growth, biodiversity, and microclimate variability. Isothermality ranged from 51 to 67 across the cities of Tamil Nadu during the Baseline which reduced to 48 to 65 in the Near Century. A reduction in isothermality often leads to higher daytime temperatures within cities. Elevated temperatures worsen air pollution. Chemical reactions in the atmosphere increase smog formation and ground-level ozone.

Temperature Seasonality reflects the variability in temperature throughout the year, affecting plant phenology, species distribution, and ecosystem functioning. It is observed that the seasonality of temperature varies across the cities of Tamil Nadu. There is an increase in this variation during the Near century indicating the influence of extreme weather events. This creates a challenge in planning afforestation activities in urban areas, as change in seasonality hinders plant growth. Temperature Annual Range is the difference between the warmest and coldest monthly mean temperatures, which impacts temperature variability and seasonal climate patterns, influencing the micro-climate of the urban areas. Overall there is very little change in the temperature annual range in the near century from the baseline. Mean Temperature of Warmest Quarter, indicates the average temperature during the warmest three months of the year, influencing heat stress and thermal comfort for urban residents. The influence of this bioclimatic variable is evidenced through the increase in the number of thermally discomfort days in the near century as discussed earlier. The mean temperature of the Coldest Quarter reflects the average temperature during the coldest

three months. There is an increase in this bioclimatic variable, indicating a warmer micro-climatic condition in urban areas, affecting energy demand for heating and cold-related health risks.

Annual Precipitation is total yearly rainfall, which is observed to increase across cities in the Near century which crucial for managing storm water runoff and ensuring adequate water supply for urban residents and ecosystems. Specifically, the precipitation of wettest month, which indicates the amount of rainfall during the wettest month, essential for flood risk assessment and water management strategies. There is negligible change in the precipitation of driest month, which is the minimum precipitation levels during the year, important for assessing drought risk and water scarcity issues. In the context of cities, the forecast for precipitation seasonality, measured by the coefficient of variation of monthly precipitation, highlights significant variability in rainfall distribution throughout the year. This variability impacts water management practices within urban areas across Tamil Nadu. Bioclimatic variables further underscore higher flood risk in urban zones compared to drought susceptibility. Integrating these Bioclim variables into city-specific sustainable habitat planning enables a deeper understanding of local climate conditions and their effects on human well-being, ecosystem health, and urban resilience.

4.4.2 Vulnerability of Tamil Nadu cities

The repercussions of climate change on a city pertain to its social, ecological, and economic dimensions. According to the IPCC AR6, vulnerabilities of cities are influenced by various factors of inequality, such as gender, socioeconomic status, race, ethnicity, age, disability, sexual orientation, and non-binary gender identities, all of which are influenced by cultural norms, diverse values, and customs. The intersections among these factors create distinct experiences of vulnerability and risk, affecting how groups and individuals adapt to challenges. The process usually necessitates input from a variety of stakeholders and relevant sectors within the city. For the relative assessment of the cities of Tamil Nadu, vulnerability indicators viz. the extent of urban green cover and built-up area, urban heat intensity, condition of drainage systems, total capacity of water resources and health facilities in terms of number beds per 1000 people and paramedical support to respond to medical emergencies during extreme climate events (Figure 18). The

extent of green cover, built-up area and water bodies of the cities and Land Surface Temperature (LST) was mapped using Geospatial technology.

It is observed that most of the cities in Tamil Nadu have very less green cover, with Chennai city recording the least extent of green cover of 8.050 sq. km. Nagercoil city has the highest proportion of urban green cover. As per the urban greening guidelines 2014, the Ministry of Urban Development recommends that the proportion of recreational areas (including parks, spaces, water bodies, etc.) to the total developed area in medium towns and large cities should be from 18 to 20% in medium towns and large cities; and 20-25% in metropolitan cities (Ministry of Urban Development, 2014). From the analysis of the proportion of urban green cover, it is observed that only Nagercoil has 19% of urban green cover, while all the other cities are below it. The overall vulnerability assessment of all the 21 cities is portrayed in Figure 18. It is found that Dindigul, Tirunelveli and Vellore cities are the most vulnerable among the 21 cities.

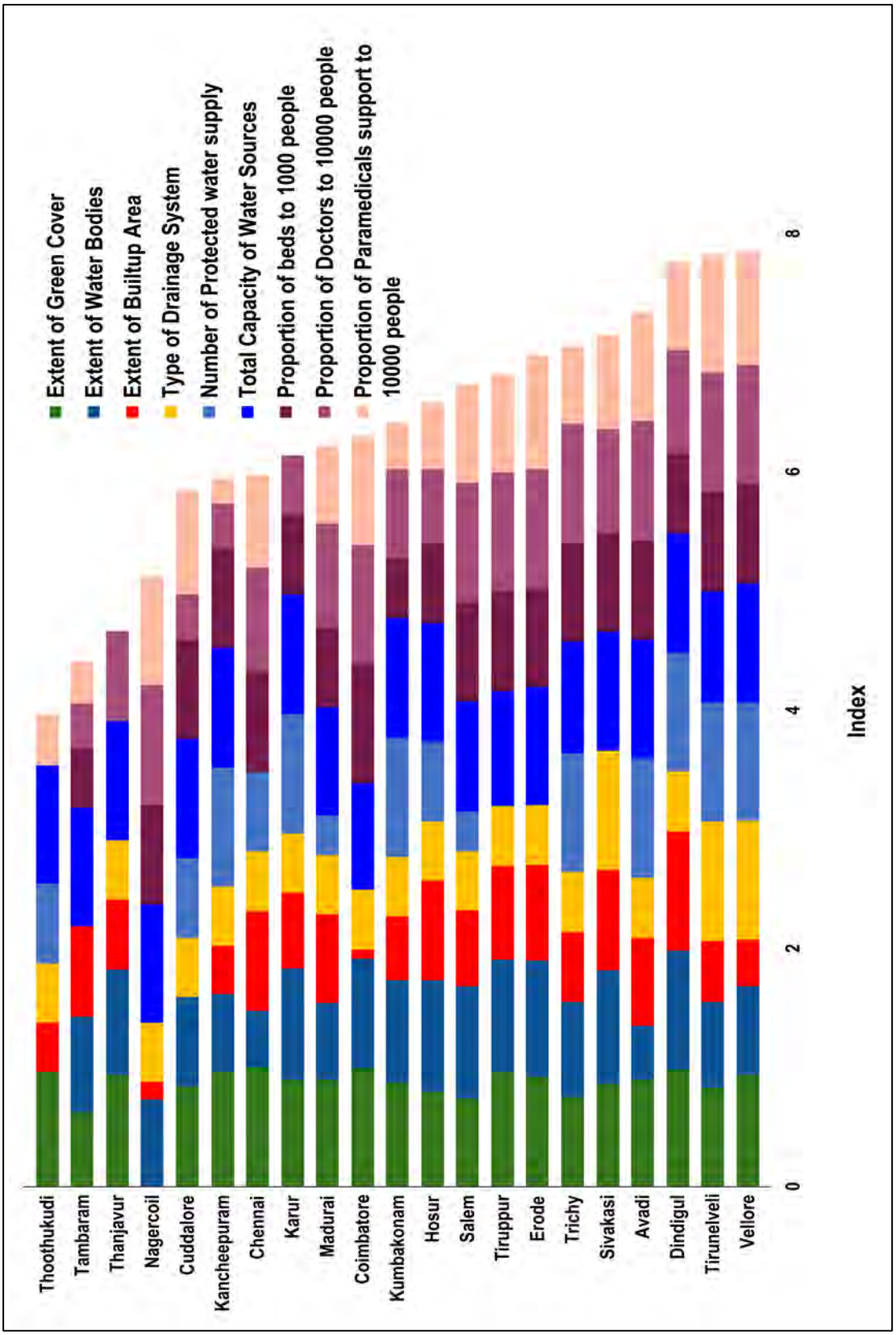


Figure 18 Vulnerability of Tamil Nadu Cities

4.4.3 Exposure of Tamil Nadu cities

The IPCC AR6 reports with high confidence that the number of individuals expected to reside in urban areas facing significant climate change impacts has notably risen. By the year 2050, an extra 2.5 billion people are anticipated to inhabit urban regions, with up to 90% of this growth concentrated in Asia and Africa. By 2050, over a billion people residing in low-lying cities and settlements are projected to face climate-related hazards especially in coastal regions. This will result in a rise in the number of individuals affected, the urban land area impacted, and the damages incurred from flood-related risks. The primary driver of increased heat exposure is the combination of global warming and population growth in already warm urban centres, with the majority of the population exposed to heatwaves residing in these urban areas. The IPCC further insists that approximately 350 million individuals in urban settings are estimated to encounter water scarcity due to severe droughts with a global warming of 1.5°C, which increases to 410.7 million exposed individuals if the temperature increases by 2°C warming. In this context, it is also evidenced that urban heat islands increase the mortality of elderly people and impair the cognition and well-being of children. The cities of Tamil Nadu were assessed based on the proportion of child population, elderly population, slum population, homeless people and population density in the city (Figure 19). The overall exposure assessment reveals that Chennai city having the highest population density and high population of homeless people is the most exposed city in Tamil Nadu. Poor infrastructure and socio-economic factors make these groups more vulnerable to heat stress and related illnesses. This is a serious concern for cities in tropical or subtropical regions with high urbanisation rates.

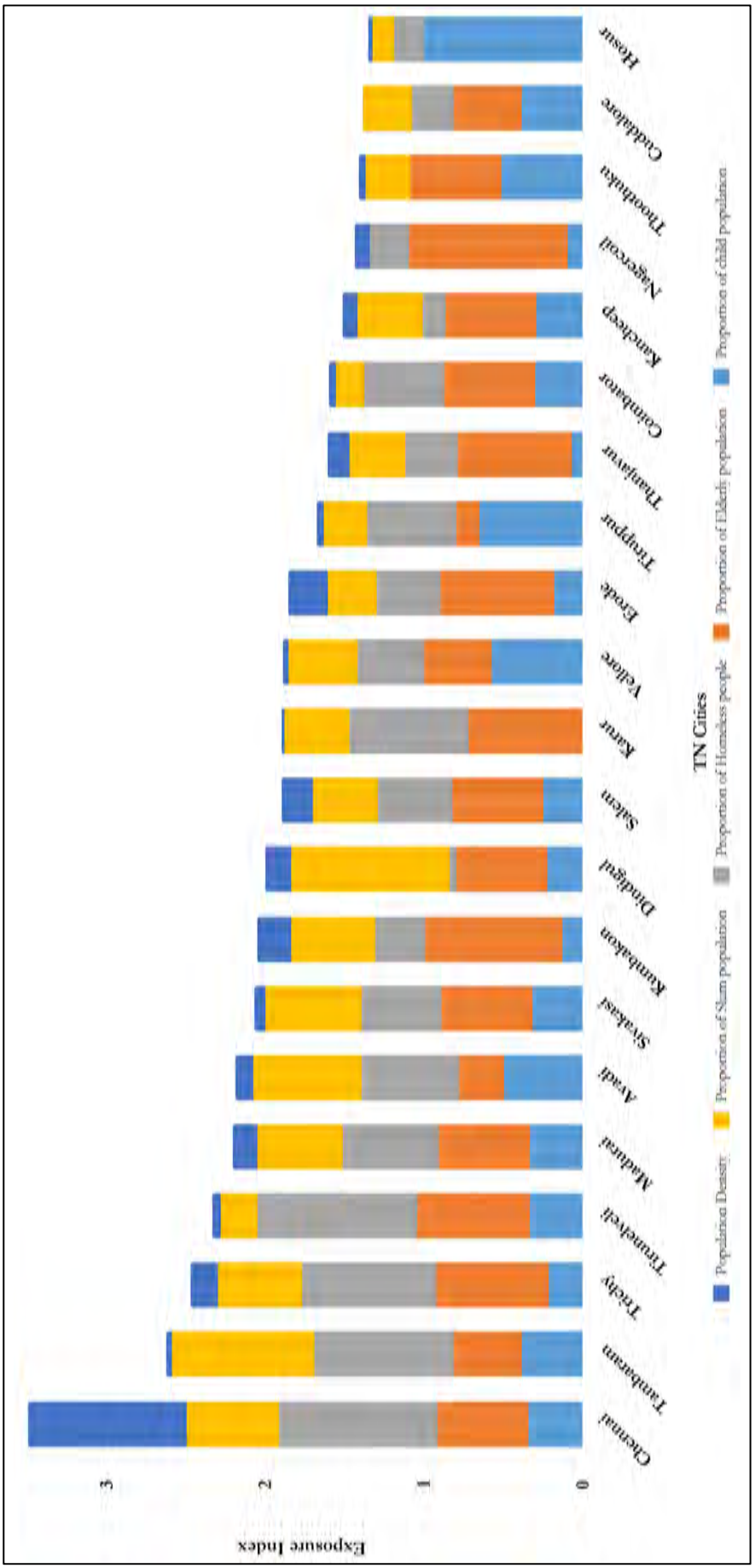


Figure 19 Exposure Index of the Tamil Nadu Cities

4.5 Climate Change Risk of Cities

The current climate risks of cities as a multiplicative function of hazard, vulnerability and exposure in the baseline period (1985-2014), vulnerability, and exposure based on the above indicators are discussed below. The cities are compared and ranked based on their relative risk index (Figure 20).

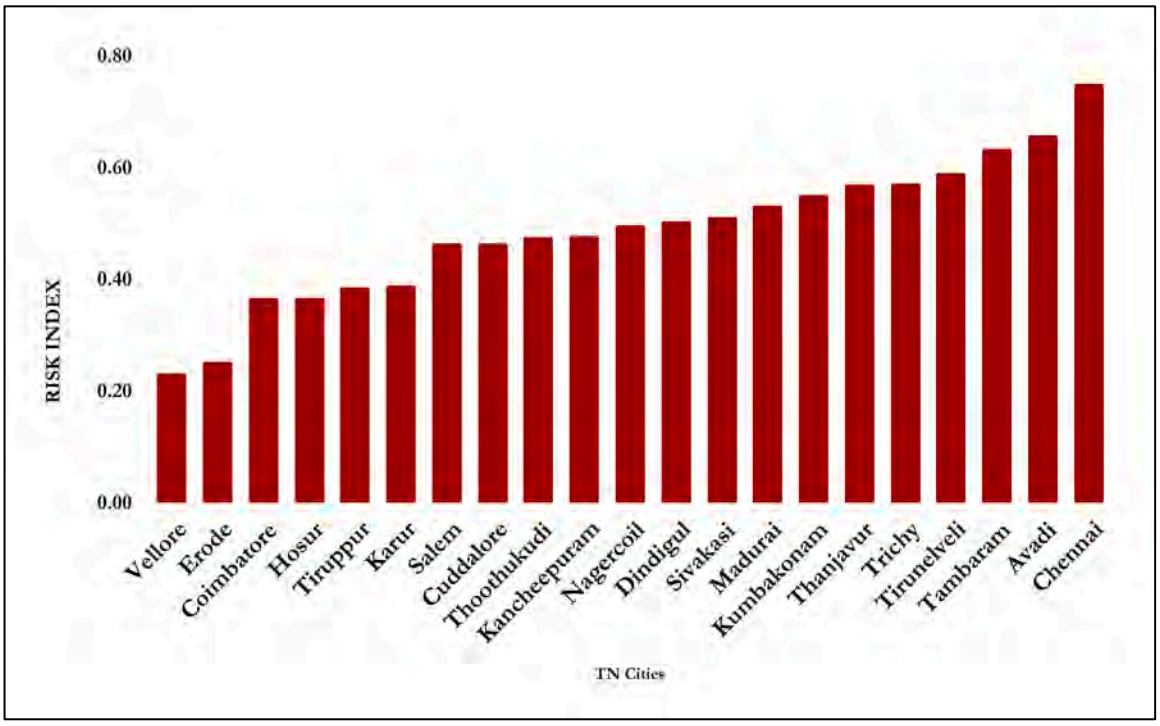


Figure 20 Climate Change Risk of Tamil Nadu Cities

It is observed that the Greater Chennai Corporation and the surrounding cities viz. Avadi, Tambaram are risk prone to the climate hazards owing to the current vulnerability and exposure of the vulnerable population. These cities are having highest exposure (Population Density) to the elevated hazard (More flood, heatwave, discomfort) making them most riskiest to the climate change impact within the State. The cities viz. Tirunelveli, Trichy, Thanjavur, Kumbakonam, Madurai, Sivakasi, Dindigul, Nagercoil, Kancheepuram, Thoothukudi, Cuddalore and Salem are cities with moderate risk to climate change. The cities with low risk to climate hazard are Karur, Tiruppur, Hosur, Coimbatore, Erode and Vellore. The important drivers contributing to climate change risk within each city is listed in Table 9.

Table 9 Important indicators contributing to the City's risk

CITIES	INDICATORS TO BE PRIORITISED
AVADI	Thermal Discomfort Days, Flood, Drought, Pollution and Sea Level Rise, Extent of Green Cover, Extent of Built-up Area, Total Capacity of Water Supply, Health facilities, Proportion of Slum population
CHENNAI	Heat Waves, Thermal Discomfort Days, Flood, Drought, Pollution and Sea Level Rise, Extent of Green Cover, Extent of Built-up Area, Number of Protected water supply, Proportion of beds to 1000, Proportion of Doctors to 10000 people, Proportion of Homeless population, Population density
COIMBATORE	Heat Waves, Pollution, Extent of Green Cover, Extent of Water bodies, Total Capacity of Water Bodies, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people
CUDDALORE	Thermal Discomfort Days, Flood and Sea Level Rise, Extent of water bodies, Number of Protected Water Supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people
DINDIGUL	Drought, Extent of Green Cover, Extent of water bodies, Extent of Built-up Area, Number of Protected Water supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people, Proportion of Slum Population
ERODE	Thermal Discomfort, Drought, Extent of water bodies, Extent of Built-up Area, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people, Proportion of elderly population
HOSUR	Extent of Green Cover, Extent of Built-up Area, Number of Protected water supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people, Proportion of Child Population
KANCHEEPURAM	Thermal Discomfort Days, Pollution, Extent of Green Cover, Number of protected water supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people
KARUR	Thermal Discomfort Days, Drought, Extent of Green Cover, Extent of Water bodies, Number protected water supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Homeless population
KUMBAKONAM	Thermal Discomfort Days and Flood, Extent of Green Cover, Number of Protected water supply, Total Capacity of Water Supply, Hospitals, Proportion of Doctors to 10000 people Proportion of Elderly Population

CITIES	INDICATORS TO BE PRIORITISED
MADURAI	Thermal Discomfort Days, Drought, Extent of Green Cover, Extent of Water Bodies, Extent of Built-up area Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people
NAGERCOIL	Heat Waves, Thermal Discomfort Days, Drought and Sea Level Rise , Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people, Proportion of Elderly Population
SALEM	Drought, PM2.5 pollution, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people
SIVAKASI	Thermal Discomfort Days, Extent of Green Cover, Extent of Water bodies, Extent of Built-up Area, Type of drainage, Total Capacity of Water Supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people
TAMBARAM	Heat Waves, Thermal Discomfort Days, Flood, Drought, Pollution, Extent of Green Cover, Extent of Water bodies, Extent of Built-up area, Total Capacity of Water Supply, Hospitals, Proportion of Slum population, Proportion of homeless population,
THANJAVUR	Heat Waves, Thermal Discomfort Days, Flood, Drought and Sea Level Rise, Extent of Green Cover, Extent of Water bodies, Total Capacity of Water Supply, Hospitals, Proportion of Doctors to 10000 people, Proportion of Elderly Population
THOOTHUKUDI	Heat Waves, Thermal Discomfort Days, Flood and Sea Level Rise, Extent of Green Cover, Number of Protected water supply, Total Capacity of Water Supply
TIRUNELVELI	Heat Waves, Thermal Discomfort Days and Sea Level Rise, Extent of Green Cover, Extent of Water Bodies Type of Drainage system, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people, Proportion of Homeless population

CITIES	INDICATORS TO BE PRIORITISED
TIRUPPUR	Extent of Green Cover, Extent of Water bodies, Extent of Built-up Area, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people, Proportion of Child Population
TRICHY	Heat Waves, Thermal Discomfort Days, Extent of Water bodies, number of protected water supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people, Proportion of Homeless population, Proportion of Elderly population
VELLORE	Heat Waves, Thermal Discomfort, Extent of Green Cover, Extent of Water Bodies, Type of Drainage system, Number of protected water supply, Total Capacity of Water Supply, Hospitals, Proportion of beds to 1000 people, Proportion of Doctors to 10000 people

Each city has specific indicators that drive their risk. Most of the cities face risk due to their vulnerability as is indicated in the table. However, Greater Chennai City has very high density of population exposed to climate hazards, that makes it a riskier city with respect to climate change.

The analysis of all the indicators across the cities (Figure 21) show that the quantum of stored water capacity plays a major role in drinking the risk of most cities, followed by the number of hospitals available in the city. Thermal discomfort and extent of green cover are the other vulnerability indicators that are significant from the climate risk point of view. Therefore, actions to address these indicators can be an initiation towards climate resilience.

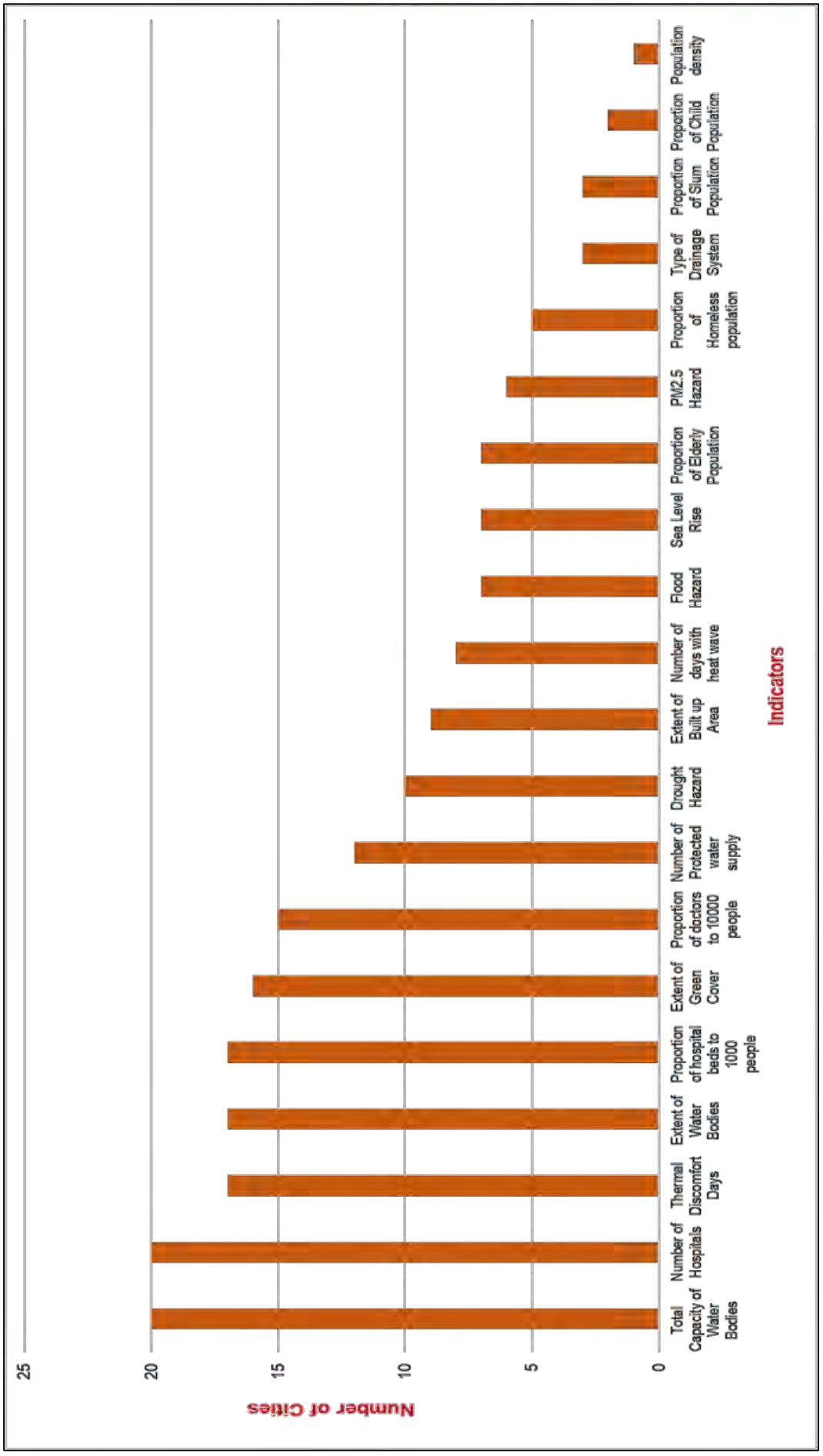


Figure 21 Prioritized Indicators across cities in Tamil Nadu

5. ADAPTATION STRATEGIES

The IPCC AR6 report identified the adaptation gaps in cities across the world, which measures the difference between the actual and experienced risk and loss due to climate change. It was reported that urban populations face more risk and loss than they can manage with current or planned adaptations and that mitigation is essential to avoid further harm. Specifically, Asian cities have the highest reported inequality in the application of urban adaptation, meaning that the urban poor are more vulnerable and exposed to climate change impacts than the urban rich. This is related to the rapid urbanization in this region, which may create challenges for planning and implementing effective adaptation measures. The IPCC, 2022 suggests the following adaptation measures for addressing the climate risks in cities:

1. Adaptation through Social Infrastructure (social, cultural and financial activities and institutions as well as associated property, buildings and artefacts that can be deployed to reduce risk and recover from loss) through actions viz. Land Use Planning, Livelihoods and Social Protection, Emergency and Disaster Risk Management, Climate Resilient Health Systems, Education and Communication, Cultural heritage/institutions.
2. Adaptation through Nature-Based Solutions that aid in Temperature Regulation, Air Quality Regulation, Storm-water Regulation and Sanitation, Coastal Flood Protection, Riverine Flood Impact Reduction, Water Provisioning and Management, Food Production and Security.
3. Adaptation through Grey/Physical Infrastructure like the Urban Morphology and Built Form, Building Design and Construction, Information and Communication Technology, Energy, Transport, Water and Sanitation, Flood Management and Coastal Management.

At the National level, the Climate Smart Cities Assessment Framework was developed which is a tool for Indian cities to evaluate and improve their performance on climate-related parameters. The framework is part of the National Mission on Sustainable Habitat, which is one of the eight climate missions of the Government of India. The framework has indicators across five categories (viz. Urban Planning, Green Cover and Biodiversity, Energy and Green Buildings, Mobility and Air Quality, Water Management, and Waste Management, that cover both mitigation and adaptation measures. The framework has been applied to 126 cities in two phases, with training and mentoring sessions provided to city officials. This framework

has been used for assessing the preparedness of the Indian cities. The Tamil Nadu State Action Plan on Climate Change 2.0 (Table 10) suggests the following strategies under the mitigation measures which are at different level of implementation.

Table 10 Activities proposed and the status of actions.

Activity	Status of Actions
Sewerage and Septage Management	Underground sewerage schemes are being implemented in 9 added areas, namely Nerkundram, Pallikaranai, Ramapuram, Manali, Chinnasekkadu, Manapakkam, Karambakkam, Mugalivakkam and Madipakkam As part of Chennai Rivers Restoration Trust (CRRT) works, modular STPs have been established at Chetpet (1 MLD), Choolaimedu (1.2 MLD), ToddHunter Nagar (4 MLD) and Kotturpuram (0.6 MLD) to prevent sewage outfalls into the waterways.
Bio mining	Bio-mining works have been completed in 64 ULBs and 48 lakh cumt of legacy waste have been processed and 491 acre of land has been retrieved. In 58 ULBs, bio-mining work is in progress.
Vision Singara Chennai 2.0	Under Singara Chennai 2.0 during 2022-23, works have been taken up to give facelift to the flyovers by providing fountains, ornamental lightings and vibrant urban green spaces at an estimated cost of Rs.9.47 crore and are in progress.
Namakku Naame Thittam	The Government, in order to improve the self-support mechanism of public and to enhance increased public participation in creating and maintaining community infrastructure, have launched the flagship program of Namakku Naame Thittam (Urban). Renovation of water bodies; formation, improvement and renovation of parks and playgrounds; installation of traffic islands, fountains, streetlights and CCTV cameras; planting of trees and installation of tree-guards; etc are being executed as part of this scheme
Construction of 54 MLD Sewage Treatment Plant at Sholinganallur, Chennai under TN Investment Promotion Programme (TNIPP)	One unit of 18 MLD capacity has been commissioned. It uses sequential batch reactor (SBR) technology to treat the sewage generated from added areas located along East Coast Road and Old Mahabalipuram Road in the southern parts of Chennai. Another 36 MLD capacity plant is under construction and will be commissioned during 2023-24.
Integrated stormwater drains in the Kosasthalaiyar basin	So far, 45% of the work has been completed. Efforts are being made to complete the project expeditiously. About 30 lakh people living in Ambattur, Manali, Madhavaram and Thiruvotriyur Zones will benefit from this project.
Chennai City Partnership Programme	Enhances 1.Urban mobility and spatial development; 2. Water and resilience; and 3. Urban governance, services, and finance. Mega Streets Programme, Operation and Maintenance of Toilets under PPP mode, Smart Cities Mission, Restoration of Victoria Public Hall, Eco Restoration of Villivakkam tank, Multi-modal integrated bus stand in Broadway

Activity	Status of Actions
Prevention, interception and diversion of sewage outfalls in Cooum, Adyar and Buckingham Canal and its associated drains	Short term interception and diversion arrangements and long term infrastructure strengthening works.
Integrated Cooum River EcoRestoration Project (ICRERP)	Administrative sanction for Rs.735.08 crore has been accorded by the Government of Tamil Nadu for the implementation of ICRERP for the stretch from Paruthipattu check dam to the Cooum river mouth for a length of 32 km. So far, Rs.495.38 crore has been disbursed to implementing agencies based on the work progress.
Adyar River Restoration Project (ARRP)	The ecological restoration of Adyar river from its origin at Adhanur lake to the river mouth for a distance of 42 km was initiated by the Government for Rs.555.46 crore. The major restoration works being implemented are sewage management, solid waste removal, river channel improvement, rehabilitation and resettlement, plantation and riverfront development.
Eco-Restoration of Ennore Creek	The Government have accorded administrative sanction of Rs.45.99 crore for the eco-restoration of Ennore creek and the preparatory activities for habitat restoration works are being taken up by Forest Department.
Kfw (German Development Bank) assisted Sustainable Municipal Infrastructure Financing – Tamil Nadu (SMIF-TN) Programme	Funds totaling Rs.11,525.68 crore are available under three lines of credit
World Bank assisted Tamil Nadu Sustainable Urban Development Project (TNSUDP)	In continuation to the World Bank assisted Tamil Nadu Sustainable Urban Development Project (TNSUDP), a new projects are proposed
Tamil Nadu Urban Flagship Investment Programme (TNUFIP) assisted by Asian Development Bank (ADB), Phase II	The project is being carried out through a consultant engaged by the Tamil Nadu Urban Infrastructure Financial Services Limited (TNUIFSL). administrative sanction has been accorded at a cost of Rs.17.80 crore under AMRUT 2.0 for setting up a dedicated GIS control room at the Board's Head office at Chinthadripet,

Apart from the above status of the implemented actions at the city levels, new projects are also being proposed. The Strengthening Smart Water Management and Urban Climate Change Resilience in Tamil Nadu project, which supports the development of a water supply master plan, a water audit, a non-revenue water reduction strategy, and a climate vulnerability assessment for Chennai and other towns. Chennai City Climate Action Plan is being developed and is under consideration through stakeholder consultation.

Though these measures are being mapped with the possibility to reduce the risk to climate change in urban areas of Tamil Nadu, they are challenged by the following two concerns:

1. It is observed that 70% of the actions are being taken up for Chennai city alone.
2. When compared to the IPCC suggested adaptation actions, only 30% of the strategies are Nature Based solutions and 70% strategies pertinent to grey or physical infrastructure.

There is less consideration with respect to adaptation through social infrastructure, which is still at the nascent stage through the launch of the Chennai City Climate Action Plan.

5.1 Climate Smart City Assessment Framework - Way forward for Climate Resilience

Cities play a potential role in being an example of climate resilient actions. The Climate Smart Cities Assessment Framework 3.0 (CSCAF 3.0) launched during February 2019 by the Ministry of Housing and Urban Affairs (MoHUA), Government of India, is a city assessment framework on climate relevant parameters for Indian cities, serving as a tool for cities to assess their baseline situation and provides a roadmap for cities to adopt and implement relevant climate actions. In addition, the dissemination of best practices adopted by Indian cities has supported in setting contextual standards in green, sustainable and resilient urban development. This framework has been applied to assess the resilience of the 11 out of 21 cities of Tamil Nadu broadly categorised into 5 sectors with 28 indicators (Figure 20). Each of these indicators have a maximum of 5 levels representing different stages of development each with a corresponding weightage, which are as follows:

(i) Urban Planning, Green Cover and Biodiversity,

(ii) Energy and Green Buildings,

(iii) Mobility and Air Quality,

(iv) Water Management, and

(v) Waste Management.

The assessment framework 3.0 attempts to address both the mitigation and adaptation measures and the weightage for each sector (Figure 22) has also been given in accordance with its relation to mitigation or adaptation potential. In terms of mitigation, sectors such as transportation, waste, energy consumption and green cover are most important while for adaptation, sectors such as water, biodiversity, urban planning, and land-use play an important role. The assessment framework 3.0 gives the highest weightage to “Urban

Planning Green Cover and Biodiversity" and "Energy and Green Buildings" categories- 25% each, considering the extent of impact that aspects of these sectors on mitigation and adaptation to tackle climate menace and so on to the remaining categories. The resilience of 11 cities is being assessed based on the following indicators.

Figure 22 Climate Smart Cities Assessment Framework Indicators

Source: Climate Ministry of Housing and Urban Affairs, 2022

5.1.1 Urban Planning, Green Cover and Biodiversity

This sector includes the following indicators viz. Rejuvenation & Conservation of Water Bodies & Open Areas, Proportion of Green Cover, Urban Biodiversity, Disaster Resilience and presence of City Climate Action Plan. Each of these indicators are assessed based on the following (Table 11) indicators and the status of TN cities is shown in Figure 23. It is observed that Coimbatore city performs fairly well in terms of urban planning, while Thanjavur city has not provided sufficient data for assessment.

Table 11 Indicators for the Urban Planning, Green Cover and Biodiversity

Indicators	Score
Rejuvenation & Conservation of Water Bodies & Open Areas	Total score for the indicator is 100. Cities will be marked in 5 levels with scores ranging from 0-100
Proportion of Green Cover	Green Cover in sq.km /Municipal area in sq.km x 100 Unit: % Maximum Score: The total score for the indicator is 100. Cities will be marked in 5 levels with scores ranging from 0 – 100
Urban Biodiversity	Data on biodiversity can be obtained from the Biodiversity Management Committee and the People's Biodiversity Register (instituted as per on the Biological Diversity Act, 2002).
Disaster Resilience	The Total score for the indicator is 100. Cities will be marked in 5 levels with scores ranging from 0 – 100
City Climate Action Plan	The total score for this indicator is 100. Cities will be marked in 4 levels with scores ranging from 0 – 100.

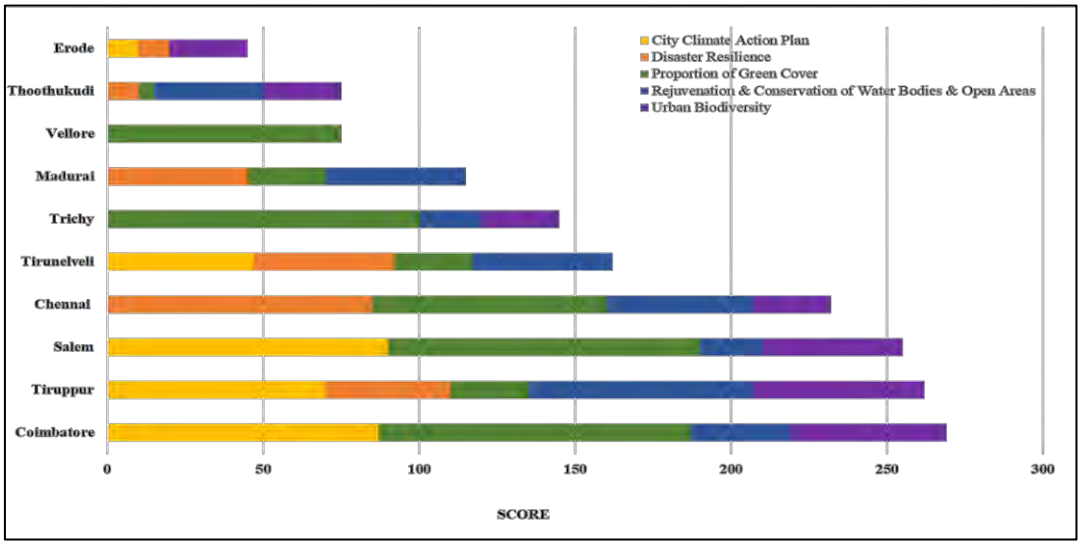


Figure 23 Urban Planning, Green Cover and Biodiversity Sector – Scoring of Cities

5.1.2 Energy and Green Buildings

The status of energy and green buildings are an indication of the readiness of the cities to mitigate climate change. It includes the following indicators (Table 12).

Table 12 Indicators for the Energy and Green Buildings Sector

Indicators	Score
Electricity Consumption in the City	The total score for the indicator is 100. Cities will be marked in 5 levels with scores ranging from 0 to 100.
Total Electrical Energy in the City Derived from Renewable Sources	The total score for the indicator is 100. Cities will be marked in 5 levels with scores ranging from 0 to 100.
Fossil Fuel Consumption in the City	The total score for the indicator is 100. Cities will be marked in 5 levels with scores ranging from 0 to 100.
Energy Efficient Street Lighting in the City	The total score for the indicator is 100. Cities will be marked in 5 levels with scores ranging from 0 to 100.
Promotion of green buildings	The score is given based on the presence of the number of measures taken towards the adoption of green buildings
Green Building Adoption	The score is given based on indication of green buildings in the city with zero score for no indication of green buildings and highest score for the occupant load in green buildings is >600 persons for every 10,000 population

Based on the Assessment of these indicators the status of the cities are depicted as in Figure 24.

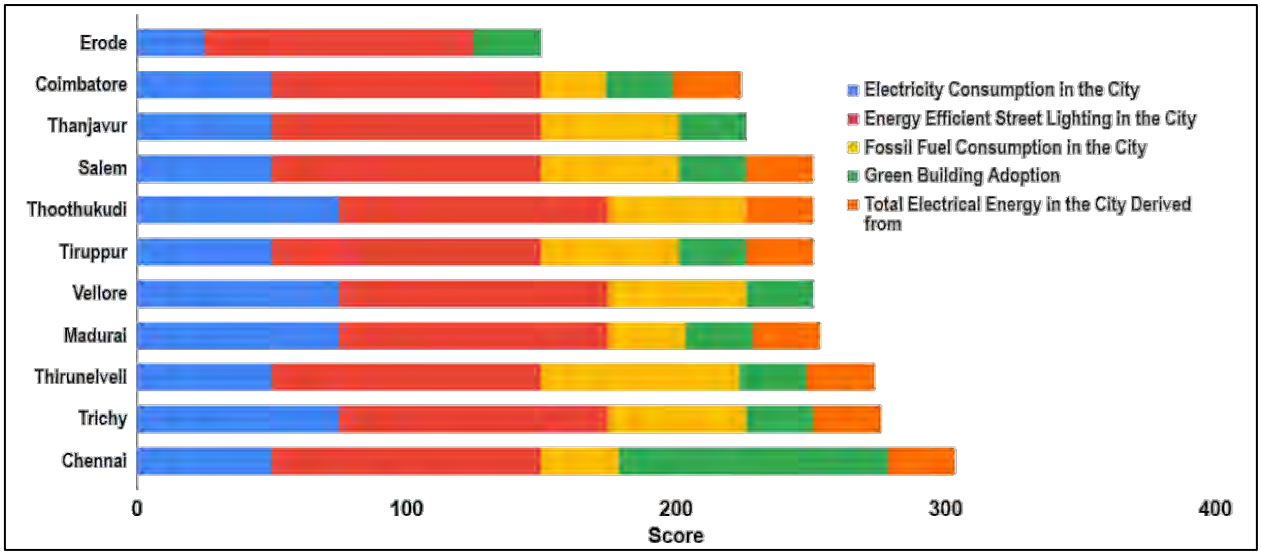


Figure 24 Energy and Green Buildings Sector – Scoring of Cities

Chennai city has taken actions towards energy efficiency and green buildings. There is a need for extensive data to be prepared and resilient to climate change impacts.

5.1.3 Mobility and Air Quality

Conventional vehicles that run on fuel release a large amount of harmful substances into the air, which can be detrimental to the environment and human health. The air quality of the cities are already stressed due to the impact of rapid urbanisation and the transportation. The impact of climate change adds to the problem stressing the health of the urban population. The indicators used for the analysis of the cities are enumerated in Table 13 and the scores for the TN cities are depicted in Figure 25.

Table 13 Indicators for the Mobility and Air Quality Sector

Indicators	Score
Clean Technologies Shared Vehicles	The score ranges from 0 to 100 for no clean technologies >25% clean technology shared vehicles
Availability of Public Transport	Zero for non-availability of public transport to 100 for >0.6 Public Transport Unit (PTU) per 1000 people
Percentage of coverage of Non-Motorized Transport network (pedestrian and bicycle) in the city	Zero for NMT Coverage: Less than 15% to 100 for NMT Coverage: greater than 50%
Level of Air Pollution (Monitoring)	Ranges from zero for no consideration to 100 for Achievement of National Air Quality Standard
Clean Air Action Plan (Planning and Implementation)	Cities will be marked in 5 levels with scores ranging from 0 for no plan to 100 for Assessing the impacts of Clean Air Action Plan implementation

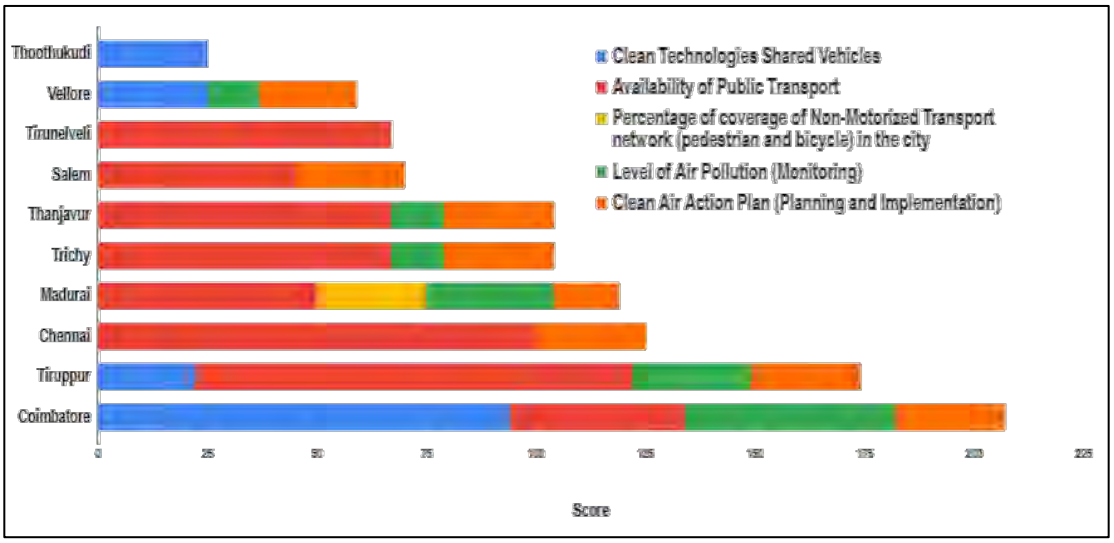


Figure 25 Mobility and Air Quality Sector – Scoring of Cities

It is observed that Coimbatore city has taken up most strategies towards the maintenance of air quality. While Erode city data must be incorporated for assessing the climate readiness of the city.

5.1.4 Water Management

As climate change brings more extreme weather, cities must get smart about water. Flood mitigation and addressing the challenges of drought are mandatory in the most populated cities. Upgrading storm water drains and diversifying water supply via conservation and reuse improves resilience. Monitoring and managing water quality is also key. Drought preparation plans help ensure adequate supply during drier times. The following key indicators (Table 15) are used to assess the water readiness of the cities. The scores for the Water Management Sector are depicted in Figure 26. It is observed that while cities viz. Thanjavur and Vellore need more data; Madurai city among the 11 cities has relatively fared well with respect to water management strategies.

Table 14 Indicators for the Water Management Sector

Indicators	Score
Water Resources Management	Actions for Water Resource Management
Extent of Non-Revenue Water	NRW study not conducted by city: 0 Most recent NRW of the city during 2018-21 is <20%
Wastewater Recycle and Reuse	No reuse : 0; ≥20% Treated Wastewater recycled and reused: 100
Flood/ water stagnation risk management	Conducting Flood/water stagnation risk assessment: 0 Implementation of actions for flood/ water stagnation management: 100
Energy-efficient water supply system and wastewater management system	Not conducted Energy Audit: 0; Achieved >20% of baseline data (2017-2021): 100

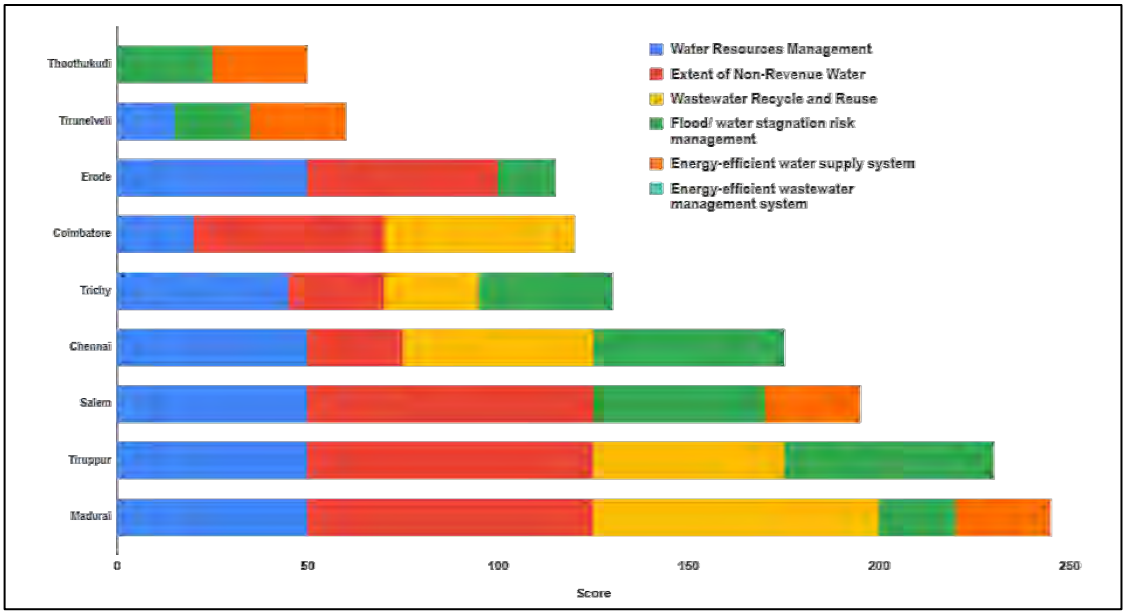


Figure 26 Water Management Sector – Scoring of Major Cities

5.1.5 Waste Management

Reducing waste and improving recycling helps cities lower emissions. The other indicators considered are in alignment with the Swach Survekshan indicators are shown in table 15 and the score for the TN cities of Tamil Nadu for the Waste Management sector is shown in Figure 27.

Table 15 Indicators for the Waste Management Sector

Indicators
Waste minimization initiatives undertaken by the City
Extent of dry waste recovered & recycled
Construction & Demolition (C&D) waste management
Extent of Wet Waste Processed
Scientific Landfill availability & operations
Landfill/ dumpsite Scientific Remediation

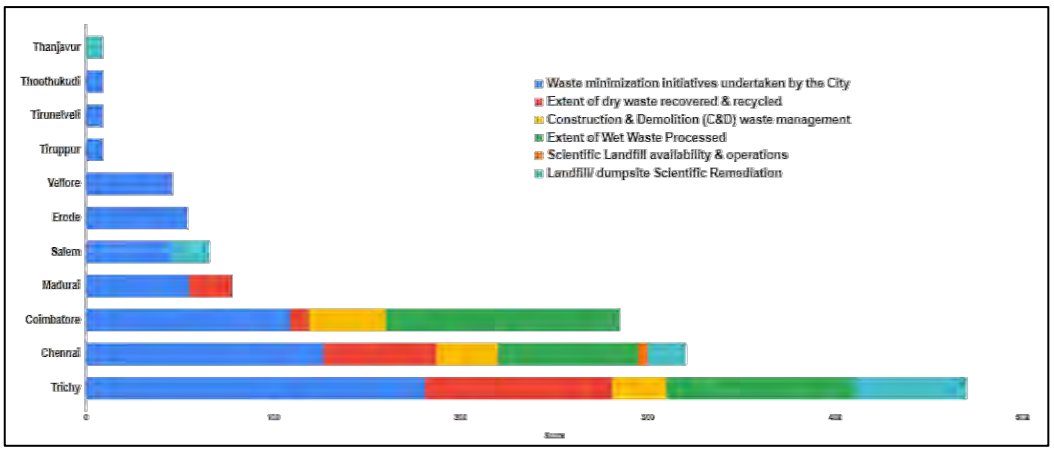


Figure 27 Waste Management Sector – Scoring of Major Cities

Except for Coimbatore, Chennai and Trichy most other cities of Tamil Nadu need more preparedness measures with regard to the waste management sector. The climate-smart city assessment of the Tamil Nadu cities considered under the CSCAF 2.0 is depicted in Figure 28. The observation revealed that Chennai has performed better than other cities overall.

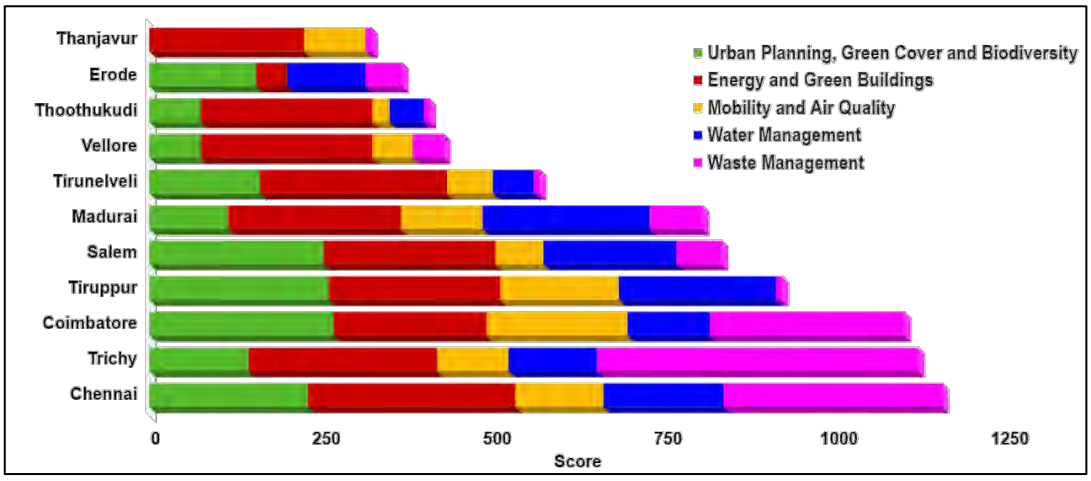


Figure 28 Overall assessment of Tamil Nadu cities

5.2 Nature of Adaptation Actions Proposed:

The evaluation of climate-smart readiness in 21 cities of Tamil Nadu reveals that the implementation of actions outlined by the indicators in the climate-smart cities assessment framework is crucial for enhancing the resilience of these cities. Figure 29 illustrates that initiatives in urban planning, green cover, and biodiversity predominantly constitute nature-based solutions that effectively mitigate the risks associated with heatwaves, floods, droughts, and rising sea levels. Water management measures are also recommended to address the risks of floods and droughts. While nature-based solutions offer comprehensive, long-term benefits by addressing multiple risks, immediate implementation of grey and physical infrastructure can concurrently reduce greenhouse gas emissions and mitigate the risks posed by disasters such as floods, droughts, and rising sea levels. The list of actions proposed to enhance the climate smart preparedness of cities is outlined in Table 17.The status of climate-smart city actions that are already being done across 21 cities of Tamil Nadu is depicted in Table 18. It is observed that the status of climate-smart city actions across 21 cities in Tamil Nadu varies significantly. Among the cities, Greater Chennai has made substantial progress, having implemented 15 actions while addressing 9 and having only 3 left to address. Similarly, Coimbatore has implemented 8 actions, with 14 proposed/addressed and 5 remaining to be addressed. On the other hand, several cities, such as Avadi, Dindigul, Hosur, Kanchipuram, Karur, Kumbakonam, Nagercoil, Sivakasi, Tambaram, and Vellore, have not implemented any actions yet, with a substantial number still to be addressed. Overall, the status reflects a diverse landscape, with some cities actively implementing climate-smart initiatives while others are still in the early stages of planning and execution. The distribution of actions across cities underscores the need for concerted efforts to ensure uniform progress in building climate-resilient urban environments across Tamil Nadu.

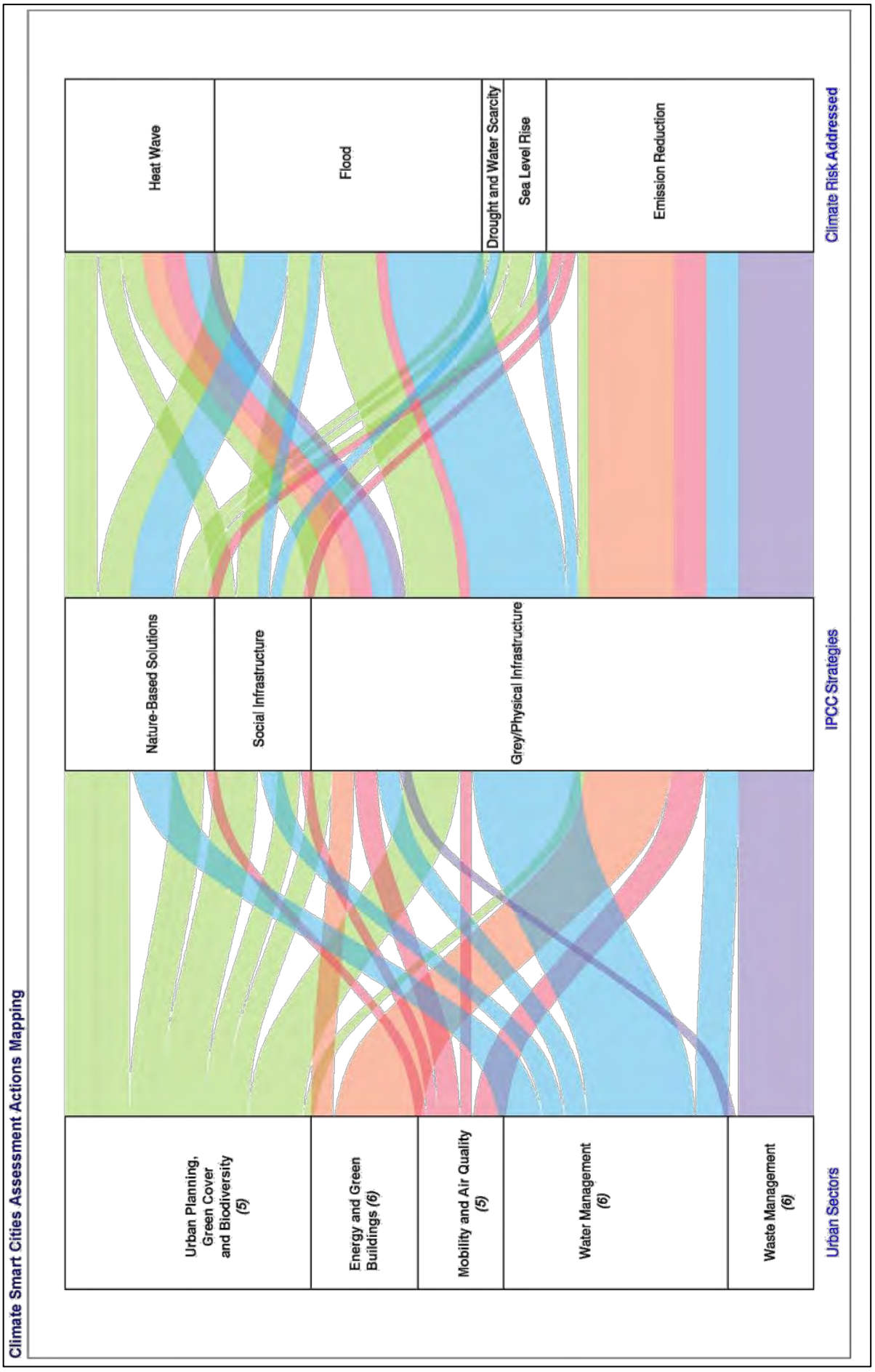


Figure 29 Nature of proposed adaptation actions and its relevance to risk addressed

Table 16 Actions proposed to enhance the climate smart preparedness

S.NO.	ACTION CATEGORIES AND SUB-COMPONENTS
I	*Climate Resilient Urban Planning, Enhancing Urban Green Cover and Carbon Sink and Protecting Urban Biodiversity*
1	Develop a comprehensive strategy for rejuvenation and conservation of water bodies and open areas in urban centers by • Including mapping existing resources, • Evaluating implemented actions, and analyzing budget allocations
2	Implement measures to increase the proportion of green cover in ULBs, in line with MoHUA's Urban Green Guidelines, 2014, and protected areas under the Wildlife Protection Act, 1972 by • Enhancing man-made green spaces within ULBs, • Safeguarding reserved and protected areas within the urban setup to bolster climate resilience
3	Establish and implement a ULB-specific strategy for the protection, conservation, and management of urban biodiversity, conduct regular assessments of urban biodiversity health and trends to inform decision-making, and track progress toward conservation goals. This further includes the following sub-actions: • Utilize citizen science initiatives and partnerships • Identify degraded or underutilized areas within the ULB for targeted habitat restoration projects, and implement nature-based solutions, such as wetland restoration
4	Develop and implement a comprehensive disaster resilience strategy aligned with international frameworks such as the Sendai Framework for Disaster Risk Reduction (DRR), NDMA Guidelines (2010, 2014, 2019), and MoHUA's SOP on Urban Flooding (2017). Key components include • Robust infrastructure development • Effective early warning systems • Continuous community engagement and practical, integrating diverse stakeholders
5	Develop and execute a comprehensive City/ULB level Climate Action Plan integrating both mitigation and adaptation strategies. Exemplary is the Chennai Climate Action Plan (CAP) released by the Tamil Nadu Government on June 13, 2023
II	*Promote Green Energy and Green Building Initiative focused on enhancing energy efficiency and promoting sustainable construction practices.*
1	Implement measures to reduce electricity consumption in the ULBs. This involves • Deploying energy-efficient technologies • Promoting conservation practices • Fostering community awareness
2	Prioritizing the transition of the city's electrical energy supply to renewable sources by • Assessing the city's current energy consumption • Identifying opportunities to replace fossil fuel-based electricity generation with renewable alternatives.
3	Implement a comprehensive assessment and reduction strategy for fossil fuel consumption. This involves • Tracking and analyzing the utilization of fossil Fuels-Petrol, Diesel, CNG, LPG, and PNG • Enabling a targeted approach to reducing carbon emissions and enhancing climate resilience.
4	Develop and enforce policies to ensure cities transition to energy-efficient street lighting by • Prioritizing technologies such as LED and sodium vapour lamps with luminous efficacy • Monitor and evaluate adoption rates to gauge progress

5	Integrate compliance and implementation procedures for various green building norms into regulations such as General Development Control Regulations (GDCRs) and building bylaws/rules. • Establish green building cells or equivalent units within Urban Local Bodies (ULBs). • Define green buildings according to recognized rating systems like the Bureau of Energy Efficiency (BEE), Leadership in Energy & Environmental Design (LEED), Green Rating for Integrated Habitat Assessment (GRIHA) and Indian Green Building Council (IGBC),
III	*Implement a comprehensive Mobility and Air Quality Improvement Plan*
1	Implement Clean Technologies and Shared Vehicles by • Increasing the deployment of shared vehicles running on clean fuels such as CNG, LPG, biofuels, and hybrid or electric technologies. • Monitor the progress percentage of shared vehicles
2	• Improve Public Transportation Accessibility by prioritizing and expanding public transportation networks
3	• Increase the percentage of coverage of the Non-Motorized Transport (NMT) network by prioritizing pedestrian pathways and bicycle lanes, tracks, and footpaths along major road networks, including all arterial, sub-arterial roads, and public transport corridors.
4	• Promote a Comprehensive city-level air-quality monitoring grid to systematically gather data, assess risks, and implement control measures
5	• Develop and Execute Integrated Clean Air Action Plans (CAAPs) at the city/ULB level in line with the National Clean Air Programme (2019) guidelines,
IV	*Implement comprehensive water management strategies with water-centric city development*
1	• Assessing current and projected water demands based on population growth, economic development, and land use changes. • Identifying potential gaps between water supply and demand under different scenarios. • Implementing adaptive management practices to optimize water use efficiency and ensure sustainable allocation.
2	Reduce the extent of Non-Revenue Water (NRW) in water distribution systems by • investing in infrastructure upgrades, deploying advanced leak detection technologies • implementing water loss management strategies • promoting community engagement initiatives
3	• Maximize the percentage of treated wastewater
4	• Institute proactive flood and water stagnation risk management measures, • Evaluate the ULBs/city's readiness to tackle flooding and stagnant water. • Focus on identifying areas where water remains stagnant for more than four hours with a depth exceeding six inches
5	• Conduct thorough energy audits to analyze energy flows within the water and wastewater management system and identify areas for conservation
V	*Implement and promote a comprehensive waste management strategy*
1	• Assess the extent of Waste minimization initiatives undertaken by the ULB, • Extent of dry waste recovered & recycled, • Extent of Wet Waste Processed, • Construction & Demolition (C&D) waste management, • Scientific Landfill availability & operations and Landfill/ dumpsite Scientific Remediation

Table 17 Status of climate-smart city actions

CITIES	ACTION TO ENHANCE URBAN GREEN COVER AND BIODIVERSITY	ENERGY EFFICIENCY ACTIONS AND GREEN BUILDING ADOPTION	ADDRESSING MOBILITY AND IMPROVING AIR QUALITY	WATER MANAGEMENT ACTIONS	WASTE MANAGEMENT ACTIONS
Greater Chennai Corporation					
Coimbatore					
Salem					
Tiruppur					
Erode					
Thoothukudi					
Tiruchirappalli					
Tirunelveli					
Avadi					
Cuddalore					
Dindigul					
Hosur					
Kanchipuram					
Karur					
Kumbakonam					
Nagercoil					
Sivakasi					
Tambaram					
Thanjavur					
Vellore					
Madurai					

6. CITY CLIMATE RESILIENCE: BEST PRACTICES

6.1 Flood Hotspot Study

Managing storm water under climate uncertainty is a major concern in urban areas throughout the world. There were several floods events recorded in Chennai, one of the major metropolitan coastal cities in India. The flood incidences were repeatedly reported in recent decades. In this study, the existing state of storm water drains are evaluated under current and future climate scenarios in one of the most flood-prone areas of Chennai viz. Velachery zone (Figure 30). The mitigation measures are recommended to increase its resilience against floods.

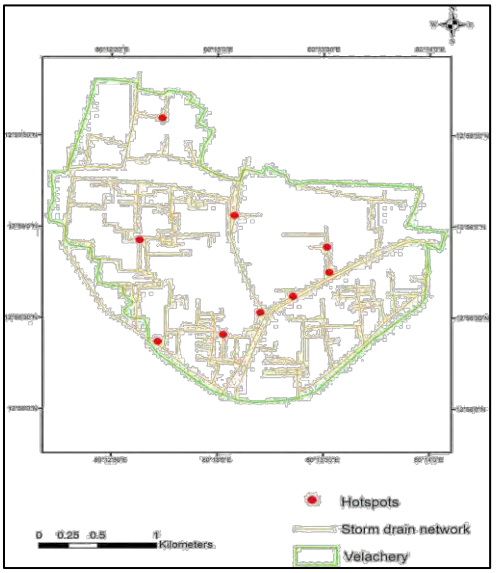


Figure 30 Identified Flood hotspots of Velachery zone.

Source: Ramachadran et al., 2019

The Intergovernmental Panel on Climate Change (IPCC) CMIP5 models of Representative Concentration Pathways (RCP) 4.5 are used to develop possible future climate change scenarios of the city. The daily rainfall data for the period 1975–2015 obtained from India Meteorological Department are used to find the extremities and to generate Intensity-Duration-Frequency (IDF) curves. The IDF curves are generated for 2, 5, 10, 50, 100-year return periods under current and future climate scenarios. The storm drainage network is delineated with a Differential Geographic Positioning System (DGPS) survey. The integrated hydraulic and hydrological modelling is carried out to assess the flood carrying capacity of storm drainage under present and future climate scenarios. The vulnerable hotspots are identified, and flood mitigation measures are suggested to reduce the flood risk at Velachery.

6.2 Restoration of Waterbodies in Coimbatore

The Smart City Plan of Coimbatore City aims to restore the eight-lake network by launching a project to develop an Eco-Restoration Master plan of eight lakes and a connecting greenway (Figure 31). The goal of this project is to revitalize environmentally sensitive areas and introduce sustainable and enhanced public spaces around the lakefronts.

The project also aims to enhance the quality of public spaces for both residents and tourists, thereby addressing the city's need for an overarching plan to lead a phased development approach for lake eco-restoration. This project is aligned with Coimbatore's long-term vision to become more sustainable and self-reliant. The study on Stakeholders and Sustainability has analyzed various aspects such as technical, financial, sustainable, environmental, social, and legal factors, which serves as the foundation for the subsequent assessment.

Figure 31 Valankulam Lake Restoration in Coimbatore City

https://www.coimbatoresmartcity.org

The rejuvenation project has led to an improvement in the growth of aquatic species and a reduction in water contamination due to water treatment in the inlets of the lakes. Pollution-free water in the surrounding area is critical for aquatic life. The restored lakes are constantly monitored through CCTV, and timing for accessing the lakes helps control the exploitation of public resources. The conversion of abandoned spaces into highly inclusive and interactive spaces has also reduced crime rates in the vicinity of these lakes, thereby transforming Coimbatore's identity.

6.3 Solar Power Plant at Thanjavur Corporation, Sirajudeen Nagar

Thanjavur Corporation has proposed to develop a 3 MW solar park at Sirajudeen Nagar WTP (Figure 32). The proposed power plant will have solar PV modules and string inverters as the major components. It is to be developed under the Long-term Open Access method, by wheeling the produced power to captive consumption for the high-tension services availed by Thanjavur Corporation from TANGEDCO. The project has been implemented since 2017 under the Retrofitting and Redevelopment sector at a cost of Rs.4.6 crores. The average solar radiation on the proposed site is above 5.34 Kwh / sq. m. Thanjavur is taking significant steps to promote renewable solar and wind energy, reduce energy consumption, and build resilience towards climate change.

Figure 32 Solar Power Plant at Sirajudeen Nagar

Source: https://thanjavurcorporation.org/projects/

The city is implementing renewable energy and energy efficiency related actions identified under its Solar City Plan. Thanjavur Pan-city proposal outlines the implementation of smart solutions across the city,

including the refurbishment of street lighting with energy-efficient light-emitting diode (LED) streetlights. These lights will be equipped with surveillance cameras and Wi-Fi facilities to bolster connectivity, enabling efficient smart traffic management, seamless connectivity, prevention of crime/accidents, and expeditious emergency and disaster response. The city also plans to install air quality monitoring systems across the city to ensure a healthy environment for its residents.

6.4 Climate Action Plan for Chennai City

The Tamil Nadu government has released Chennai's first Climate Action Plan (CAP), which aims for a Resilient and Proactive Chennai through achieving the carbon neutral goal by 2050 and Water Balance (Figure 33).

Figure 33 Chennai City Climate Action Plan and Key Strategies

Source: Greater Chennai Corporation

The CAP focuses on six priority areas: electrical grid and renewable energy, building energy, sustainable transport, solid waste management, urban flooding and water scarcity, vulnerable populations and health. The plan envisages 80% of inner-city travel by public transport, walking and cycling by 2050. It also aims to electrify 100% of the MTC bus fleet by 2050 and incentivize electrification of private vehicles to achieve 100% electrification by 2050. The plan also includes increasing green cover to 35% by 2050 and marking flood risk zones and rehabilitating the population from there. The CAP was developed with support from C40 Cities in collaboration with the Urban Management Centre, Ahmedabad, and aligns with the Paris

Climate Accords, setting emission reduction targets of 1% increase by 2030, 40% decrease by 2040 and achieve net zero by 2050, compared to 2018-19 emission levels.

6.5 Ahmedabad's Heat Action Plan: A Model for Urban Heat Resilience in India

In the face of extreme heatwaves and water scarcity, Ahmedabad, India, has implemented innovative climate resilience strategies. The city developed an early warning system to forecast extreme temperatures and implemented a heat action plan that includes cooling centers, community outreach, and emergency response protocols. Additionally, the Sabarmati Riverfront Development Project enhanced flood resilience and improved public spaces. These initiatives have made Ahmedabad a pioneer in urban climate resilience, offering lessons for other Indian cities (Ahmedabad Municipal Corporation, 2019).

7. KNOWLEDGE DISSEMINATION

As a part of the study on sustainable urban habitat covering the thermal discomfort, urban heat intensity and urban green cover assessment and the climate risk and climate smart preparedness assessment of cities in Tamil Nadu, the knowledge dissemination was done through the capacity building programme to create awareness in climate change impacts on cities for the policy makers.

The officials from Directorate of Municipal Administration, The Greater Chennai Corporation, Directorate of Town Panchayat, Tamil Nadu Urban Infrastructure Finance Service Limited (TNUIFSL), Chennai Metropolitan Development Authority, Tamil Nadu Urban Habitat Development Board and Tamil Nadu Pollution Control Board participated in a training programme. Two two-day capacity-building sessions were organized for planners and officials. Approximately 100 plus officers representing the ULBs of Tamil Nadu received training on climate risk information through this programme. The training programme provided a comprehensive understanding of various aspects of climate change and its impacts on the cities of Tamil Nadu. The relative climate risk of the 21 cities of Tamil Nadu as a function of the hazards of heat waves, flood risk, drought risk and sea level rise integrating the vulnerability and exposure was communicated to officers. The climate resilience of Tamil Nadu cities assessed by the Climate Smart Cities Assessment Framework gave an insight into the preparedness of the cities to face climate change challenges. The attendees received the necessary framework and tools to identify the current vulnerability

and readiness of their cities and local bodies, so as to make well-informed choices concerning adaptation priorities for the cities.

Figure 34 Glimpses of the Capacity Building Programme

These identified priorities were heat mitigation, flood risk reduction, waste management through practices such as bio-mining, enhancing the urban green cover, switching over to energy efficient systems and sustainable urban transportation. The programmes served as the foundation for the formulation of the City Climate Action Plan and empowered participants with the knowledge and skills required to address the challenges presented by climate change in the cities of Tamil Nadu and create sustainable and Climate Resilient Cities. The glimpses of the Capacity Building workshop is shown in figure 34.

8. WAY FORWARD

The way forward for the Sustainable Habitat includes Climate Smart Cities Assessment for all the Urban Local Bodies of Tamil Nadu involving a comprehensive analysis across multiple sectors pivotal for climate mitigation.

- Data Collection and Analysis: Implement meticulous data collection and analysis methodologies across the identified domains to inform strategic decision-making.
- Sector-specific Analysis: Conduct detailed evaluations in areas such as energy efficiency, low-carbon energy, and transport systems to pinpoint opportunities for reducing carbon emissions and enhancing sustainability.
- Initiate Climate Smart Cities Assessment: Launch a comprehensive assessment program for all Urban Local Bodies in Tamil Nadu, focusing on multiple sectors crucial for climate mitigation.
- Green Space Enhancement: Prioritize the augmentation of green spaces and carbon sinks across urban areas to mitigate climate change impacts and bolster urban resilience.
- Sustainable Solid Waste Management: Evaluate current waste management practices to minimize environmental degradation and foster circular economy principles.
- Human Health and Infrastructure Assessment: Incorporate an assessment of climate change's impact on human health and infrastructure, aiming to develop an early warning system for climate risks in cities.
- Strategic Planning: Utilize insights from assessments to develop tailored strategies for building climate-resilient cities that prioritize environmental stewardship and sustainable development.

REFERENCE

1. Climate Action Plan Chennai City - https://data.opencity.in/dataset/bedee49c-deeb-4aab-be30-ec7ceac60d74/resource/42465716-438e-492c-8559-89cae8deb718/download/ccap_gcc_cscl_english.pdf
2. Chandramouli, C., and Registrar General. "Census of india 2011." Provisional Population Totals. New Delhi: Government of India (2011): 409-413.
3. Directorate of Census Operations, Tamil Nadu. (2014). District Census Handbook, Chennai. Retrieved from [https://censusindia.gov.in/nada/index.php/catalog/1130].
4. Directorate of Municipal Administration and Water Supply, Tamil Nadu. (2023). Municipal Administration and Water Supply Department Policy Note 2023-2024, Demand No. 34. Retrieved from https://cms.tn.gov.in/sites/default/files/documents/maws_e_pn_2023_24. pdf.
5. Eslamian, M.K.G., Vivek Gupta, Saeid, 2017. Hydrological Drought: Water Surface and Duration Curve Indices, in: Handbook of Drought and Water Scarcity. CRC Press.
6. Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., Kanae, S., 2013.Global flood risk under climate change. Nature Clim Change 3, 816–821. https://doi.org/10.1038/nclimate1911
7. Indian Meteorological Department : FAQ_heat_wave.pdf (imd.gov.in)
8. IPCC (2014) 'Summary for Policymakers', in Edenhofer, O., Pichs-Madruga, R., Sokona, Y.,Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P.,Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T. and Minx, J.C.(Eds.): Climate Change 2014: Mitigation of Climate Change. Contribution of WorkingGroup III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA
9. IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

10. Ministry of Housing and Urban Affairs. (2019). ClimateSmart Cities Assessment Framework. Retrieved from https://niua.in/c-cube/sites/all/themes/zap/assets/pdf/ CSCAF_3_0_Technical_ document.pdf
11. Smart cities and Academia towards Action and Research: SAAR Part B: Climate Change and Resilient Cities, March 2023, National Institute of Urban Affairs.
12. URDPFI Guidelines, 2014. Ministry of Urban Development- https://mohua.gov.in/upload/ uploadfiles/files/URDPFI%20Guidelines%20Vol%20I.pdf
13. Chinnappa V, Rajiah M, Devarajan T. Green Cover (Tree) Analysis of ChennaiMetropolitan Area Using High ResolutionSatellite Imagery. Polish J Environ Stud [Internet]. 2021 [cited 2023 May 30];30:3943–3954. Available from: http://www.pjoes.com/Green-Cover-Tree-Analysis-of-Chennai-nMetropolitan-Area-Using-High-Resolution-nSatellite,132820,0,2.html.
14. Ministry of Urban Development. Urban Green Guidelines. 2014.
15. Panwar H. Proportion of Climate Centre for Cities. 2022.
16. Ministry of Health and Family Welfare NC on PC. Report of Population Projection 2011 - 2036. Natl. Comm. Popul. Minist. Heal. Fam. Welf. 2019.
17. Nagendra H Sub-regional Assessment of India: Effects of Urbanization on Land Use, Biodiversity and Ecosystem Services. Urban Biodivers Ecosyst Serv Challenges Oppor A Glob Assess. 2013. p. 1–755.
18. Yousif, Tawhida A., and Hisham M. M. Tahir. "Application of Thom's Thermal Discomfort Index in Khartoum State, Sudan." Journal of Forest Products & Industries 2, no. 5 (2013): 36-38. ISSN: 2325–4513.
19. Thom, E.C. (1959): The discomfort index. Weather wise, 12: 57–60
20. Ahmedabad Municipal Corporation. "Ahmedabad's Heat Action Plan: A Model for Urban Heat Resilience in India." Ahmedabad Municipal Corporation, 2019. https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2018.pdf.
21. City of Copenhagen. Copenhagen: Solutions for Sustainable Cities. Third edition. January 2014.

Centre for Climate Change and Disaster Management
Department of Civil Engineering, Anna University, Chennai - 600 025

Vision

The CCCDM to be the Centre for Excellence to address challenges of Climate Change and Disaster Management

Mission

CCCDM shall contribute to the sustainable development by

- **Promoting climate science and disaster risk reduction research**
- **Disseminating Knowledge of regional climate risks and cadastral level climate resilient actions to cope up with changing climate**
- **Strengthening the capacity for climate change adaptation, mitigation and disaster risk reduction**

The Director
Centre for Climate Change and Disaster Management
First Floor, Kalanjiyam Building, CEG Campus
Anna University, Chennai - 600025

www.annauniv.edu/cccdm

cccdm.au@gmail.com

044-22357943/44