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***Front cover image**: Peri-Urban Initiative Chennai*

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1 EXECUTIVE SUMMARY

This deliverable provides a 'problem analysis' of the peri-urban areas of the Chennai region, their climate change risk and the adaptation challenges they face.

1.1.1 Scope of Chennai region

The Chennai region is defined as the entire Chennai Bio-region consisting of 4 river-basins' watershed. We pick three scales — macro, meso, and micro where these themes of urbanisation and climate change entangle, creating both challenges and opportunities. These scales play a role in teasing out how various actors and stakeholders interact and how they work within different governance arrangements at each scale. The three scales are:

a) Macro/Bio-regional Scale
b) Meso/Landscape Scale
c) Micro/Community/Neighborhood Scale

The critical map (***Figure 1***) shows these three areas of interest.

Peri-urbanization can be seen as a process of being and becoming over time and space. One conception of the peri-urban is to employ ecological boundaries instead of administrative ones manufactured and rendered porous through multiple processes such as urbanization.

At the Bio-regional/macro scale, we explored using the Chennai watershed (made of up the basins of four rivers that drain through Chennai) that cuts across adjacent state boundaries to understand the larger intersectionality between Urbanization processes and climate change.

The Landscape/meso scale sits in between the oft-used micro and macro scales, which are relatively more well-defined in terms of administrative boundaries and governance structures. Hence, this scale presents added complexity in terms of the multitude of agencies and administrative bodies that are active at this scale. The site chosen for the landscape scale is the Kovalam sub-basin to the south of Chennai which consists of wards within Chennai city limits and village panchayats just beyond, capturing the peri-urban continuum and the wide spectrum of communities and stakeholders the grid encompasses. It also captures the 'corridor effect,' a symptomatic feature of Chennai's urban expansion. This landscape between Muttukadu on the coast and Siruseri in the hinterlands comprises multiple ecologies and communities. These exist at varying levels of fragmentation. The risks and vulnerabilities are also varied and complex.

The Community/ neighbourhood scale is the smallest scale and is usually managed by village panchayats. However, villages like Katchipattu that sit at the crossroads of globalizing forces show that other actors and stakeholders in the region can have direct and indirect impacts on their lives and livelihoods.

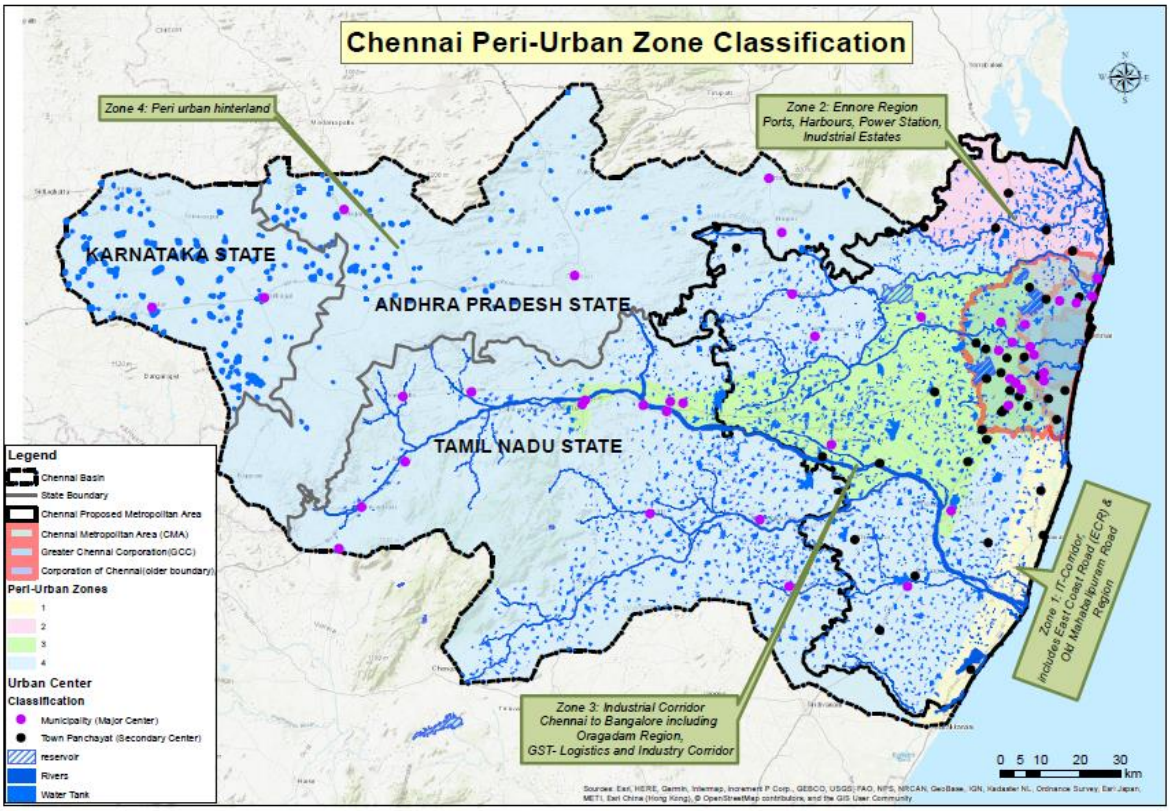

Figure 1: Chennai peri-urban region area of interest

In each case study scale, we explore key issues & challenges on the peri-urban / climate-environment interface.

1.1.2 Where is the Chennai region peri-urban

The Peri-cene has used global mapping systems and local consultations to address the question – where is the peri-urban? This is especially complex in an urbanization context such as the Chennai region, with its many satellite towns, extended suburbs, urban greenspaces, water bodies and semi-rural hinterland.

Overall, a straightforward definition of peri-urban is shown in "***Figure 2***"-

- all locations not in the grey urban areas, but inside the 60km radius
- yellow and green squares of between 50-300 p/km2, outside the 60km radius on the map.

A detailed framework that includes different peri-urban types is shown in ***Figure 2***, which refers to the mapping of FUAs ('Functional Urban Areas').

a) ***'Urban edge'***: suburban / extended settlements / within urban area (e.g., within Greater Chennai Corporation (GCC) and current Chennai Metropolitan Area (CMA))

b) ***'Urban fringe'***: Scattered/extended / sprawl near/within the urban area: (e.g., smaller settlements or scattered suburbs in the catchment of the Kosasthalaiyar and Palar River basin;

c) ***'Urban greenspace'***: open land / forest / other, near / within main urban area:(e.g., forest cover within GCC and metropolitan area);

d) ***'peri-urban settlement'***: Larger satellites, higher density sprawl / ex-urbs. (e.g., further towns in the upstream river catchment like Industrial town Sriperumbudur)

e) ***'peri-urban spread'***: Smaller satellites & further / lower density sprawl / ex-urbs. (e.g., smaller scattered settlements in the south Kovalam basin).

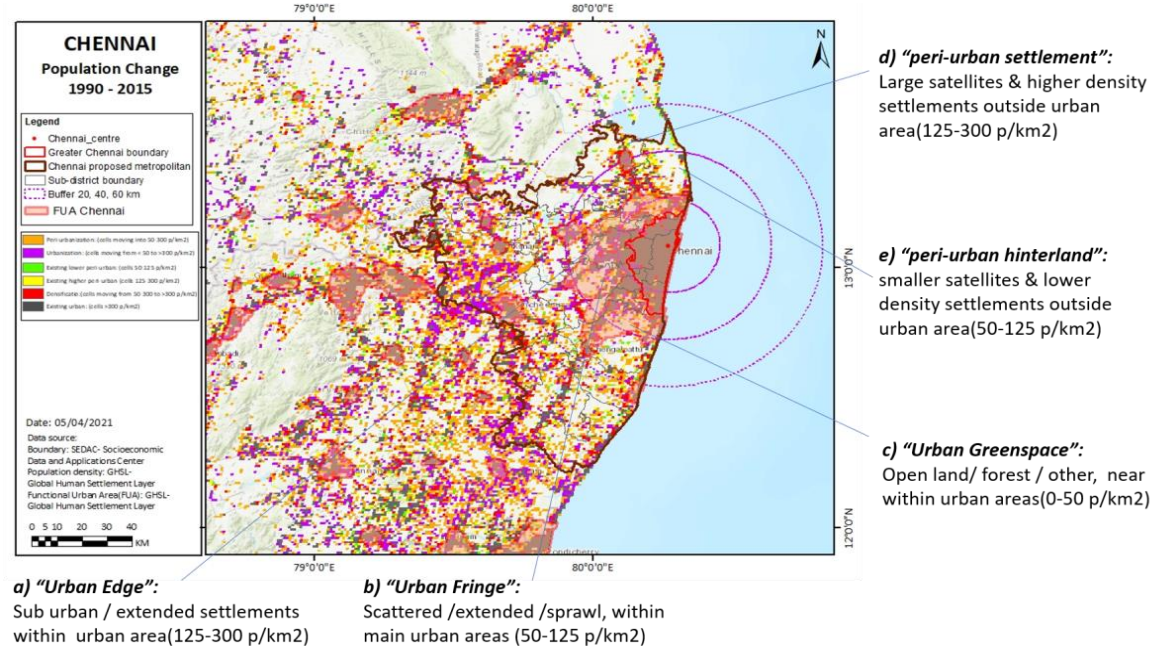

Figure 2: Peri-urban typology Chennai region

The vital statistics are summed in Table 4(calculated for the whole 200 x 200km square shown in the map format). The calculation includes Greater Chennai, the proposed metropolitan area and hinterlands of north and west of Chennai. Much of the open and peri-urban land area is both within inside and outside of the FUAs (functional urban areas):

- Open land & peri-rural (<50 p/km2) accounts for nearly10% of the land area with less than 0.5% of the population; however, this has grown more than 100% since 1990;
- Lower density peri-urban (<125) covers 17% of land area with less than 1% population, with a growth of more than 100% since 1990;
- Higher density peri-urban (<300) covers 22% of land area with 2.65% of the population, with the growth of more than 100%;
- By comparison, the urban/suburban / town areas (>300 p/km2) covered half of the highly urbanized Chennai; they contain 96% of the population with relatively high growth of 52% over the period.

The overall picture is of higher population growth in the urban/suburban areas with moderate growth in the higher density peri-urban areas.

1.1.3 What are the main climate risks in the region?

Climate change is the most pressing challenge of this century. The effects of Extreme Climate conditions have changed the functioning and development of Urban cities. Chennai Region is one of the largest urban spaces in the world and, at the same time, highly vulnerable to climate change. In the past decades, the city has experienced Floods and drought due to climate change, and the recurrence has only increased in recent times. The future projections of climate conditions in the region are predicted to be on the rising trend, making the city region more vulnerable to risks of extreme events like Floods and Drought.

1.1.4 What is the role of governance in the Chennai region peri-urban?

Overall, these diverse peri-urban areas are both generators of climate risks (particularly inundation, drought) and providers of climate change adaptation functions (for example, related to natural water management through the cascading braided tanks that are interconnected with one another and biodiversity conservation).

To address these issues, appropriate governance frameworks are needed, encompassing the wide range of sectors and stakeholder groups interested in the future of these areas. Current governance frameworks are fragmented, spatially and sectorally, although emerging good practices exist.

- informal partnerships which exist with a mandate and role within more extensive institutional arrangements: e.g., Independent third sector formal organizations which play an active role in informal partnerships (e.g., Meenavar Sangam/fishermen collectives; Water-User Associations);
- Formal governance partnerships which bring together different levels and units of government: e.g., Chennai River Water Restoration Trust.

One key focus for the Chennai case study has been extreme weather events like flood and drought in the peri-urban, and the use of the local traditional water management to mitigate these disasters: and this raises topical questions on water governance, which crosses administrative boundaries and economic sectors. Flooding and flood risk management, concerning current flood hazards and also in the context of projected climate change induced increases in flood risk, are key concerns in the Chennai basin, given the sudden risks posed to communities, livelihoods and critical infrastructure. Indeed, recent flood events associated with extreme rainfall events in November 2021 have further focused on this risk.

The potential for water management measures to sit as one of the different elements of a broader flood-drought risk management response in the Chennai basin has risen up the agenda. Managing and restoring these traditional water-bodies encompasses a wide range of interventions: From restoring degraded reserve-forests Upstream in the catchment areas to clearing the drainage channels, desilting the tanks, removing invasive species in the Water-spread area, removing encroachments especially along with soft-edge, strengthening the bunds and associated infrastructure, addressing point and nonpoint pollution risks and preserving the natural ecology of the associated wetlands.

These issues are explored, from a spatial perspective, within this deliverable. Working to conserve and enhance the water management functionality of landscapes in the peri-urban hinterlands of the Chennai watershed can reduce flood risk in downstream urban areas and mitigate drought upstream while also delivering benefits locally. However, this raises significant governance challenges that remain unaddressed.

The follow-on deliverable, D4.2b, builds on the problem analysis outlined within this report and considers potential adaptive governance responses and pathways that could support these outcomes

2 Introduction

2.1 Report Scope

The Peri-cene project is creating the first ever global assessment of the peri-urban and its climate change risks and adaptation challenges. It explores forward 'adaptive pathways' in a Policy Lab with 18 city-regions worldwide, together with two in-depth case studies in India and the UK.

These case studies focus on the ***'Chennai region'*** (India) and the ***'Manchester region'*** (UK). Each has a very different history, development pressures, socio-economic trends and climate risks. The in-depth findings from the UK and India will be compared to the outcomes emerging from the other 18 cities in the global partnership, first via mapping and spatial analysis and then by the design of adaptive pathways. Overall, the Peri-cene project aims to:

- ❖ Provide a state-of-the-art analysis of climate impacts and vulnerabilities in the peri-urban/rural areas.

- ❖ Provide models for adaptive / collaborative governance for climate / peri urban interactions, by facilitating stakeholder dialogue & co-design.

This deliverable focuses on the Chennai region case study, which contributes to the Peri-cene project aims, through a focus on the following two objectives:

- To explore peri-urban climate risks and adaptation responses in the Chennai watershed (D4.1 focuses on this objective).
-
- To explore adaptive pathways and governance approaches to reduce climate risks in peri-urban and connected urban areas (D4.2 focuses on this objective).

The Chennai Region Case study approaches these objectives from three different scales, from the micro- Neighborhood scale to the Macro- larger watershed bio-regional scale, to understand aspects of climate change risk and response approaches. Particular attention is paid to the various water-related risks for the larger water shed. The focus here is on peri-urban climate change risk, adaptation and resilience themes more broadly. The aim is to provide a high-level analysis of typical spatial and non-spatial dynamics around peri- urbanization and climate risk.

At the meso/Landscape scale, we try to understand the diversity of actors across diverse landscapes from coast to hinterlands within a single sub-basin of Kovalam. The risks, vulnerabilities, dynamic interactions of various actors and the associated causal effects are complex, which this section tries to outline.

At the micro/neighborhood scale, we have chosen a Dalit hamlet of Katchipattu in the Sriperambadur taluk, a region bestowed with water-bodies, cultural sites that have been **"bypassed"** by recent developments that have led to an economic boom in the region (a highway, Special Economic Zones, gated industrial and residential communities). The "economic development" gave locals no benefits; it only ruined their air, water and rendered them unemployed. It's an entirely new assemblage of socio-technical elements in the making. The twin global processes- globalization and climate change have only furthered socio-economic deprivation of the local populations whose lives as subsistence agriculturalists were closely entwined with the natural environment. Unemployment coupled with poverty and marginalization has led to a lot of social unrest amongst the youth and angst against the outsiders taking over our space, thus leading many to resort to illegal means to make quick money.

This scale is used to understand socio-economic and political dynamics within communities that are further marginalized and driven to despair by anthropogenic driven climate change in the peri-urban.

This deliverable (D4.1a) concentrates on a 'problem analysis' of the Chennai Region, which provides the background to the case study. This then sets the context for the related deliverable that explores adaptive governance and pathways (D4.2a).

Generally, the Peri-cene project has to work with a complex set of causes, effects, and responses in a wide variety of locations worldwide. Peri-urban development, climate risk, and adaptive governance and pathways are complex and often controversial. This Chennai region case study cannot, therefore, aim to describe all possible interactions between peri-urban land use and development and climate risk and adaptation in a large and complex region. It can, however, aim to demonstrate practical and illustrative ways of working with complex information and highlight creative ways of exploring adaptive governance approaches and pathways for the future.

2.2 Report Structure

This report is structured according to the following chapters:

The Chennai region*:* this chapter provides the Chennai region and insights and data linked to historic and current development and landscape patterns. This provides a platform for understanding the Chennai region and its peri-urban areas.

Climate risks & impacts in the Chennai region*:* this chapter provides an overview of current and projected future weather and climate risks and identifies flood-drought risk due to erratic monsoons as the most significant climate change hazard facing the Chennai region. It also highlights dangers that are currently relatively rare, including saltwater intrusion and storm surges, which may become more frequent over the coming decades with climate change.

Chennai Case study: Three scales

Chennai bio-regional scale: In this section, Chennai watershed is used as one of the lenses to understand Chennai's peri-urban processes and the challenges it brings.

Landscape-scale- Kovalam sub-basin: This section explores the Kovalam sub-basin, highlighting key themes linked to the various peri-urban landscapes within the basin and associated climate change risk and adaptation themes.

Community/scale- We delve into the local dynamics of a bypassed community of Katchipattu and the socio-economic vulnerabilities of the marginalized in the context of anthropogenic driven climate change.

Conclusions**:** this chapter brings together the key issues raised by this research and points towards the related deliverable (D4.2b). This takes forward the 'problem analysis' outlined here with an outline of adaptive governance and pathways for reducing climate change risk in the Chennai region's peri-urban areas and enhancing the adaptation 'functions' they can provide to neighbouring urban areas.

Annexes: include a summary of existing governance, review of relevant projects and resources on climate change risk and adaptation in GM, the '20-questions' template for the 3 zones of the wider regions and a list of reference.

2.3 Report methodology

The overall approach here is based on the combined Peri-cene framework:

- The '***Cause-effect Model'*** follows a mainly functional frame of cause and effect, in direct problems and responses:

- The ***'Synergistic Model'*** addresses wider systems, with deeper layers of value (social, economic, cultural, etc.), potential for transformation, and strategic level problems and responses.

Each Model has a role and purpose. The *Causal Model* is a practical place to start to gather data and explore the tangible peri-urban-climate-environment interactions. The *Synergistic Model* is more realistic for real-world problems (with deeper layers of complexity) but more challenging for research and knowledge management and more suited to creative dialogue and co-design.

The Peri-cene 'cause-effect' model contains four main themes (based on the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5), as in Connelly et al. 2018):

- peri-urban development and urban/regional spatial systems
- climate change physical hazards and risks
- climate vulnerability and sensitivity
- governance and adaptive capacity

The causal model builds on the IPCC AR5 (IPCC 2014) climate risk framework, which considers climate risk to be a function of (climate) hazard, exposure to that hazard, and vulnerability to that hazard. Vulnerability is further divided into two components: sensitivity and adaptive capacity. The IPCC definitions are provided *(**Table 1***). The climate risk framework, which explicitly separates exposure to extreme weather and climate change hazards such as flooding and high temperatures, has been demonstrated to be particularly useful in spatial planning and adaptation pathways to increase resilience (Connelly et al. 2018). This approach guides the Manchester region case study.

Table 1: Climate risk definitions (Source: IPCC 2014)

Term	Definition
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.
Hazard	The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.
Exposure	The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected

Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
Sensitivity	The degree to which a system or species is affected by climate variability or change is affected by adversely or beneficially. The effect may be direct … or indirect.
Adaptive Capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

The Peri-cene Framework is structured around the '20-question' template, which informs interviews, modelling and mapping undertaken within the project.

- Each of the 4 themes in the Causal model (peri-urban, climate, vulnerability, governance) has 4 questions each, making up questions 1-16 in the template.
- The Synergistic Pathway Toolkit model provides questions 17-20, with the results of the 4-part process (baselines, scenarios, synergies, strategies).

The '20-questions' template is used to summarize each of the three zones in this study (see 10.2) . This 20-question format cannot fully describe the longer story and detailed analysis of each zone in each city-region. But it aims to help summarize and compare between zones and locations around the world.

2.3.1 Application to water Management

This report also explores issues linked to flood-drought risk and water management response in the Chennai watershed. It is recognized that traditional water management through cascading tanks is part of a more comprehensive suite of water-related disaster management responses, including structural flood defenses, which work collectively to reduce flood risk to people, businesses and infrastructure. This case study element responds directly to the Peri-cene agenda, focusing on climate change risk and adaptation themes (water-related disasters and associated management) of particular relevance to peri-urban locations. This detailed investigation enables insights to complement broader generic analyses undertaken within the project.

Barriers and limitations to the traditional tank systems, including those linked to funding, siting, governance and maintenance, are explored in D4.2b.

3 The Chennai region

Here, the Chennai region is framed as a natural river basin that comprises five major rivers Araniyar, Cooum, Adyar, Kosasthalaiyar, and Palar. It includes the administration of three states Karnataka, Andhra Pradesh and majorly Tamil Nadu. Chennai is the capital city of Tamil Nadu and these rivers flow inside Greater Chennai Corporation (GCC), Chennai Metropolitan Area (CMA) together with its hinterland of adjacent local authorities before it drains to the sea.,

Chennai (until 1996 known as Madras) in south-east India's a sprawling city along the Bay of Bengal's Coromandel Coast. The city is one of the top 10 fastest growing economies in the world. It grew rapidly with an estimated population of 8.6 million in 2011, compared to 3.5 million in 1971 (Census, 2011). A diverse economic base feeds into the city's Gross Domestic Products (US $58 billion), including information technology (IT), automobile and hardware manufacturing, health care and financial services (Global Metro Monitor, 2015). However, it also contains unemployment, pollution, social deprivation, unplanned urbanization, etc. The region is poised for further economic and population growth, with a proposed metropolitan expansion covering 8878 sq km from earlier 1189 sq km, including the adjacent districts of Kanchipuram, Chengalpattu and Tiruvallur, along with the Arakkonam and Nemili division within the Ranipet districts. The capital city Chennai is governed by the GCC, whose jurisdiction was expanded to 426 square kilometers (sq. km) from 174sq. km in 2011. Each district includes smaller urban and rural areas like corporations, municipalities, smaller towns, and villages, governed by their local bodies at the bottom level and at the top by district administration. The critical map *(**Figure 3**)* shows the wider region in its context and highlights overlapping areas of interest.

- Chennai Basin (Natural landscape includes major rivers Araniyar, Kosasthaliyar, Cooum, Adyar and Palar).
- Proposed Chennai Metropolitan Area covering GCC and adjacent areas of various districts includes Kancheepuram, Chengalpattu, Thiruvallur and part of Ranipet.
- Both Chennai Basin and proposed CMA representing the commuter belt of peri-rural areas to the north, south and west of Greater Chennai.

For illustrative purposes, circles marking a 20, 40, 60km radius from the metropolitan centre are included in ***Figure 3*** This shows the Chennai region areas of interest along a gradient from the natural watershed upland, through the urban fringes and the city centre of Chennai at the coast to the suburbs and into the open farmland and villages of adjacent districts.

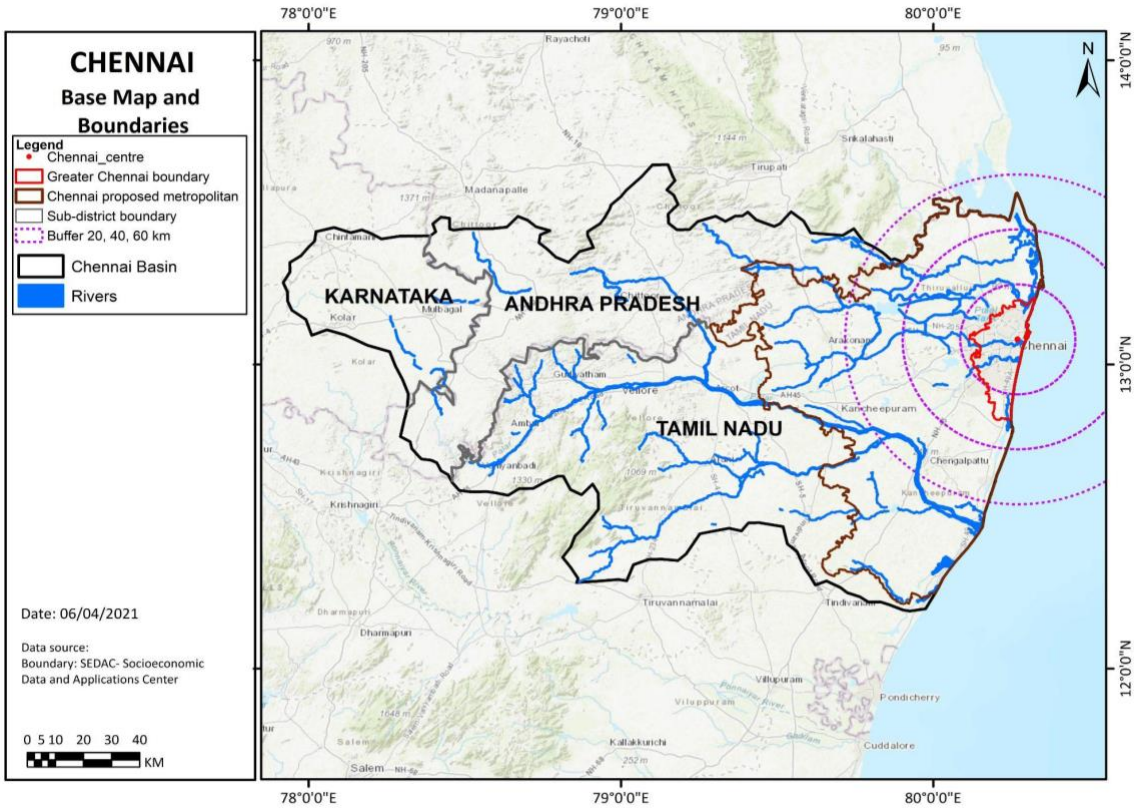

Figure 3: Chennai region overview

At Greater Chennai's core, the city of Chennai was one of the largest cultural, economic and educational centre of south India.Its history can be traced back to 2nd century AD when the polymath Ptolemy documented Mylapore's port trade links with Roman and Greeks. A flourishing trade received considerable quantities of gold in exchange for products like pepper and fine cloth during that time (Second Master Plan for CMA,2026). The trading attracted Portuguese, Armenians and Dutch to settle and rule the city between the fifteenth and seventeenth centuries (Manohar & Muthaiah, 2016). Religion played a crucial role partly shaping the social geography of the city, given the traditions of communities clustering around temples and religious centres(Roy et al, 2018). In 1639, the East India Company got a tract of land from the local ruler to build a factory and warehouse for trading purposes. The next year the British built Fort St. George, which became the anchor of this growing colonial city. Madras was declared as the first Municipal Corporation in the British Commonwealth outside of Britain in 1688. Over the next 200 years, Madras urbanized and added a range of infrastructure, including railways (in 1856), water supply (in 1872), a sewage system (in 1907), electric lighting (in 1910), and electrified meter gauge railway (in 1928) (Chennai Resilient Strategy 2019).

Madras grew from a city of 70 sq. km with 540,000 people to a sprawling 80 sq. km with 860,000 people between 1900 to 1940's (Second Master Plan for CMA,2026). The important development that happened is electrified suburban metre-gauge railway between Beach and Tambaram in 1931. This has given a fillip for the development in the outlying suburban areas as far as Tambaram, and the development of the area occupied by the long tank at Nungambakkam as a planned residential neighbourhood by the Corporation. Post-independence city boundary expanded to 129 sq. km to accommodate an annual population growth rate of 2% between 1951 to 1961 and of 3.51% between 1961 and 1971.During this period Madras saw the growth of new residential as well as industrial suburbs particularly on the west and south. The reason being economy activity which pushed location

of a number of industries both public and private sector undertakings. City was growing further and once again expanded to 176 sq.km in 1978. City's boundary no longer remained well defined. The developments extended into the adjoining areas, particularly, on the north up to Ennore, west up to Avadi and south up to Vandalur. They also saw deterioration in water supply and drainage services and mushrooming of many slum areas all over the city. Urban planning continued to follow the pre-independence trends and practices, specifically in terms of continuing development without due consideration of the environment. The entrance of international funding agencies into urban development in Chennai during this period further complicated the situation by developing rapidly without understanding of the ecological space.

Chennai Metropolitan Development Authority (CMDA) was created in 1971 as an ad hoc body but later in 1974 it became a statutory body. The idea of creating CMDA is to plan the city in future with the increase in population and spatial expansion demanding effective planning and sufficient infrastructure support. Chennai Metropolitan Areas were fixed as 1189sq.km that includes the city corporation limits. In 1981, there were only 24 villages with a population of more than 10,000 in the CMA. Liberalization of the economy in the early 1990s provided an additional push for aggressive development to attain economic growth. Industries and residential settlements came up on the periphery of Chennai through both government planned and unplanned interventions. The majority of the villages experienced high growth that were clustered around development epicentres along the southern and western fringes of the CMA.

In 2011, the city area (which was now named Greater Chennai Corporation area) was expanded a third time to 426 sq.km. According to the census, the city housed 8.6 million people in 2011, making it India's fourth largest metropolitan city and the 36th largest metropolitan city in the world (Chennai Resilient Strategy 2019). Today, Chennai's economy has expanded substantially into a service and knowledge economy, while continuing to support thriving automobile and Information Technology (IT) industries, which are complemented by the healthcare industry, financial services, post-secondary educational institutions and manufacturing of various types of hardware. However, the risk is also exacerbated due to the unplanned urbanization which is visible during the flooding and drought season. City recently experienced the worst flood hits in 2015 and again in 2021 even though it became continuous, where the primary reason being ignoring the ecological function of the water bodies. This was followed by a period of acute water scarcity, leaving the city to fluctuate between too much and too little water, a condition that is expected to get worse.

In its wider region, Greater Chennai is surrounded by various districts that includes Chennai basin along with the proposed Chennai metropolitan area in the upstream with vast farmlands, hills, forest, water bodies and mixed metropolitan peri-urban areas. The location is well served by highways and rail networks that connect the capital city of Indian cities. In the wider peri-urban area, there is a complex family of satellites – larger towns (includes Municipalities), smaller towns, new commuting settlements, peripheral public housing, and scattered settlements. The hinterland landscapes around Greater Chennai's, both agriculture and livestock farming has been declining. Expansion of urbanization in the hinterland puts pressure both in the upstream and downstream. Green space, water bodies and farmlands have been converted to larger urban infrastructure, industries, housing plots and commercial development.

3.1 Where is the Chennai region peri-urban?

The first question is - similar to Manchester and other cities where is the peri-urban in the Chennai region? This question is not so simple, in a conurbation such as the Chennai region, with its many satellite towns, extended suburbs, urban greenspaces and river-valleys, post-industrial semi-rural areas, and so on. We can list multiple layers of the peri-urban, in a combined 'socio-ecological region':

- Residential density – with peri-urban somewhere between urban and rural
- Proximity to the metropolitan economic zone – again, between urban and rural
- Physical bio-region: water catchments, topography, food zones, climate types;
- Economic region: commuting, labour market, housing market;
- Social region: other layers of local identity, migration, culture etc;

For a simple definition, the Peri-cene typology (***Table 2***), provides a summary of a complex picture, based on two main factors:

- Residential population density: the peri-urban is defined as between 50-125 and 125-300 persons/km^2, as defined by the GHSL system (Pesaresi et al 2019)

- The FUA ('Functional Urban Area'), i.e., zones of clustered economic activity, from a global classification (OECD 2020)

Table 2: Peri-urban types in the Chennai wider region (similar to Manchester region).

PROXIMITY	***Within the FUA***	***Outside the FUA***
DENSITY p/km^2		
125-300	***a) 'Urban edge'***: suburban / extended settlements / within urban area *(e.g., within GCC and current metropolitan area)*	***d) 'peri-urban settlement'***: Larger satellites, higher density sprawl / ex-urbs. *(e.g., further towns in the upstream river catchment like Industrial town Sriperumbudur);*
50-125	***b) 'Urban fringe':*** Scattered / extended / sprawl near / within urban area: *(e.g., smaller settlements or scattered suburbs in the catchment of the Kosasthalaiyar and Palar river basin;*	***e) 'peri-urban spread':*** Smaller satellites & further / lower density sprawl / ex-urbs. *(e.g., smaller scattered settlements in the south Kovalam basin).*
0-50	***c) 'Urban greenspace':*** open land / forest/ other, near / within main urban area:(*e.g., forest cover within GCC and metropolitan area);*	-

The peri-urban typology map in ***Figure 4*** is based on a global system 'GHSL', which charts all land and urban areas on a 1km square grid.

- Orange shaded areas show the 'functional urban areas', defined by the OECD as areas of most concentrated urban / economic activity.

- Yellow squares show the higher peri-urban densities of 125-300 p/km2
- Green squares show the lower peri-urban densities of 50-125 p/km2
- Orange red and purple squares show changes from 1990-2015 (see the legend on the left)
- The circles of 20, 40, and 60km show a very rough travel time radius of up 1 hour (from the centre of Chennai
-

Overall, a very simple definition of peri-urban in this crowded region, would be -

- all locations not in the grey urban areas, but inside the 60km radius:
- yellow and green squares of between 50-300 p/km2, outside the 60km radius on the map.

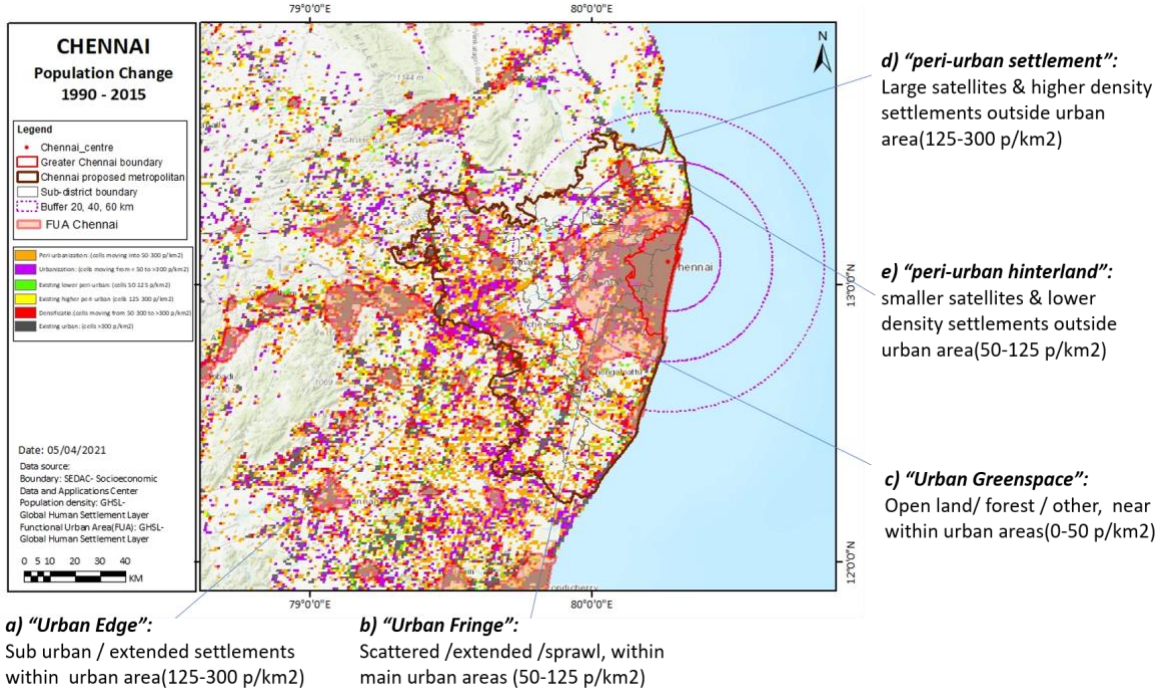

Figure 4: Peri-urban typology Chennai region

3.1.1 Where is the peri-urban growth and change?

Similar to other global cities, Chennai city regions contain many settlement types and sizes. Chennai has grown in a linear manner, and unsustainably stretched as far as about 40 km. The growth is along the five road corridors taking the shape of a radial pattern. Urban growth took place along arterial roads, particularly the three corridors starting from south to west. Much of Chennai's recent urban expansion has been southwards. It is bound on the East by the Bay of Bengal, and Northwards, it touches the boundary of Andhra Pradesh. Thus, it is predominantly the South that provides space for the city to grow. In this context, the Old Mahabalipuram Road (OMR) has been the seat of urban expansion, expanding the frontiers of the city towards the World Heritage site and tourist attraction of Mahabalipuram. Parallel to this is the East-Coast Road, that has also witnessed some development over recent years. South Chennai has since been growing as an IT corridor; in this process of expansion, the city has engulfed several fishing and agricultural villages and hamlets – of which Chennai has traditionally been an agglomeration (Pallavi Tiwari, 2019). The 'peripheries' in Chennai also have organically developed into job centres, where housing is relatively cheaper, and educational facilities are available. They become growth centres in their own right. Perungalathur and Padappai smaller towns are few examples.

Western region of Chennai is also growing due to industrial activity. An entirely new industrial landscape emerged in peri-urban Chennai. The small town of Sriperumbudur which is located 40 km from the city of Chennai on the Chennai-Bangalore highway has become a symbol of Chennai's industrial success story. In the industrial corridor between

Sriperumbudur and the village of Oragadam, an extremely dense cluster of industrial plants has emerged. In the last ten years in this corridor alone, 23 globally acting firms were established. Another element that is profoundly transforming the peri-urban landscape in Chennai are large prestigious residential projects mainly to cater for the needs of the professional workforce from India and abroad (Homm, Sebastian, 2012).

Figure* 5** maps built up area change, with areas in red showing new development occurring over the period 2001-2018, at a 30metre resolution. This map highlights the intensity of, and spatial patterns characterizing, new development across the Chennai region. ***Figure 6 maps changing patterns of population density across this area. This presents a picture of areas of shrinkages, particularly within the urban cores of Chennai and its wider region set alongside areas growth within the same urban cores but also notably within peri-urban areas lying between the major urban centers.

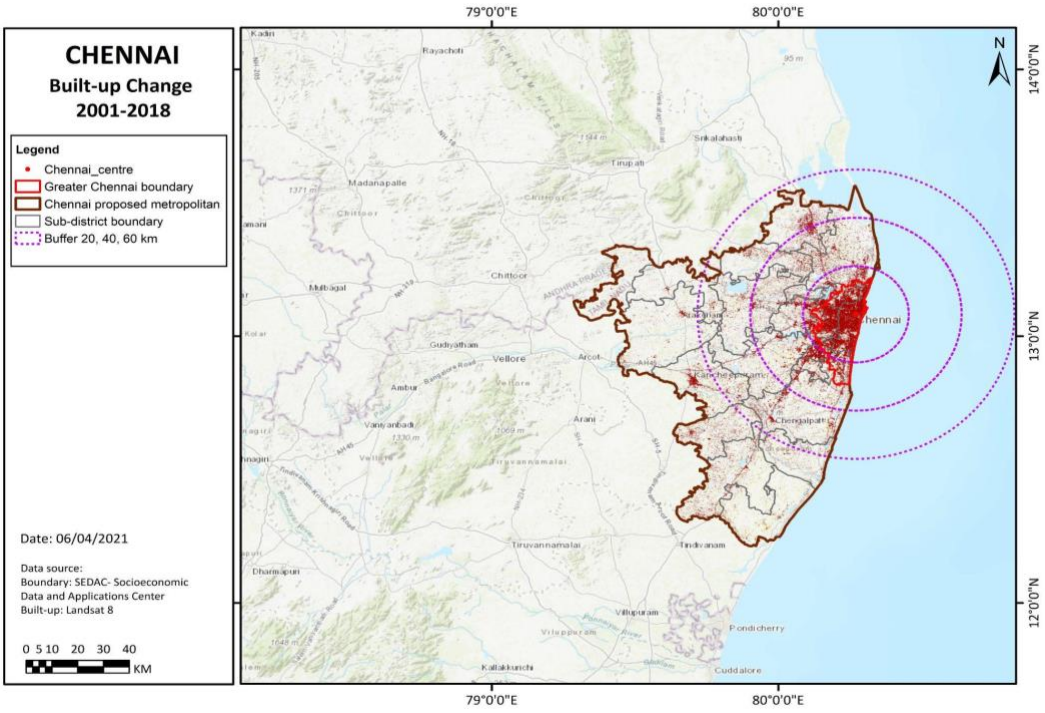

Figure 5: Built up Change in the Chennai region (2000-2018)

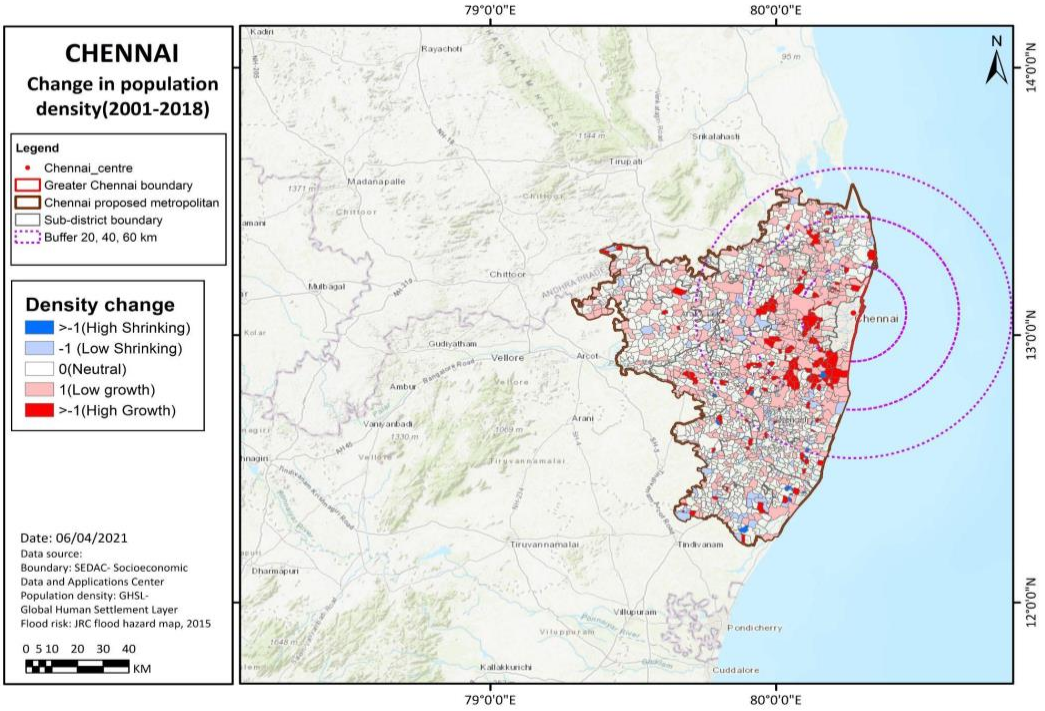

Figure 6: Change in population density in the Chennai region (2001-2018)

The vital statistics are summed in ***Table 3*** (calculated for the whole 200 x 200km square shown in the map format). The calculation includes Greater Chennai, Proposed metropolitan area and hinterlands of north and west of Chennai. Much of the open and peri-urban land area is both within inside and outside of the FUAs (functional urban areas):

- Open land & peri-rural (<50 p/km^2) accounts for nearly10% of the land area with less than 0.5% of the population, however this has grown more than 100% since 1990;
- Lower density peri-urban (<125) covers 17% of land area with less than 1% population, with a growth of more than 100% since 1990;
- Higher density peri-urban (<300) covers 22% of land area with 2.65% of population, with growth more than 100%;
- By comparison the urban / suburban / town areas (>300 p/km^2) covered a half of the highly urbanized Chennai; they contain 96% of the population with a relatively high growth of 52% over the period.

The overall picture is of higher population growth in the urban/suburban areas with moderate growth in the higher density peri-urban areas.

Table 3: Vital statistics summary of peri-urban

Peri-urban classes		**total land area 2015**	**total population 2015(in % to the total)**	**25yr CHANGE (% on 1990)**	**annual % change compound**
Open land & peri-rural	< 50 p/km	9.40%	0.18	126.40%	3.32%
Lower density peri-urban	<125 p/km2	17.00%	0.88	141.00%	3.58%
Higher density peri-urban	<300 p/km2	22.10%	2.65	141.40%	3.59%
Urban & suburban	urban >300 p/km2	51.50%	96.29	52.30%	1.70%
Total	Total area	100%	100%	54.40%	1.75%

Development pressure to provide more housing, infrastructure and commercial space is intense in certain locations. This development pressure creates several ecological and environmental challenges that the current governance and administrative machinery is unable to cope with. Many of these problems have resulted from the growth of the city beyond it carrying capacity and the disconnect between urban and environmental planning.

These issues provide a background to this Peri-cene case study, within which the Chennai region is defined as Greater Chennai plus its surrounding hinterland areas. There is no single unit or boundary which covers this region.

4 Current and projected climate risks & impacts

4.1 What are the main climate risks in the Chennai region?

General Context

Climate change has proved to have greater influence in triggering extreme events like floods, droughts, tropical cyclones and heat waves in the current times and is projected to increase in the future. The increasing trends in climate disasters around the world has been a wakeup call for leaders to come together and find interventions and formulate global strategies. Urban cities around the world are now more vulnerable to the effects of climate change leading to massive economic losses (WMO 2021).

Moreover, in the context of India, the nation alone estimated a loss of about 87 billion dollars in 2020, due to climate disasters explicitly (WMO, 2021). Studies show that India has been receiving hotter days, increased occurrence of Tropical cyclones, and extreme rainfall (Yaduvanshi et al., 2021), in recent decades making the country more vulnerable to climate impacts. Urban cities on one hand have significant risks to climate hazards predominantly due to human induced pressures like population growth, manmade hydrological alteration (Gupta & Nair, 2011). While most of the urban cities in India are densely populated, it is especially in the regions where large urban encroachments on the floodplains take place pose a higher risk of flooding. Interestingly, there is an increasing incidence of flooding related reports in various cities in the recent two decades (De et al., 2013), conforming to the fact that cities are indeed becoming more vulnerable to changing climate (WMO, 2021). This project focuses predominantly on the Chennai city and its region as one of the case study areas. We explore further the Climate related risks in the Chennai city and its region.

Chennai city Profile:

The Chennai metropolitan Region is one among the largest urban spaces in the world *(Demographia, 2021*). Driven by population growth and rapid land use change, the city region is expected to grow twice in its size by 2026 (*Aithal & Ramachandra, 2016*). Economically, Chennai city is one amongst the fastest growing cities in the world according to Forbes (*Kotkin, 2012*) including vast transportation connectivity.

Climate Context:

The Chennai region predominantly receives its rain from the North eastern Monsoon Rainfall (NEMR) (*Rajeevan et al., 2012*). The NEMR plays an important role in prediction of rainfall over regions in Tamil Nadu including Chennai, since NEMR is greatly influenced by large scale circulation in the pacific sea (*Wang et al., 2018*).

Study Method:

In order to look at the changing climate pattern at the city scale, it is imperative to have downscaled data from the global levels and regional levels (*Hall, 2014*). Thus, recently published papers between (2017 - 2021) were selected, that mostly focused on the context of Chennai's extreme climate events, which also analyzed, documented and projected Chennai's climate change under extreme climate scenarios of the greenhouse gas emission pathway. The following are summarized:

- *Rainfall:* The Chennai region receives 50 percent of its total rainfall from the NEMR during the

months of October, November and December (*Rajeevan et al., 2012*). we further summarise the following:

1. Chennai city has recurrent flooding for the year 2006, 2007, 2008, 2010, 2015, and 2021 due to single day extreme rainfall. *(Jeganathan et al., 2021; Guhathakurta et al., 2011*)

2. The Total Average Rainfall as precipitation on the day of 2015 Chennai floods, was observed to be at 40cm (Jeganathan et al., 2021), in contrast to the total Average Rainfall of 22.5cm during the day of 2021 Chennai floods (IMD,2021).

3. The Projection for future Rainfall based on the IPCC, A1B Scenario is observed to be steady in nature and decreasing slightly by 5% for the mid-Century year (2041 – 2070), and 1% by the end of the Century year (2071 – 2098) (*Tamil Nadu State Action Plan for Climate Change (TNSAPCC) 2017*)

4. The Intensity and frequency of extreme rainfall is observed to be increasing projected in the scenario RCP 4.5 and RCP 8.5 *(Athira & Agilan, 2020*)

- ***Temperature:*** The total average temperature around the region has also increased by 1.2 0 C from the period of 1951 to 2010 (). The Climate projections for Chennai region under the IPCC, A1B scenario, predicts an increasing temperature of about 2.4 0 C – 2.5 0 C for the mid-century year (2041 – 2070), and 3.3 0 C – 3.6 0 C by the end of century year (2071 – 2098).

Table 4: Climate projections for Chennai region (TNSAPCC 2017, Jeganathan et al., 2021)

Climate variable	2020 (2010 - 2040)	2050 (2035 - 2065)	2080 (2065-2095)
Maximum Temperature (deg C)	1.0	2.0	3.1
Minimum Temperature (deg C)	1.1	2.2	3.2
Annual Rainfall (Percent change-%)	(2 - 7)	(1-4)	(4-9)

Sea Level Rise (SLR) context for Chennai region:

A local level study on the Sea Level Rise, projected using the SLIMCLIM climate model for the Tamil Nadu coastline (*Ramachandran et al., 2017*) under various timelines of the IPCC, AR5 - RCP scenarios, predicts an increasing trend of inundation due to Sea level rise for the Chennai coastline with a maximum SLR noted at 77.88 cm by 2100. The other projected values from the study for Chennai region are mentioned in the Table 5.1, below. Furthermore, recent study conducted by IIT Madras 2017 on loss and damage on inundation due to Sea Level Rise are summarized below:

1. Inundation of about 1432 ha of Land area in Chennai region from Ennore to Mahabalipuram due to 1.0 m SLR

2. Total coastal population of about 13,36,682 are at risk for 1m SLR in Chennai region from Ennore to Mahabalipuram
3. A total estimated value of approximately 105 billion USD from infrastructures like Ports,

Roads, and Land respectively is lost due to 1m rise in SLR in Chennai region Similarly. on the coastal erosions in Chennai

4. Coastal area of about 27.79 sq.km is classified as highly vulnerable for erosion due to seven coastal factors which includes Sea level rise as one among them (*Jeganathan et al., 2021*)

Table 5: Projected loses on infrastructure cost due to sea level rise- (rupees crore) -(IIT Madras, 2017)

Coastal District	Ports	Roads	Lands	Power Plants
Chennai	8577.5	11	3,44,963.5	
Kanchipuram	500	118	7,19,315.5	
Thiruvallur	9450		4,79,034.5	13,814

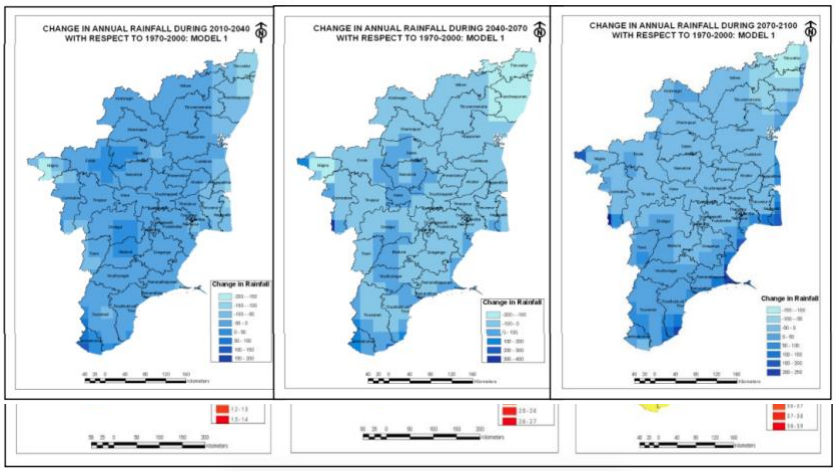

Figure 7: Climate change Projection Over Tamil Nadu (Bal et al., 2015)

(Source: Centre for Climate Change and Adaptation Research (CCCAR), Anna University, Chennai)

Past occurrence of extreme climate events around Chennai region:

Reviewing papers on past occurrences of extreme climate events in Chennai region revealed sparsely available information in such regards. Most of the studies, although available, are centered on the 2015 Chennai flood event, and other studies trying to understand climate anomalies during the November - December month of 2015. Nevertheless, a study *(De et.al (2005*) that reviewed extreme climate events in the country for the past century, reveals an increasing number of extreme events throughout the decades, and in Tamil Nadu specifically, the number of heat waves and drought are observed to be increasing considerably, and becoming more recurrent in nature. Although, Tamil nadu is experiencing more dry days compared to the past *(Rajkumar et al., 2021; Dash & Mamgain, 2011)*, the number of one day extreme precipitation events has been observed to have increased (*Indian meteorological department*). Similarly, in the case of cyclonic events, there has been an increasing number of cyclonic storms observed during the pre-monsoon and post monsoon seasons (Mishra, 2014). The local warming of Bay of Bengal has shown to have much larger influence than rising Global temperatures, in triggering Extreme climate events in Chennai city *(Krishnamurthy et al., 2018*).

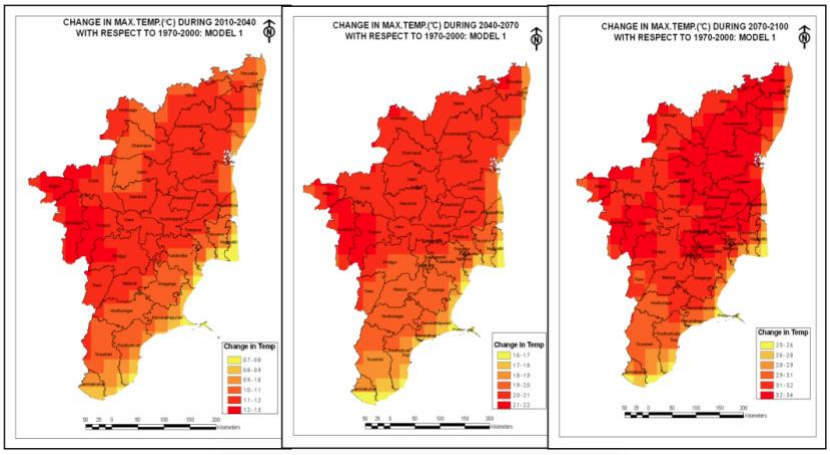

Table 6: Frequency of climate events in Chennai (Chennai Resilience Strategy, 2019)

Events	1985-2000	2000-2020 (current day)
Floods	3	8
Cyclone		7
Droughts		7

Heat Wave	4	6
Tsunami		1

Risk and Vulnerability to extreme climate events around Chennai region:

Flood Risk: Chennai city is known to be highly vulnerable to climate change (*TNSAPCC,2017*), and predominantly, the coastal regions are classified as very highly vulnerable zones. The state of the city's vulnerability is shown to be influenced by various factors, firstly its inherent topography results in less free runoff flow, secondly due to external conditions partly by climate change like Surface temperature and rainfall, but mostly by human induced factors like degradation of water bodies, improper solid waste system, under capacity drainage systems (*Gupta & Nair, 2011*). In the past few decades, Chennai has grown physically, in the 20th century (*Gupta & Nair, 2011*), and also grew 8 times in population between 1901 - 2001 due to the large influx of migrant population from other parts of Tamil Nadu and also from other parts of the country. This has also led to an increasing number of slum formation at the banks of water bodies and flood plain zones (*Diwakar, P. (2021)*. Floods were some of the major disasters that took place in the city in the past years due to heavy rains influenced by the warming and ultimately depression at the Bay of Bengal. Given the Tremendous growth and lack of space in the city, even the smallest of Floods create considerable damage. Although, the trends of rainfall in Chennai have not increased or decreased in the century, the recurrent occurrence of single day extreme floods in the city comes down to following factors as summarized from (*Krishnamurthy et al., 2018; Gupta & Nair, 2011*):

1. Drainage channels that have ended up being blocked due to heavy encroachments.
2. Inadequacy of Storm water drainage system and lack of Proper Maintenance of the drainage system.
3. Increasing land use changes open spaces to Impervious surfaces.
4. Lack of coordination between institutional Agencies involved.

Drought Risk: Chennai Region is predicted to experience more recurrent droughts in the future as the projection for rainfall is on a decreasing trend from (*Shankar et al., 2020)*. 2019 was the driest year for Chennai with a rainfall recorded around 10cm preceding failed monsoon in the year 2017 and 2018. The Chennai city depends on four reservoirs namely: Red Hills, Cholavaram, Poondi and Chembarabakkam as a source of potable water, which was heavily depleted leading to declaration of "Day Zero". An analysis *(Praveen et al., 2016*; *Gupta & Nair, 2011*) on occurrence of drought events in South India, reveals the influence of Global climate on the North-Eastern Monsoon during October - December, that was deficit leading to dry weather conditions. The risk of Drought is exacerbated with other factors summarized below:

1. Increasing demand for Water with an increasing population.
2. Lack of ground water recharge mechanisms.
3. Encroachment and construction on water bodies deteriorating the integrity of Water bodies.
4. Decreased water holding capacity of water bodies.

Adaptation capacity for extreme climate events around Chennai region:

Chennai is located on the highly exposed southeast coast of India and is relatively low and flat. Recently, the city has suffered more frequent and intense floods, drought and cyclones. Three major rivers, the Adyar, Cooum, and Kosasthalaiyar, frequently inundate following even short periods of rain. The Climate Change Vulnerability Index of 2021 ranks Chennai the highest among large Indian

cities in terms of exposure to climate change-related threats *(Maplecroft, 2021*). Another study shows that Chennai is ranked the most socioeconomically vulnerable to climate change among the metropolitan cities in India *(Malakar & Mishra, 2017*). The risk of flooding in Chennai is expected to worsen with climate change. Higher temperatures and more frequent droughts are expected to exacerbate water scarcity in the city.[1]

Chennai region in the Global context

The Chennai region is one among the 21 cities around the world in the Peri-cene Policy Lab. Each one is placed in its global context, with spatial projections from the IPCC-AR6 (summarized from *Krishnan et al., 2020*).

Temperatures:

1. The Mean surface air temperature in India for the Mid-century (2040 - 2069) is projected to be at the range of 1.39 - 2.70 deg C. Other temperature projection is mention
2. The frequency of warm days and warm nights is predicted to increase in the next decade.

Precipitation:

1. Summer monsoon precipitation is projected to decline with weakening of large-scale circulation, and decrease in the frequency of depression forming at the Bay of Bengal.
2. Increase in frequency of high intensity localized rainfall is likely in the next decade.

Table 7: Regional Climate projections for India (Krishnan et al., 2020)

2070-2099	RCP2.6	RCP4.5	RCP8.5
Mean Surface air temperature	1.33 +(-) 0.24	2.44 +(-) 0.41	4.4 +(-) 0.45
Annual Mean Temperature	4.71 +(-) 0.35	4.10 +(-) 0.45	4.44 +(-) 0.45

More detailed information on future projections from IPCC AR 6 expert meeting are summarized below (Mandakini Chandra et al., 2021).

- Average precipitation is sparsely projected to decline by 2030 and the intensity of climate events is projected to increase
- Increase in frequency of monsoon breaks or dry spells.
- Dry Days in the summer is projected to increase by 30 days with a maximum temperature exceeding 35 deg C.
- Increase in coastal Flooding with increased occurrence of category 5 cyclonic storms.
- Increased occurrence of concurrent droughts and heat waves

More extreme weather events are likely to occur in the future. Indeed, it is these extreme weather and climate change events that cause the greatest damage to people, infrastructure and ecosystems.

[1] [1] More climate risk can be drawn from here: Chapter 3 https://www.environment.tn.gov.in/Document/tnsapcc/Chapter%203.pdf and Chapter 4 https://www.environment.tn.gov.in/Document/tnsapcc/Chapter%204.pdf of TNSAPCC 2.0

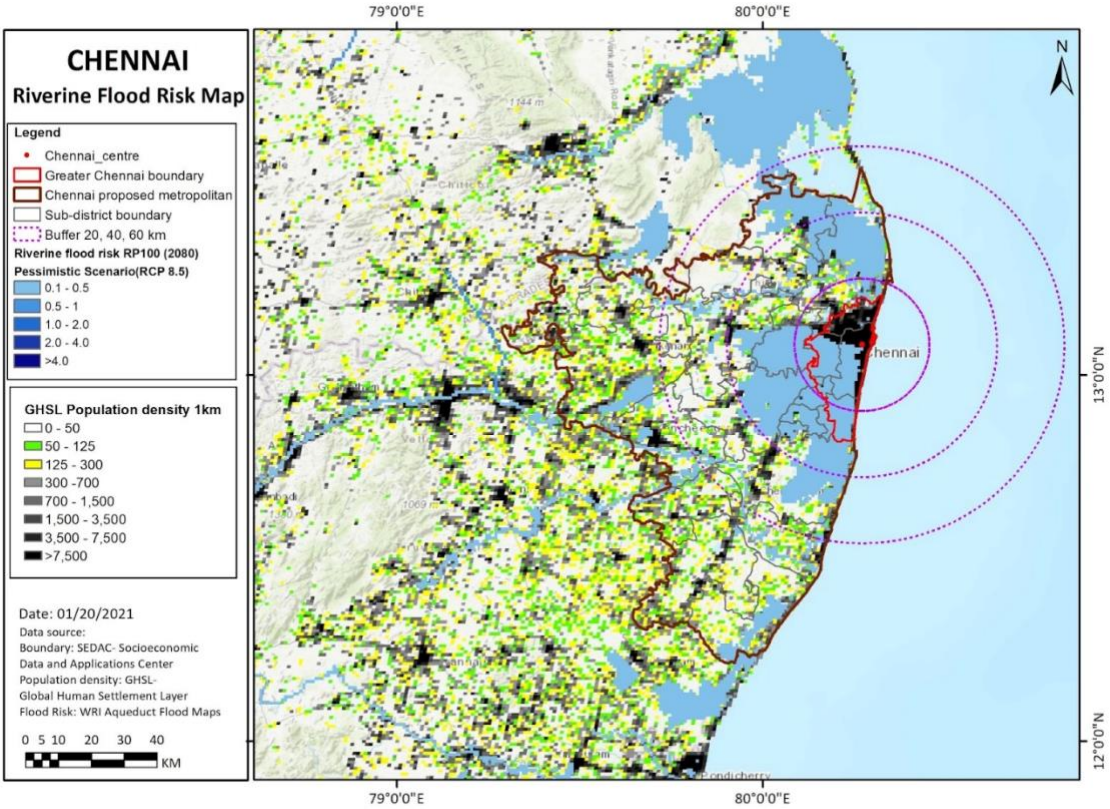

Figure 8: Riverine flood risk

5 Peri-urban climate risk and adaptation

The previous chapter has highlighted the nature of the climate change risks facing the Chennai region over the coming decades. Drought and Flooding are the key risks going forwards, although hazards linked to rising temperatures, including heat waves with related implications for people and critical infrastructure, are also a potential risk. An important point to acknowledge is also the risk from extreme weather events and erratic monsoons, in addition to gradual climate change.

Chapter 3 introduced the peri-urban areas of the Chennai region, which are often fragmented landscapes of marginal farming and urban settlements punctuated by waste dump yards, transport and energy infrastructure networks, commercial and retail parks and coastal retreats.

This has contributed to social polarization, widening income gaps, gentrification and rising property values in some areas.

The Covid 19 pandemic has recently accelerated trends towards home working and the desirability of living in peri-urban and rural areas, thereby intensifying these issues.

5.1 What are the effects of climate change on the peri-urban?

The next question is – why is the peri-urban so important for climate change: and how do we track this, given the uncertainties of climate projections, and the complexities of the peri-urban. There are two kinds of answers – the first is about the local conditions within the peri-urban areas, and the second sees the peri-urban as part of a whole city-region system.

For the local conditions in the Chennai's peri-urban, many such areas are at high risk of climate change impacts:

- Flooding and inundation of low-lying areas especially new low-income housing agglomerations which is partly a result of water-bodies' encroachments.
- Drought periods, with effects on ecosystems, landscape types and local farming. Agricultural lands being converted for non-agricultural purposes; especially towards speculative real-estate and water-supply economy.
- Over-extraction of ground water coupled with sea-level rise causing salt water intrusion into coastal aquifers.
- Extreme heat, which affects vulnerable social groups, in particular the elderly and outdoor workers.
- In the coastal & estuary peri-urban areas of the various river basins (along the coast), sea level rise, coastal erosion and saline incursion is a growing problem.

For the second question on the whole city-region: the Chennai basin's peri-urban is also clearly inter-connected to the urban and rural areas, as part of an extended city-region:

- Water management in the peri-urban has a direct effect on the flood risk and exposure of downstream urban areas;
- Landscape management in the peri-urban has an indirect effect on water: e.g., where upland land-use and ownership creates problems of storage & run-off;
- Farming practices in the peri-urban create further problems of run-off, chemical pollution, soil erosion, clearance of natural areas etc.

- The urban heat island effect may be alleviated by outward movement to the peri-urban, with increase in urban greenspace and decrease in density
- Housing development in the peri-urban is a direct effect of urban pressure, and the need for natural capital and greenspace: however much new development is disruptive of landscape and water systems, increasing the flood risk downstream.

Some key issues can be seen on the land-use/cover map (**Figure 9**):

- conversion of agricultural land for non-agricultural purposes especially in the light of speculation real-estate.
- Coastal erosion exacerbated due to structural interventions
- Encroachments along water-bodies

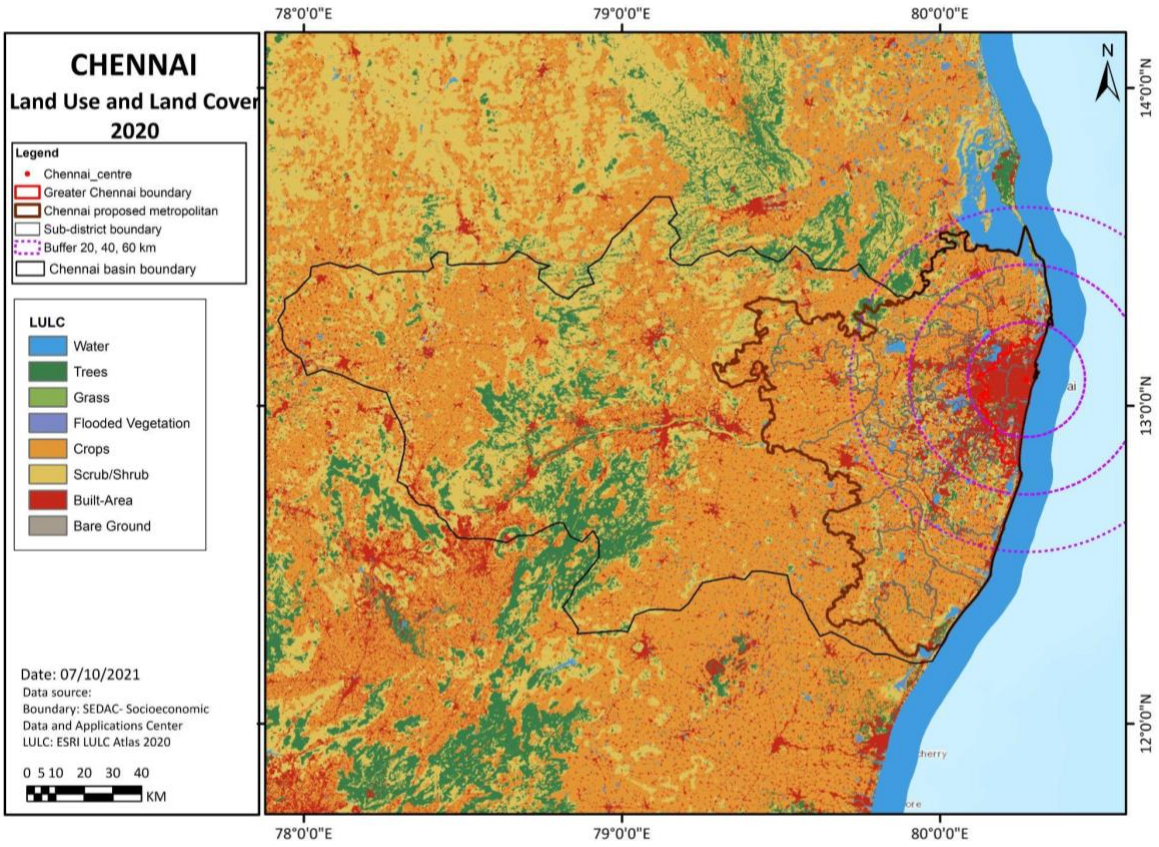

Figure 9: Chennai Land-use/Landcover

6 Chennai: A Case study

The Chennai case study uses the Synergistics framework earlier described in the report to develop an assessment of peri-urbanization and climate change and how they interact with each other in the case of Chennai. The framework which addresses peri-urbanization dynamics, climate impacts, vulnerability and governance is applied using two different filters or lenses on the peri-urban. The first one divides the Chennai region into different zones based largely on the morphology and geography of the Chennai watershed. The second lens is that of scale and this is used primarily in the content of governance.

Figure 10 shows the Chennai peri-urban zones that are identified for the study. The larger river basin region can be divided into 4 zones with specific characteristics.

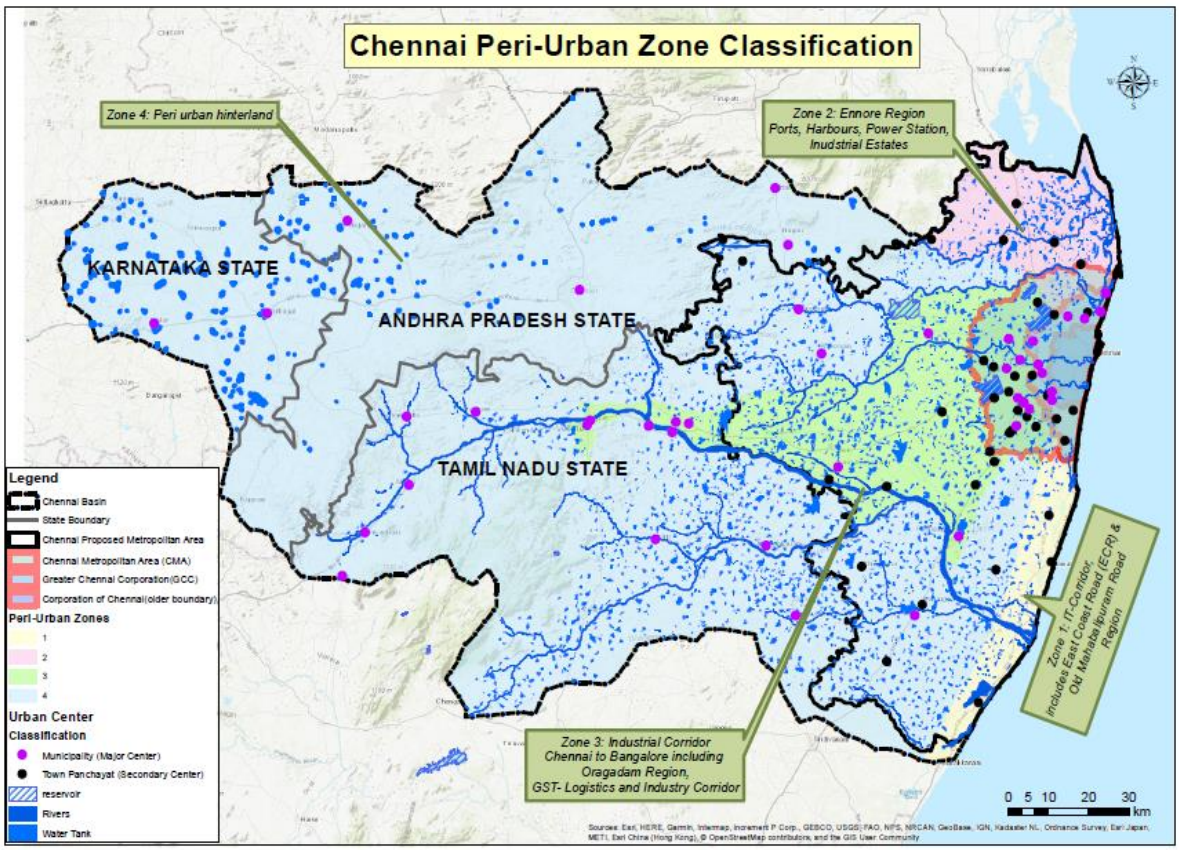

Figure 10: Chennai peri-urban zones

Ennore Region: With the Chennai and Ennore region, the north of Chennai is a heavy-industries complex along the ecologically-degraded coastline, amid scattered towns and farmlands.

Industrial corridor : Most automobile industries came up in the South-west region of Chennai and with the Chennai-Bangalore highway the Metropolis expanded in that direction. Urbanization cuts across the hinterland landscape along the major highways criss-crossing industrial hubs, and gated communities. The region interspersed with local villages and farmlands, and with rapid urbanization the ancient system of water bodies now at risk of encroachments and dilapidation.

I.T. corridor: This area covers the southern coastal-to-hinterland landscape with OMR and ECR,

acting as its backbones. While the former is a hi-tech industrial corridor the latter is known for being an entertainment / scenic / tourist retreat, interspersed with fishing villages, salt pans and small-scale farms.

Hinterland: The Chennai hinterland area includes a large watershed including catchment areas, spruced with mid-sized cities, villages and farmlands and small-medium scale industries. (This area overlaps 3 states: Tamil Nadu, Karnataka and Andhra Pradesh).

The following table is a summary of the Peri-cene Framework to illustrate the differences between the four zones.

Table 8: Chennai region zones

Chennai region overview of zones

	Chennai - Ennore	Chennai - Industrial corridor	Chennai - I.T. corridor	Chennai - hinterland
Peri-Urban	Heavy-industries complex along ecologically-degraded coastline and scattered towns and farmlands	Major highways criss-crossing industrial hubs and gated communities interspersed with farmlands and water bodies	Coastal-to-hinterland landscape with hi-tech industrial and entertainment/scenic corridors, interspersed with fishing villages, salt pans and small-scale farming	Large watershed area with mid-sized cities, villages and farmlands and small-medium scale industries
Climate Risk	Sea level rise, increase in extreme events - storm, storm surges	Extreme rainfall events triggering floods and droughts and subsequent impacts on land, biodiversity	High-risk coastal infrastructure, floods, fragmented land/waterscape	(heat, precipitation and storm: impacts on water systems & agricultural livelihoods)
Vulnerability	urban eco-social-economic mix in some areas has growing vulnerability	Fringe villages and towns adjacent to water bodies at higher levels of risk from flooding;	Rapid urbanisation leading to fragmented landscapes coastal infrastructure risk and loss of livelihoods	marginal livelihoods in sensitive landscapes with growing pressure of urbanization
Governance	Quasi-government arrangements with industries, limited overview and regulation;	pockets of civil society action and local innovation could trigger pathways of transformation	fragmented local governance, complex	fragmented local governance & civil society
Synergistics	from the world's first industrial city-region to the first post-industrial eco-region	Growing pressure on fragile landscapes & settlements: potential for socio-eco-resilience	potential new forms of eco-urban form & design, in new forms of community	Can a new eco-social order emerge?

In the last few decades, Chennai's growth story as an industrial hub (fourth-largest metropolitan area in India) has led to significant urbanization, drastically altering its complex land/waterscape, making it vulnerable to multiple climate risks. It was evidenced recently by the 2015 floods and the immediate years of drought that followed. Regional climate analysis has predicted more intense rainfall in shorter periods in fairly vast areas with drought elsewhere due to decrease or variability in precipitation (Sperber. K. R. et al. 2016). Climate change increases the vulnerability of local populations to flash floods, soil erosion, long-term freshwater shortages and declining agricultural yields.

Hence, the central focus of the larger Chennai watershed-scale case study has been around natural and man-made water-scapes (eris, 4 rivers basins, sea, 5 wetlands, Buckingham canal), and their role in moderating natural water-related disasters like flash floods, droughts, cyclones, sea-level rise that region is prone to.

Since the Chennai region intermittently faces the challenges of water scarcity and flooding, with the city dealing with too little or too much water, water management through an elaborate system of connected/cascading tanks and stream channels has been a significant part of the history of the Tamil

Nadu lowland and the neighboring Deccan plateau in Karnataka and Andhra Pradesh since the 11th century. The city's hinterland ecology has contributed to managing these risks inherent to its climatic landscape.

As the city expands and urbanizes into these hinterlands, the story of Chennai's peri-urban crumbles with every cycle of exasperated flood and drought- climate vulnerabilities and the tale traces back to neglected water-bodies, their interconnections and shrinking wetlands in its journey fuelled by grotesque greed for growth. It results from urbanization and rising land prices, poor institutional mechanisms to regulate water use, and government-sponsored large infrastructure projects for water & sanitation, which further degrade small reservoirs, their hydrological inter-connections and associated water management practices.

The larger question is that for it to sustain itself can the city develop pathways to address the twin challenges posed by urbanization and climate risk?

For the case study, three scales were chosen — macro, meso, and micro where these themes of urbanization and climate change entangle, creating both challenges and opportunities. With multiple tools, we analyze and observe the impacts of this growth and the fallout at three sites representing each scale. These scales play a role in teasing out how various actors and stakeholders interact with each other and how they work within different governance arrangements at each scale.

6.1 Three Scales

6.1.1 Bio-regional scale

One conception of the peri-urban is to employ ecological boundaries instead of administrative ones that are man-made and rendered porous through multiple processes such as urbanization. At the macro scale, we explored the idea of using the Chennai watershed as one of the lenses to understand Chennai's peri-urban processes and the challenges it brings.

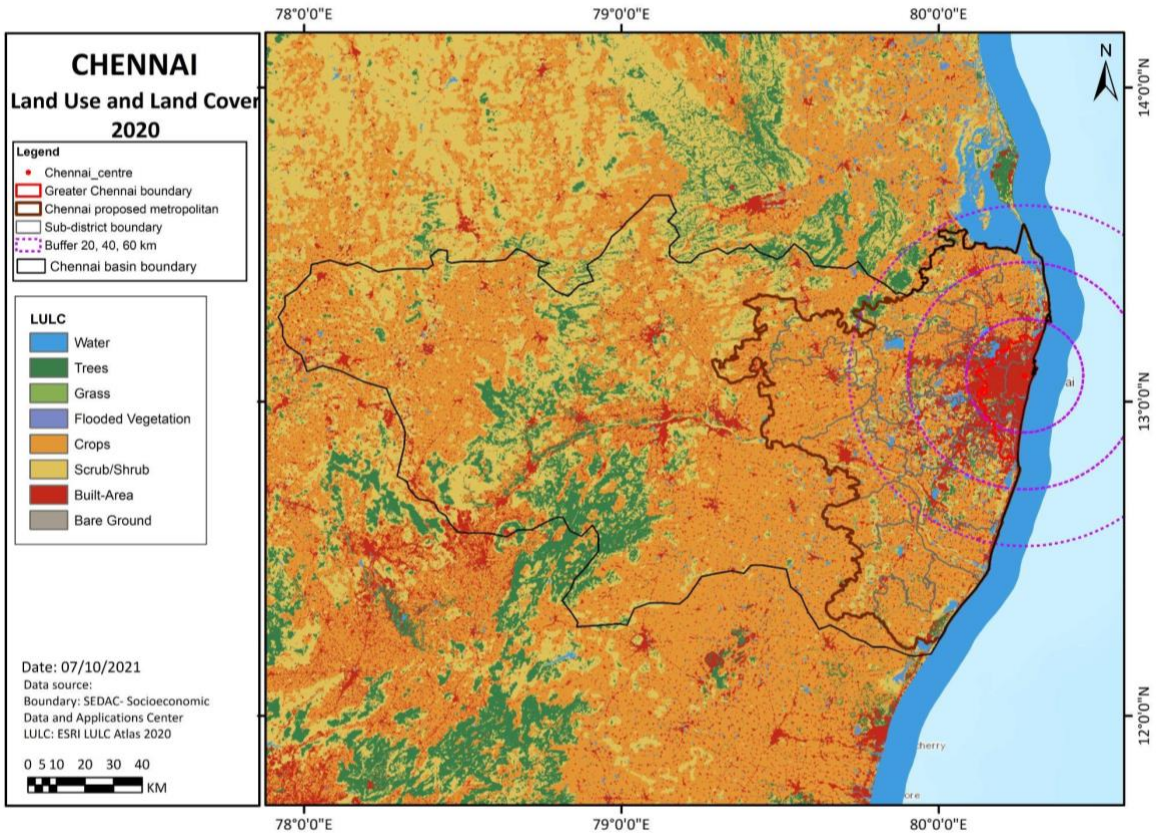

Figure 11: Chennai Bio-region scale land-use and landcover

It is made up of the basins of four rivers that drain through Chennai and transcend adjacent state boundaries. With extreme weather events being the order of the day, focusing on Chennai's hydrology and the associated green spaces→ the larger water basin encompassing the 4 rivers, numerous cascading tanks, 5 associated wetlands and the sea helps us perceive, understand and map the various larger dynamic interactions at play between seemingly unrelated causal factors and understand climate-change risk profiles and design interventions beyond the conventional realm of piecemeal administrative boundaries.

Chennai's Waterscapes and their issues: -

The four main west to east running streams in the CMA are the Kosathalayar, Cooum and Adyar and Araniyar. In the proposed expanded area, there will be a total of five major rivers – Araniyar, Kosathalayar, Cooum, Adayar, and Palar.

Cooum and Adyar are seasonal rivers, and with a large part of their river basins lying in the city, they act as the primary drainage channels for excess storm-water running into the sea. They, hence suffer from pollution from Municipal Solid Waste and Domestic untreated sewage due to drain lines that are illegally connected to storm-water drains.

The British constructed the artificial salt-water navigation channel called the Buckingham canal in the 19th century that connected most of the natural backwaters along the coast to Chennai (Madras) port. Connected to most water systems of the city, it runs north-south cutting across Chennai was conceived as an inland waterway for transport (once 60m in width) that has now been rendered unusable due to pollution and encroachments (6m width between Cooum and Adyar) (Prabhakar, B. 03 Jul 2017). due to encroachments by industries, residents and even Government infrastructure

projects alike. Chennai's Mass Rapid Transport System (MRTS), which runs on top of the canal between the stretch from Thiruvanmiyur to Central Station, has been one of the prime reasons for reducing its width. The water in the part of the canal between Ennore creek and Central railway station, (industrialized zone), is found to have high viscosity since the industrial effluents and sewage are let out untreated. The canal beyond Thiruvanmiyur to Muttukadu is still pristine and ecologically sensitive, though giving in to urbanization slowly.

In addition to these waterscapes, as the map shows, are inter-connected water bodies almost smeared across this vast stretch of land. These water bodies were central to agrarian communities and towns that pre-date the Chennai city timeline. The terminology of water bodies has historically been varied and detailed, and the management of these has been customized according to the type. The classification of water bodies was based on three main parameters – extent, depth and the flow pattern and determined their nomenclature- *ery, kulam, kuttai, thangal, odai, madavu* and *urani* (See ***Figure 12***) (Vencatesan, A. 2019).

Figure 12: Nomenclature of water bodies used in South India

(Source: India Water Portal)

Chennai receives 60% of its rainfall from the North-east Monsoon that occurs in the form of cyclonic rainfall, which produces extreme rainfall occurrences over short duration time periods. The rest of the year, the city suffers from tropical heat and periods of water scarcity.

These tanks are an integral part of the city's landscapes and were responsible for its resilience. They served as water reservoirs that were used primarily for irrigation, mitigating the climate vagaries resulting from wet monsoons and dry periods after. With the city's blue-green spaces crumbling and many of the tanks being compromised and encroached upon owing to urbanization and the resulting

decline in agriculture has compounded the risk of floods in adjacent and downstream areas along with more extreme periods of drought and water scarcity.

Three of these erstwhile erys have been reclassified and currently act as reservoirs catering to the water demands of the city of Chennai- Chembarambakkam, Poondi and Red Hills. Thervoy Kandigai-Kannankottai reservoir; Kattur and Thataimanji near Minjur, and water bodies in Orathur and Arambakkam in the southern Adyar basin are newer proposed reservoirs reserved for the city's water needs.

The coastal region of Chennai is a part of Zone One-North Tamil Nadu coast and is located between the Pulicat Lake and the Kaliveli Lake-Thengaithittu Estuary as its extremities. It consists of diverse coastal habitats, including sand dunes and beaches, mangroves, lagoons and backwaters, mudflats, estuaries, oyster reefs and sea-grass beds. Pulicat lagoon, Adyar Estuary, Kovalam creek, Mudaliarkuppam backwaters and Yedaiyanthittu Estuary are among the locations where biodiversity is high (913 species of Marine Fauna (MNS) (The Hindu, 08 June 2021). The major threats to these have been identified as coastal erosion and pollution.

While coastal erosion has been exacerbated due to rapid industrialization and urban expansion (>30% of Chennai's coast is shrinking) (The Times of India, 27 July 2018), which in turn is disrupted by groyne formation along the coast (prevalence in the Kovalam-Muttukadu belt and North Chennai-Pulicat Lake), affecting the coastline in other parts. For instance, the Construction of the sea wall in the northern part of Chennai for the Chennai Port has caused coastal erosion north of the structure and accretion to the south. While Fishing hamlets and old temples of North Madras have been swallowed, Marina Beach is widening. Due to the same process, sandbanks have developed near river mouths of Adyar and Cooum, obstructing the water flow and thereby further exacerbating the floods (The New Minute, 23 Oct 2017).

Marine Pollution has been heterogeneous across the coastline. While Adyar estuary suffered from poorly treated effluents, it was Municipal domestic waste for Kovalam and a mixture of both for Pulicat. In Odiyur and Kaliveli, the threats, though lower when compared to the other regions, were mainly from Microplastics (The Hindu, 05 Dec 2021).

The Coastal Chennai region will be affected by sea-level rise with increasing storm surge leading to inundation, coastal erosion, saltwater intrusion, and loss of coastal biodiversity and ecosystems. urban infrastructure and (Peri-Urban Chennai would experience total damage ranging from Rs. 459–7 706 billion (the US $7.5–126 billion) at 2010 prices (Nambi. A et al). It could render not just urban infrastructure but also parts of coastal agricultural land unfit for cultivation with serious implications on food security.

Coastal landscapes, when preserved in their pristine form, act as protection against the ever-so-common extreme weather events. It was noted during the 2004 tsunami that the well-developed Sand dunes of Mudhaliarkuppam and Odiyur (some around 30ft high) had this capacity to constantly draw in the incoming tidal waves and not allow them to reach the village. There have been similar stories about mangroves and oyster reeds holding and binding the coast. However, habitat degradation is happening at an alarming scale; Pazhaverkadu, which derives its name from its famed mangroves, has been lost almost completely on the Tamil Nadu side, and so have the mangrove-dependent fauna (The Hindu, 05 Dec 2021).

Due to the over-utilization of groundwater resources, seawater intrusion is of the highest levels along the east coast, particularly to the North of Chennai between Ennore to Ponneri. The Anna university study has also found that seawater had intruded to a depth of 10 m, up to the extent of 2 km, between Thiruvanmiyur and Injambakkam, south of Chennai. Chennai's levels are at 25000 uS/cm (>3000uS/cm indicated saline intrusion into groundwater) (The Hindu, 05 Dec 2021). North Chennai's

wells like Minjur, Tamaraipakkam, Panjetty, and Minjur well-fields (In Minjur, several farmers continue to depend on the tanks for paddy and groundnut cultivation.) have been known as a source from where the water tanker lorries draw water to cater to the city's excess water needs (of the 830 MLD (million liters a day) water there's a 320 MLD deficit in supply as admitted by Metrowater Board) (The New Indian Express, 07 Dec 2021), not serviced by the City water supply, especially during the hot summer months where most parts of the city suffer from acute water shortage.

There is an unsustainable transfer of groundwater resources, especially from wells around these tanks in the peri-rural hinterland to the city's urban areas through water tanker lorries. It has seemed to be a more fruitful economic activity than agriculture, one of the many factors contributing to land-use change in the Peri-Urban.

Chennai's average food miles are much higher than other major Indian cities 1137Km/mega-gram (weighted mass average) (almost double Surat's food-miles (537km/mg) ;(Boyer. D, et al. 2019). Chennai's reliance on the far region of Assam for the majority of its rice supply could pose serious threats to the city's food security measures when supply-chain disruptions occur. While agriculture doesn't stand remunerative enough owing to increased input costs, climate vagaries and the ery system being disrupted, other non-farm employment opportunities, speculative real-estate and thereby sky-rocketing land prices, presence of a lucrative water market, for a city to remain resilient, especially in times of the Pandemic where global supply chains crashed, peri-Urban agriculture has to be bolstered.

Climate Risks and Vulnerabilities:

- Climate change is bound to trigger extreme weather events along with an alarming rise of sea levels. Extreme flooding and Ddrought cycles have become a common phenomenon

- Housing pressure, from both local and incoming resident's results in increasing conversion of peri-urban lands into residential plots. However local governments aren't able to catch up to the rapid urbanization resulting in most of these areas lacking in infrastructure facilities and proper planning.

- Farming & farmland is under short term threat from real-estate speculation and medium-term threat from climate change.

- Biodiversity and natural areas are under medium term threat from climate change, particularly from the warming up of the bay waters, erratic monsoons and extreme weather events.

- Social polarization generated by presence, sometimes in close proximity, of areas of high affluence and deprivation. (Katchipattu and Sriperumbudur)

Key impacts & multipliers:

- Agriculture not remunerative; and with increasing climate change vulnerabilities multiply; forcing traditional users out of agriculture. Mono-cropping decreasing fertility adds to woes. Other primary activities including fishing affected due to urbanization woes in the peri-urban who's infrastructural capacities don't meet up to the urban sprawl

- Increasing population has increased the need for low-income housing. Owing to non-availability of land, it has led many government interventions to violate and encroach water-bodies. Housing pressure & rising values locates new housing in high-risk areas of flooding

zones.

- Owing to poor adaptation to changing life, certain communities are bypassed by development due to urbanization, and hence increasing social polarization.

Governance Challenges in Peri-Urban Chennai Region:

Post analysis of each climate change induced disaster struck in Chennai has always critically raised concerns of the governance. Lack of coordination, working in silos, multiple agencies with overlying activities, non-transparent, bureaucracy dominated rigid systems, minimal civic engagement and so on are the few of many such weaknesses that crop up to present the state of governance in Chennai and its surrounding areas. While the background paper is not aiming to define and discuss governance as a concept as such, it delves into to understand and explore adaptive governance (collaborative, knowledge based, contextual, emergent and transformative) (Andrew & Amanda, 2020) in context of Chennai and its surrounding areas. It explores and attempts a rapid assessment of 3 Ps (Policies, Projects, and Programs) related to the State and especially Chennai on climate change governance.

6.1.2 Landscape Scale- Muthukadu- Kovalam Sub-basin

We use a diverse landscape to the south of Chennai- the Mutthukadu- Kovalam sub-basin. It consists of regions within Chennai city limits and village panchayats just beyond, capturing the peri-urban continuum and the wide spectrum of communities and stakeholders the grid encompasses. It also captures the 'corridor effect,' a symptomatic feature of Chennai's urban expansion. Chennai is built on radial link roads, which naturally lead to corridors. Two such roads, OMR and ECR, form the backbone of this southern corridor and landscape, which the Buckingham Canal separates. They are in turn connected by lateral bridges 13 Km apart, Sholinganallur to the north and Kelambakkam to the south.

The mesoscale sits in between the oft-used micro and macro scales, which are relatively more well-defined in terms of administrative boundaries and governance structures. Hence, this scale presents added complexity in terms of the multitude of agencies and administrative bodies that are active at this scale. However, it is ideal for demonstrating the multiplicity of actors in the peri-urban across the various landscapes that are in play, along with the kind of complex natural disaster risks they are prone to that are aggravated due to anthropogenic activity.

The region is at the cusp of urbanization as shown in the ***Figure 13***, giving ample space and time for future policies to be shaped based on holistic delivery of social and environmental justice (learning from the wrongs of North Chennai's urbanization (Ennore sub-basin).

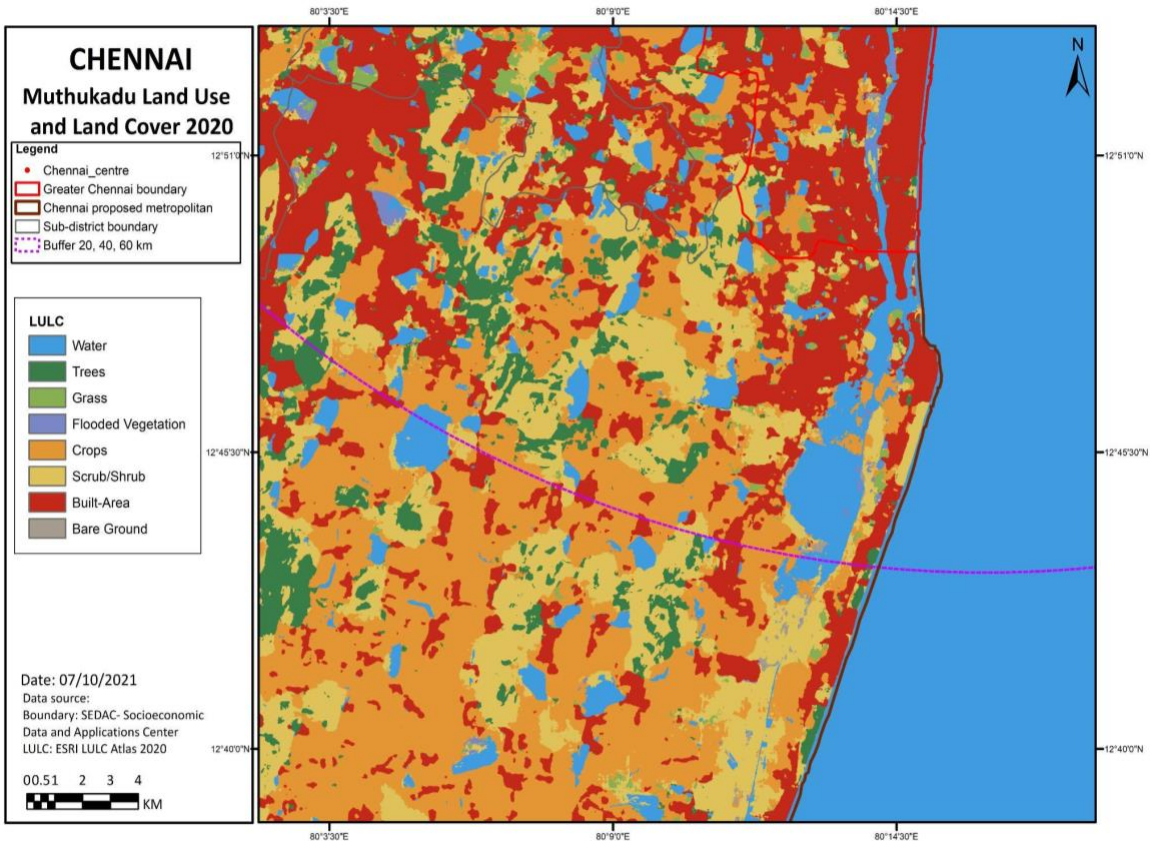

Figure 13: Muthukadu-Kovalam region land-use and landcover

Roughly covering 460 sq. km, the Kovalam sub-basin originates from Kattankulathur, passes through Thiruporur block[2]; Beginning with the hinterlands to the west comprising reserved forest areas around Shonallur and the sub-basin confluence happening at east by the Bay of Bengal. Between Muttukadu on the coast and Siruseri in the hinterlands capped by the Pallikaranai marsh in the North and Kovalam creek in the South, the landscape is one of multiplicity. Multiple ecologies and communities exist at varying levels of fragmentation. The risks and vulnerabilities are also varied and complex.

The Kovalam basin as shown in the ***Figure 14*** includes the Kovalam estuary, 15 Lakes (including Kilkattalai Lake, Narayanapuram Lake, Pallavaram Lake, Madipakkam Lake, Perungudi Lake, and Sitheri Lake), and Pallikaranai marsh. It accounts for 15 percent of the freshwater bodies in the city, 29% occupied by vacant scrub reserve forest land; however, it suffers 44 percent of encroachment — both commercial and residential according to a study conducted by the Greater Chennai Corporation[3].

[2] "Kovalam Basin Has 44 per Cent Encroachment, Says Study," Deccan Chronicle, September 11, 2016, https://www.deccanchronicle.com/nation/in-other-news/110916/kovalam-basin-has-44-per-cent-encroachment-says-study.html..

[3] "Project: The City of 1,000 Tanks Chennai - World Water Atlas," accessed December 11, 2021, https://www.worldwateratlas.org/narratives/water-as-leverage/wal-team-city-of-1-000-tanks.

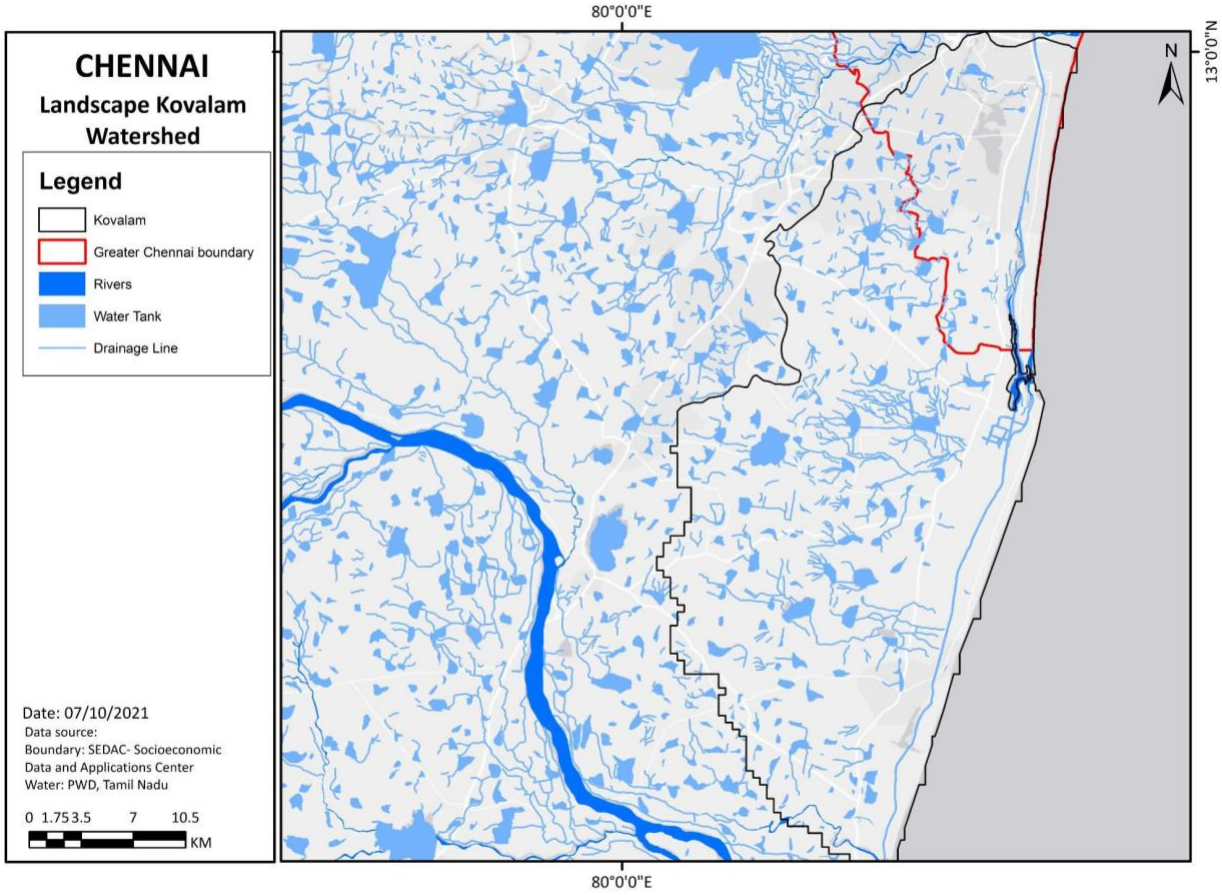

Figure 14: Kovalam watershed drainage line and water system

Cascading Water-bodies/ery's: The area to the west of State Industrial Promotion Corporation of Tamil Nadu limited (SIPCOT), Old Mahabalipuram Road (OMR), has an elevation of around 3m above mean sea level. As it is a part of a coastal depression, many cascading water reservoirs/tanks called eris were constructed in the lower, middle, and upper parts of the sub-catchment, which drain into the Buckingham canal. These braided reservoirs have a complex system of drainage involving culverts even once that pass under the carriageway of OMR. During the monsoons, the runoff from the forest area fills up the tank system and slowly releases its water to the downstream tanks.

The tanks and erys near the village of Thazhambur drain towards the North. Three of the tanks (Pudupakkam Eri, Sitteri, Siruseri) are located directly upstream of the major outflow to the Buckingham Canal and drain through the Phase-I area of SIPCOT into an outlet called Kazhipattur Madavu, that in turn drains into the Buckingham Canal. The Padur Pudupakkam Hissa Eri near Prakash Nagar drains towards the east, while the Padur's pond drains westward.

Water from the Manamathy tank group, South of Kelambakkam, passes through the vast salt pans of the great salt-lake, the backwaters into the Buckingham Canal (BC) via Muttukadu into the Bay at the Kovalam village. Bounded in the southwest by the hills of Thirukazhukundram and River Palar, it's fed by the reserve forests of Adhanur and Thaiyur. The drainage is in the Southwest to Northeast direction, consisting of well-connected micro-steams consolidating into larger ones keeping the wetland landscape intact. Owing to the gentle slope, the runoff to the sea is slow and staggered and

is why there is ample percolation into the aquifers; groundwater is available even at 3m depths[4].

The design of the traditional tank system is an engineering marvel. It accounts for buffering and collecting the sheet flow from the forest uplands, the discharge control structures optimizing for water flow for infiltration, and leaving enough space for flood retention. It contributed to the resilient water management of the whole basin.

Pallikaranai Marshland[5]: The backwaters and the Pallikaranai marsh act as natural flood absorption sinks for the numerous cascading uplands and isolated watersheds between the Cooum and Adyar estuaries from where the stormwater drains via. Radial Road, Okkiyam maduvu, Buckingham canal, Muttukadu Creek into the Bay of Bengal. Around 32 irrigation tanks' stormwater drains into the marshland through 8 inlets, and maintaining its ecology and ensuring the flow is free of debris is important in mitigating floods.

The solid waste disposal in Perungudi has created a substrate that has led to the rapid proliferation of Prosopis Juliflora on the North-east Boundary of the marshland; invasive plants establish where disturbances create bare soil. Small culvert channels on either side of the radial road are severely affected by this water hyacinth, and this has to be removed periodically. Otherwise, it will cover the entire water spread area, affect water flow and block sunlight from reaching native aquatic plants causing them to perish. They need to be kept in check to conserve water in the Wetland and enable the free and fast flow of rainwater. Other invasive species like cattail, water lettuce, and duckweed need to be managed/eliminated as they can interfere with the hydrology and the land-water ratio of Pallikaranai.

Figure 15: Solid waste disposal in Pallikaranai Marshlands

(Source: Laasya Shekhar)

The areas known for periodic inundation in the monsoons, like Perungudi, Thoraipakkam, Sholinganallur, Perumbakkam, and Semmancheri, are situated in and around Pallikaranai, which is a naturally formed marshy wetland is below sea level between OMR and Velacheri – Tambaram road

[4] "Project: The City of 1,000 Tanks Chennai - World Water Atlas," accessed December 11, 2021, https://www.worldwateratlas.org/narratives/water-as-leverage/wal-team-city-of-1-000-tanks.
[5] "Chennai_Report.Pdf," accessed December 10, 2021, http://nwm.gov.in/sites/default/files/Chennai_Report.pdf.

in South Chennai. Since there are no defined courses for the inflow channels falling into the Pallikaranai marshland, the developed areas in the locations suffer from waterlogging whenever the water level in Pallikaranai marshland rises above the normal level. Incidentally, the high-tech industrial corridor located on such swampy wetlands was one of the worst-hit areas in the 2015 Floods, costing businesses located their billions of dollars.

The dynamics of micro-habitats within the protected area and the shifting mosaics of major habitats in the entire watershed landscape that sustains the marshland need to be carefully monitored to ensure its ecological sanctity and prevent water-related disasters in this region.

Buckingham Canal: South Buckingham Canal from Kotturpuram to Marakkanam is sandwiched between the two growth corridors and cuts the Kovalam Sub-Basin in the North-south direction. It is presently unnavigable except for local inland fishery usage. However, it serves as a massive interceptor canal collecting urban runoff waters, sewage, and storm waters (especially from the cascading waterbodies upland) which are drained into the coastal outlet of Muttukadu/Kovalam and eventually the Bay of Bengal. However, rapid development in these areas has seen encroachments on channels and water bodies, resulting in blocking of the drainage systems causing inundation in low-lying areas and roads adjacent to channels. The canal additionally suffers from water pollution because of untreated sewage, industrial effluents being let into the canal from the urban conglomerations along the ECR and OMR.

Listed below is a summary of the Buckingham Canal's Main Ecological Functions: -

1. Drainage outlet for the isolated watersheds located along the coast.
2. As a flood absorbing water body for a shorter duration and also
3. As a barrier against seawater intrusion.

Muttukadu Creek, backwaters and the coast[6]: The backwater ecology consists of the Mutthukadu lagoon, the Kovalam/Mutthukadu creek, through which the Buckingham canal discharges into the basin before draining into the sea. Forming the eastern edge of the Kovalam basin, the ECR is populated with tourism real estate, amusement parks, fishing villages, poramboke(Commons) lands, and abandoned salt-pans. Sea level rise, coastal erosion, and sedimentation around the mouth of the Muttukadu Creek are key problems. The Muttukadu creek and its salt pans seem to limit further developments eastward towards the coast, and it is the only sea outlet for the South Chennai watershed.

[6] "Project: Rising Waters, Raising Futures Chennai - World Water Atlas," accessed December 11, 2021, https://www.worldwateratlas.org/narratives/water-as-leverage/wal-chennai-team-rising-waters-raising-futures.

Figure 16: Coastal erosion near Kovalam

(Source: Peri-urban Initiative)

The backwater consists of a brackish estuary behind a coastal ridge. It is a critical eco-sensitive region with the Lagoon and mudflats hosting a range of species, from prawns to migratory birds. It is of immense ecological value in ensuring the resilience of South Chennai and in safeguarding the livelihoods of local fishermen and salt-pan workers of the region.

While the coastal ridge of ECR is around 10m high, the estuary region, which is around 3m above mean sea level, makes the areas to the west vulnerable to sea-level rise; the risk is exacerbated during monsoons and storm surges. Owing to sea-level rise and blockage due to sedimentation at the mouth, the salinity levels of the Lagoon have been increasing, affecting the Lagoon's ecosystem. The wastewater runoff brings pollutants into the Lagoon causing further Habitat loss, which deteriorates the environmental systems, heightens vulnerability for the livelihoods that depend on them, and weakens natural defenses against storm surge and sea-level rise.

While the natural direction of waterborne sand transportation is from South to North, engineering interventions interfere with the same. To the South of the Muttukadu outlet, the local sea jetty traps sand and prevents it from being transported further northward. It causes sediments to accumulate to the South of the outlet, resulting in siltation inside the outlet of the mouth of the Lagoon and substantial erosion on its northern side.

Sea-level rise coupled with increasing groundwater extraction by the urban zones has caused saltwater intrusion in the Kovalam aquifer, one of the large aquifers close to the coast.

These issues are explored further within the Peri-cene project and reported in D4.2b through detailed transect studies.

Climate Risks and Vulnerabilities:

Climate change is bound to trigger extreme weather events along with an alarming rise of sea levels. It could lead to more frequent occurrence of severe cyclonic storms and loss of coastal hamlets. With

rising sea temperatures in the Bay of Bengal, marine life of the region is affected, the wild catch has drastically reduced, affecting the livelihoods of several coastal fisherfolk.

- Natural coastal scapes- beaches, sand dunes, tidal marshes, estuaries and mangroves are the city's natural shock absorbers, protecting it from storms, coastal erosion, salt-water intrusion and sea-level changes. They've all fallen prey to forms of market-driven coastal urbanization—including real estate, tourism, industrial development, and energy infrastructure which has rendered the coast vulnerable to natural and anthropogenic driven climate change.

- Housing pressure, from both local and incoming resident's results in increasing conversion of erstwhile water-tanks and wetlands (used to mitigate flood-drought risks) into housing plots. These areas prevent water flow into the down-stream tanks causing inundation of the whole region.

Key impacts & multipliers:

- With poor governance structures, disintegrated institutions working in silos and policies disconnected to stake-holders and ground-level realities, the local ecologies and indigenous communities are rendered further vulnerable in the aftermath rapid urbanization

- Patterns of uneven urbanization displace, encroach upon customary fishing communities' lands, threatening marine life with increased effluent discharge and other anthropogenic factors that drive climate change; create a low-wage labour force (from the displaced community) and expand the region's Carbon, water footprints. They only reinforce the socio-economic inequality and vulnerability as seen with the coastal fisherfolk of Karikattukuppam, Muttukadu nearly 15 years after relocation post the tsunami.

- Constant slum eviction and resettlement plans, often to gentrify urban areas or promote private real-estate development, or in the name of ecological restoration happen at the expense of low-income households; it promotes insecurity by repeatedly disrupting their lives and livelihoods

6.1.3 Neighbourhood Scale - Katchipattu

The smallest or the micro scale is defined at the level of a neighbourhood. Similar to the other two, we use the term "neighbourhood" as a conception of a spatial scale that is not defined by administrative boundaries. The closest administrative boundary at this spatial scale would be a village panchayat boundary or a ward in an urban setting. For this scale, the site we have chosen is a village located on the outskirts of a town called Sriperumbudur, the entire region bearing several markers of a peri-urban setting: large scale industries and industrial compounds adjacent to scattered towns and villages, gated communities and real estate development reflecting the demand for housing beyond the city, schools and colleges that have built campuses with limited land availability in the city, infrastructure provision along a gradient depending on the type of habitation (formal, informal) and socio-economic characteristics (income level, proximity to urban areas) and highways and roads crisis crossing villages and ecologies, a representation of global forces altering the local landscape.

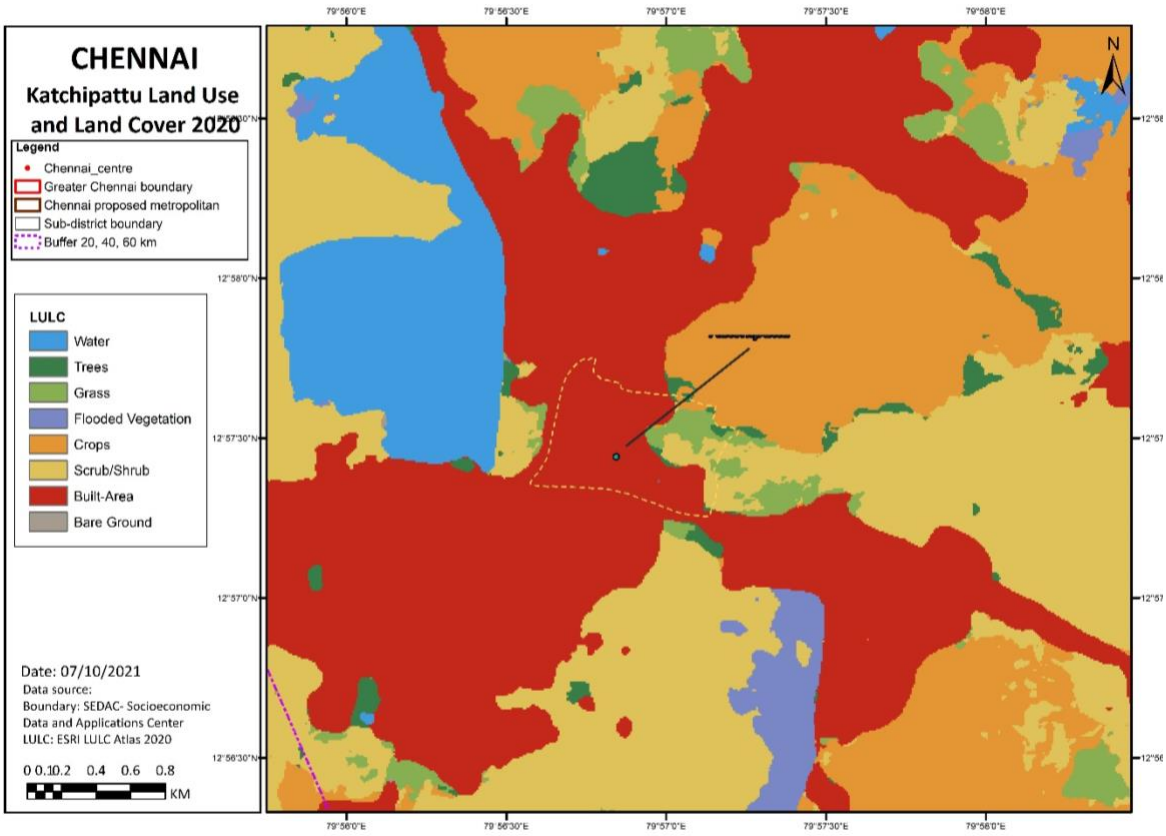

Figure 17: Katchipattu land-use and land cover 2020

Katchipattu is a hamlet located just outside the town of Sriperumbudur and is behind the Rajiv Gandhi memorial, a site that brings in a large number of tourists each year. It has a population of approximately 5120 of which the majority belong to a marginalised section of society (Dalit community that were previously referred to as "untouchables"). Agriculture and weaving were major occupations until a few years ago when residents were forced to shift to working in industries due to water related issues. Many were either labourers in agricultural lands nearby or were part of the larger weaving community in a region that was a popular weaving hub. By some estimates, a significant section of the village population — around 32%— is unemployed (Rajiv Gandhi National Institute of Youth Development, 2016).

In terms of infrastructure and natural resources, the village once had 9 ponds interlinked as per outlet of one feeding to another. Our earlier investigations in the village showed us that access to drinking water and sanitation facilities are major challenges. Many of these are dried up and abused to an extent, losing the connection between water and village. Today, the entire village (1876 households) relies on one tank for drinking water resulting in several villagers walking more than 5km to fetch this basic need. For domestic purposes, households rely on community taps linked to bore wells connecting 15 households per tap. With respect to sewerage and sanitation, the majority of households have access to a household toilet, although there are instances of open defecation especially near the ponds. This level of poor basic infrastructure and services are similarly witnessed in other villages and towns in the surrounding vicinity despite major economic developments that have taken place in this region.

Sriperumbudur, a town of about 40 Kms from the city centre of Chennai is somewhat of a poster child for the Chennai growth story. It has three Special Economic Zones (SEZs) housing global giants like Nokia and Saint Gobain which were set up to create thousands of jobs. These industrial parks and SEZs were envisaged to "help towns such as Sriperumbudur, Ranipet and Ambur to attract investments, create a skilled workforce and create an inclusive, sustainable and balanced regional growth" (TNUIFSL 2009).

Figure 18: SEZ in Sriperumbudur

(Source: Seekanpaul Arumainathan)

However, the emergence of these SEZ's and gated communities has led to increased fragmentation in access to basic services such as water and sanitation, transport and housing (Adelina et al 2015). This type of development envisaged specified effects will occur automatically through a "trickle down urbanisation" which have turned out to not be so (Cohelo and Vijayabaskar 2014). In Sriperumbudur, in contrast to accelerated growth, the town itself has not seen a considerable increase in quality of life or social development (Adelina et al 2015). This extends to hamlets such as Katchipattu that can hence be regarded as "bypassed" spaces. Accompanying this is rife real estate speculation that has significantly altered the landscape with land value skyrocketing around villages that were largely agrarian communities.

Our work in Katchipattu identified several problems faced by the community - the primary issue being unemployment. As in the case of other low-income settlements in the city, "company jobs' ' in large numbers within industrial areas located in Sriperumbudur remain an aspiration for young workers of Katchipattu village. This is because the youth, especially boys, face severe social stigma associated with their residential addresses. The women, on other hand, are willing to work, but require flexibility in taking care of their households and children while working.

Figure 19: Lack of basic services in Katchipattu

There are other problems that plague the region that exists just beyond the boundaries of this village. Many of the water bodies around here that are part of a larger system of connected tanks are in a state of neglect or disrepair (see ***Figure 19***). A large number of industries in the surrounding region discharge wastes illegally into surrounding water bodies, thus depleting the ecological fabric of the landscape and the ecosystem services potential that the rich ecology and biodiversity around here offer. Water is also a source of conflict in the region, as water is regularly transported from reservoirs and underground aquifers to city dwellers, depleting

the level of water available for local agricultural activities.

Climate Risks and Vulnerabilities

- micro-habitat and ecological systems of Katchipattu are compromised, both through long-term and short-term developments. Recently, we've seen how periodic floods and droughts have ravaged farmers in this part of the world. The unpredictability of the monsoons, especially the north east monsoon (on which farmers of this region depend) has caused extreme weather events in this region has rendered the community vulnerable.

- It's a combination of things that drove local people out of their primary livelihoods - failure of rains, vagaries were worsened by urbanisation and industrialisation in their neighbourhood; and there are many perturbing questions these vagaries raise for their future. With worsening climate impacts, it's harder for them to see a return back to the land. We are already beginning to see social disintegration taking place, as options dwindle. Like in so many other places, it's how climate change can worsen existing vulnerabilities or inequities, that makes bypass communities' tale a powerful one to tell.

Threat Multipliers

- The SEZ's, the Highway and the disruptions in natural drainage caused by these structures has caused a plethora of problems, predominantly centred around how local water-bodies that could act as tools to mitigate the flood and drought in this region have been subject to neglect and encroachment, worsening already marginalized communities' vulnerabilities.

- Unplanned urbanization and development of enclaves whose benefits bypass local communities but not the adverse impacts of environmental degradation. Lack of strong civil society, poor consultation owing to unequal representation of all stakeholders of the region have led to authorities' bull-dose their "development plans"

With agricultural opportunities dwindling and the newer job opportunities being taken over by migrant populations, Unemployment coupled with deprivation and marginalization has led to a lot of social unrest amongst the youth and angst against the outsiders taking over our space. It has led many to resort to illegal means to make quick money. It has further reduced their employability chances as the community on the whole is labelled notorious.

7 Conclusion

This deliverable has focused on providing a 'problem analysis' centered on peri-urban areas in the Chennai region, and relevant climate change risks and adaptation themes. The key emerging issues can be summarized as:

- Peri-urban areas within the Chennai region are diverse and represent a wide-ranging combination of landscapes, industries and communities. These areas are constantly evolving, buffeted by multiple drivers of change operating from global to local scales.

- The Chennai region's peri-urban areas are generators of climate risks, particularly water related disasters. These risks arise due to a combination of factors linked to themes including land use management and ongoing climate change. Approaches are needed to lessen the contribution that peri-urban areas make to generating and worsening climate change risks.

- Peri-urban areas within the Chennai region are also providers of climate change adaptation functions. These will become particularly significant in the coming decades as the climate continues to change and extreme weather events become more frequent and intense. A key example relates to opportunities to implement traditional water tank management measures, which is explored within this report. Other adaptation functions include the creation of food sovereign spaces to support local ecology conservation around water-bodies in a changing climate and offering livelihood opportunities to the landless local populations whilst ensuring their nutritional security. Strategies are needed to encourage and progress these opportunities.

The climate change risk and adaptation agenda clearly highlight the connections between peri-urban areas and urban areas. In the Chennai case study, most often involve heavy rainfall events crumbling of drainage infrastructure, generating inundation of low-lying areas (including those encroachments) and associated damage in urban areas. Recognizing and planning for these relationships via holistic and spatially appropriate (in the sense of water tanks restoration in this case) plans and strategies is needed. However, these arrangements are not currently in place in the Chennai region where administrative boundaries do not recognize biophysical realities and watershed-based approaches are only just starting to emerge D4.2b takes this exploration of the Chennai region forwards, and explores issues of adaptive governance and adaptive pathways, in the search for positive interactions between peri-urban and climate risk themes. Particular attention is paid to governance approaches that can engage stakeholders, collaboratively and across administrative boundaries, in the development, implementation and maintenance of water management measures in the wider Chennai region. Attention also needs to be paid to the issue of how Water management measures, and activities linked to their future maintenance, can be funded. It is these governance challenges, framed within the context of developing and implementing agro-ecology solutions that in turn drive better water bodies management measures, which provide a key focus of the Chennai region case study and form the basis of D4.2

8 ANNEX

8.1 Abbreviations

AR	Assessment Report
BC	Buckingham Canal
CCAR	Centre for Climate Change and Adaptation Research
CMA	Chennai Metropolitan Area
CMDA	Chennai Metropolitan Development Authority
ECR	East Coast Road
FUA's	Functional Urban Areas
GCC	Greater Chennai Corporation
GDP	Gross Domestic Products
IMD	India Metrological Department
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
NEMR	North eastern Monsoon Rainfall
OECD	Organization for Economic Co-operation and Development
OMR	Old Mahabalipuram Road
SEZ	Special Economic Zone
SIPCOT	State Industrial Promotion Corporation of Tamil Nadu
SLR	Sea Level Rise
TNSAPCC	Tamil Nadu State Action Plan for Climate Change
TNUIFSL	Tamil Nadu Urban Infrastructure Financial Services Limited

8.2 '20-questions' template

The application of the Peri-cene Framework to the Chennai region and its case study zones, is shown in four main stages. This is based on the 'peri-urban-climate-risk' cause-effect model: a fifth stage covers some of the 'synergistic model', i.e. the deeper and wider impacts and potential responses or pathways. Each stage has 4 topics, making a total of '20 questions', high level responses to which are outlined in the Table below.

		CITY-REGION	*ZONE A*	*ZONE B*	*ZONE C*
HEADINGS	*THEMES & TOPICS*	*ENNORE & THIRUVALLUR*	*INDUSTRIAL CORRIDOR*	*IT-CORRIDOR*	*HINTERLAND*
PERI-URBAN					
	OVERVIEW	*Heavy-industries complex along ecologically-degraded coastline and scattered towns and farmlands*	*Major highways criss-crossing industrial hubs and gated communities interspersed with farmlands and water bodies*	*Coastal-to-hinterland landscape with hi-tech industrial and entertainment/scenic corridors interspersed with fishing villages, salt pans and small-scale farming*	*Large watershed area with mid-sized cities, villages and farmlands and small-medium scale industries*
Spatial patterns	· *Urban direct expansion* · *Urban / rural fringe & gradient*	*Concentration of heavy industries and public infrastructure (port, power plants etc.) along the coast and medium-to-large scale farming to the west, mid-sized towns in early stages of urbanisation, fishing communities along the coast, middle to large scale farming*	*Planned industrial/manufacturing hubs (Special economic zones), colleges and residential schools close to major highways leaving Chennai, unplanned flats (gated communities) and plotted housing, interspersed with villages, mid-sized towns, farming land and water bodies*	*Hi-tech hubs and gated communities and villas interspersed with fishing villages, farms and waterbodies with two major roads running through*	
	· *Counter-urbanization effect*				
	· *Urban agglomeration effect*				
Functional dynamics	· *Population growth & housing*	*low to medium growth in population with small and medium-sized towns and villages*	*Exponential growth in population in last two decades owing to SEZs and educational institutions; mixed housing options (low, middle and upscale), agricultural land converted to housing plots and other public infrastructure; manufacturing hubs with global investors in automobile, engineering and chemical industries, small town economies and mixed farming; speculative real estate,*	*Upscale gated communities, beach homes, amusement parks juxtaposed with small coastal fishing villages transitioning into a post-industrial economy — IT hubs, electronics and information services alongside traditional livelihoods - fishing, salt pan work and recent hobby cultures - eg: horticulture gardens Mid-to-high population growth, speculative real estate development, hostels for IT workers, slum resettlement colonies and social housing schemes, fishing hamlets*	
	· *Technology & infrastructure*	*heavy-industries (petrochemicals, fertilisers), power plants and port dominate coastal strip; mostly rural and small-town infrastructure inland*			
	· *Economy & employment*	*mix of industrial, farming and local livelihoods*			
	· *Real estate & markets*				
Social-eco dynamics	· *Social demographics & lifestyle*	*rural, small town cultures inland; disenchanted communities closer to urban coastal strip, losing livelihoods and ecologies to industrial heavyweights; sensitive coastal/delta ecology, thriving large-scale farming/paddy cultivation, protected forest areas; plans for economic boost in the region with industrial hubs*	*very mixed - ranging from rural to upper-middle class lifestyles with global aspirations, income security, education, proximity to basic services etc; farming landscape with intricate network of connected water bodies in different levels of decline due to planned and unplanned changes in landscape*	*Middle and upper-middle class lifestyles interspersed with large-scale slum resettlement complexes : with complex ecologies - backwater lagoons, marshes and wetlands; loss of casuarina groves and wetlands Fragmented enclaves, modern aspirations,*	
	· *Environment & resources*				
	· *Policy & governance*				
	· *Culture & ethics*				

Global-local dynamics	· *Internal structures* · *external interactions* · *power dynamics* · *challenges & conflicts*	*high level of inequality, limited options for upward mobility, port and industries connect region to global economies, large-scale farmers include affluent classes from neighbouring state*	*undercurrent tensions between local, global and governing bodies in the region over shared resources (land, water, employment opportunities) resulting in pastiche of formal and informal processes, new hierarchies; planned hub-and-spoke model through well-connecter corridors to the city failed to take off but resulted in corridor-centric growth*	*The IT Corridor was developed as a high-investment corridor, "future of the city", ECR transitions from weekend getaway to attracting high-end residential real estate; Lots of global traffic owing to IT and electronics investments, expat communities; multiple ecosystems at risk from surge in populations in the past 2 decades*	

CLIMATE RISK					
	OVERVIEW		fragmented	High-risk coastal infrastructure, floods, land/waterscape	
Climate change direct effects	· temperature, · precipitation, storm etc · coastal effects	Sea level rise, increase in extreme events - storm, storm surges	Extreme rainfall events triggering floods and droughts and subsequent impacts on land, biodiversity	Extreme rainfall events, drought, sea level rise	
Climate direct hazards & impacts	· wildfire, heatwave, drought, · flood, storm, cyclone · landslide, sea incursion etc,	land lost to sea level rise, coastal erosion, agricultural lands lost to fluctuating extremes	degraded water bodies leading to floods.waterlogging	degraded water bodies leading to floods.waterlogging, gradual sea level rise and storm surge-risk	
Indirect hazards & nexus effects	· water resources · farming & forestry · energy & resources · ecosystems & microclimates · critical infrastructure	two major reservoirs, a river that drains into the Bay of Bengal and other water bodies that dot the landscape; medium to large-scale farming, protected forest areas	complex waterscape - connected waterbodies of different sizes, rivers, reservoirs that feed the city; small to medium-scale farming still practised but in decline owing to changing lands and rainfall patterns;	degraded ecologies, polluted water bodies and channels, coastal risks — impacts on indigenous livelihoods	
Peri-urban impacts on climate	· CO2 emissions from energy · GHG emissions from land-use · Land-use & forestry change · Carbon storage				

VULNERABILITY					
	OVERVIEW	urban eco-social-economic mix in some areas has growing vulnerability		Rapid urbanisation leading to fragmented landscapes coastal infrastructure risk and loss of livelihoods	
Physical sensitivity & capacity	· Soil & vegetation	coast - deltaic/coastal region heavily degraded from industrial activity; inland - fertile soils along river subject to flooding	land affected by changing rainfall patterns and land-use patterns; west-to-east gentle slope that allows water to flow from one waterbody to another; mixed land-use	Low-lying brackish water and freshwater bodies, dry tropical scrub, mixed land-use	
	· Topography & stability				
	· Settlement form & structure				
Techno-economic capacity	· technical & infrastructure	large-scale infrastructure subject to risk from SLR and storm surges, coastal erosion	industries susceptible to fluctuations in water availability; risk from floods - parts of region heavily affected during 2015 floods leading to loss of lives, livelihoods and economic activity	Speculative developments leading to encroached water bodies and wetlands	
	· Markets & value effects				
	· Employment & livelihoods				
Eco-social-cultural capacity	· Affluence / deprivation	varying levels of affluence amongst farming communities; differences in affluence between inland and coastal fishing communities that range from small boats to large-scale trawlers; ignored part of city with local rebel groups and cultures amongst the youth, highly vulnerable communities	Fringe villages and towns adjacent to water bodies at higher levels of risk from flooding; gated communities and planned housing also at risk but lesser exposure to loss of livelihoods and can access bank savings (some contingency measures)		
	· Education / communication				
	· Cultural issues				
Governance adaptive capacity	· Local government	mixed access to infrastructure with many communities deprived of basic access to services	Most new housing projects sold on the promise of proximity and access to services, emergency care, schools etc but isolated during the floods of 2015; resilience to disasters is a mixed picture, can depend on social capital and other related factors	fragmented local governance, complex	fragmented local governance
	· Public services & infrastructure				
	· Emergency services				
	· Civil & community				

GOVERNANCE					
	OVERVIEW				
Formal government & planning	· Spatial planning green belt etc	Quasi-government arrangements with industries, limited overview and regulation; mostly panchayat and local governance structures since there are many villages and small towns in this region	SEZ act allowed large-scale conversion of land with many layers of informality built into it; enforcement and extent of pollution control on industries unclear with many polluted water bodies and ecosystems; rampant real estate speculation, plotted developments across the region	Challenges constitute regulating and provision of basic services like sewage disposal and clean drinking water as it contains zones which are amongst the last few added to Chennai municipal boundaries; created pockets of large slum resettlement housing amidst gated communities and hostel dwellings	
	· Housing policy				
	· Infrastructure development				
Adaptive governance & institutions	· Public sector	protests and activism particularly around the plight of fishermen livelihoods, climate change and polluting the ocean	awareness of importance of water bodies amongst farmers leading to local protests, however limited mobilisation of local groups; NGO's working on conservation of water bodies especially post-floods in critically affected areas	Rise of new-age farmers, restaurants with locally-grown food, small-scale horticulture and hobby gardening centres creating niche clienteles and simultaneously new imaginations around environmental awareness and conservation - mostly individuals or small citizen groups	
	· Private sector				
	· Civic sector				
	· Citizens etc				
Informal governance & livelihood	· Informal land-use, settlements		consistent conversion of land from agricultural to industrial, commercial, housing etc. complex web of land brokers, real-estate investors, local political heavyweights enabling this conversion process	large tracts of land on lease to individuals which have been rented out to tenants, farmers, salt pans etc. SEZ's have separate arrangements with firms that have set up offices within these planned areas	
	· Corruption & nepotism				
	· Social innovation & enterprise				
System resilience & intelligence	· Social learning & collaboration		pockets of civil society action and local innovation could trigger pathways of transformation	potential for new-age farmers and environmentally-conscious to create pockets of resilience if they work together; small fishing hamlets and farming communities possess varying levels of social capital	
	· Social co-creation & mobilization potential				
	· System transformation potential				

SYNERGISTICS					

	OVERVIEW	from the world's first industrial city-region to the first post-industrial eco-region	Growing pressure on fragile landscapes & settlements: potential for socio-eco-resilience	potential new forms of eco-urban form & design, in new forms of community	Can a new eco-social order emerge?
Systems / syndromes (present baselines)	Main cross-cutting issues: e.g. . Airport / port cities: . Rural livelihoods: . Informal development	Port and heavy-industry cluster/rural livelihoods	special economic zones/rapid urbanisation	rapid-growth corridor/IT/electronics/service economy	Commuter settlement structure increases vulnerability to climate change
Scenarios (future possibilities)	Critical themes: (STEEP): e.g. . Social cohesion declines . AI / IOT emerges . Climate change accelerates	Climate change accelerates sea level rise, storm surge: complete loss of habitat and fishing communities/traditions Industry adopts high-risk infrastructure social and ecological breakdown	breakdown of fragile ecosystems unable to cope with climatic stress	impacts of climate change felt across the landscape, further breakdown of social cohesion, isolated communities	social divisions & exclusions multiply up
Synergies (future ideas, opportunities)	Potential ideas, connections, opportunities	synergies around climate activism and youth rebellion in the region challenging vested interests, reclaiming local livelihoods	Synergies of ecosystems & social systems: new semi-rural livelihoods: digital solution to fringe location	synergies of alternative eco-socio-economic models - tourism, nature trails, small agricultural cooperatives, revival of local ecologies	Synergies of agri-landscape & socio-economic landscape
Strategies (present pathways, actions)	Goals, objectives, targets for ways forward.	using moments of crisis to dial up activism in the region; expanding and exploiting connections with fishermen from other parts and even other states; ensure guided urbanisation (learnings from other regions) with ample focus on landscape and ecosystems	integrated adaptive upland landscapes: agro-forestry & eco-social innovation: innovative urban / building design for unstable & high risk locations	regional/landcape planning and monitoring bodies, local resilience enhanced through ecosystems stewardship and smalls-scale economies	Integrated adaptive lowland per-urban, with regenerative adaptive agriculture & ecosystems stewardship

8.3 References

A Arivudai Nambi et al., "Building Urban Resilience," n.d., 36.

Adelina, C. et al (November 9 - 21, 2015). Peri-urban Dynamics and Sustainability in Chennai: the Case of Sriperumbudur. N-AERUS XVI, 2019: Who wins and who loses. Dortmund, Germany.

"[Commentary] Looking beyond the Chennai City, at the Chennai Watershed," Mongabay-India, April 16, 2019, https://india.mongabay.com/2019/04/commentary-looking-beyond-the-chennai-city-at-the-chennai-watershed/.

"Farmers Blamed for Depleting Groundwater," The New Indian Express, accessed December 7, 2021, https://www.newindianexpress.com/cities/chennai/2015/aug/06/Farmers-Blamed-for-Depleting-Groundwater-795400.html.

"Over 30% Chennai Coast Shrinking Due to Sea Erosion: Study," The Times of India, July 27, 2018, https://timesofindia.indiatimes.com/city/chennai/over-30-city-coast-shrinking-due-to-sea-erosion-study/articleshow/65155838.cms.

"Seawater Intrusion Seen North of City - The Hindu," accessed December 5, 2021, https://www.thehindu.com/news/cities/chennai/seawater-intrusion-seen-north-of-city/article30437575.ece.

"Shrinking Wetlands, Green Cover Have Exposed Chennai to Climate Risks," The News Minute, October 23, 2017, https://www.thenewsminute.com/article/shrinking-wetlands-green-cover-have-exposed-chennai-climate-risks-70444.

Aithal, B. H., & Ramachandra, T. V. (2016). Visualization of urban growth pattern in Chennai using Geoinformatics and spatial metrics. Journal of the Indian Society of Remote Sensing, 44(4), 617–633. https://doi.org/10.1007/s12524-015-0482-0

Athira, T., & Agilan, V. (2020). Impact of climate change on rainfall over Chennai. IOP Conference Series: Earth and Environmental Science, 491(1), 012008. https://doi.org/10.1088/1755-1315/491/1/012008.

Bal, P. K., Ramachandran, A., Geetha, R., Bhaskaran, B., Thirumurugan, P., Indumathi, J., & Jayanthi, N. (2015). Climate change projections for Tamil Nadu, India: Deriving high-resolution climate data by a downscaling approach using precis. Theoretical and Applied Climatology, 123(3-4), 523–535. https://doi.org/10.1007/s00704-014-1367-9.

Bhavani Prabhakar, "Can Buckingham Canal Acquire New Meaning for Chennaites?," Citizen Matters, Chennai (blog), July 3, 2017, https://chennai.citizenmatters.in/new-research-on-buckingham-canal-relevance-for-chennai-2279.

Brookings Institute. Global Metro Monitor, 2015. Retrieved from: https://www.brookings.edu/research/global-metro-monitor/.

Byravan, S., Rajan, S. C., & Rangarajan, R. (2010). Sea level rise: Impact on major infrastructure, land and ecosystems along the Tamil Nadu Coast. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2195874.

Census of India 2011. District Census Handbook. Village and Town Wise Primary Census Abstract (PCA).Directorate of Census Operations Tamil Nadu.

Chapter 4: Climate Change Risk and vulnerability assessment. TNSAPCC. (2017). Retrieved December 10, 2021, from https://www.environment.tn.gov.in/Document/tnsapcc/Chapter%204.pdf.

Chennai Metropolitan Development Authority (CMDA).(2008).Second Master Plan for Chennai 2026. Government of Tamil Nadu.

Chennai Resilience Centre.(2019). Resilience Chennai Strategy. Retrieved from: https://resilientchennai.com/wp-content/uploads/2019/07/Resilience-Strategy_20190703.pdf.

D. Boyer, J. Sarkar, and A. Ramaswami, "Diets, Food Miles, and Environmental Sustainability of Urban Food Systems: Analysis of Nine Indian Cities," Earth's Future 7, no. 8 (2019): 911–22, https://doi.org/10.1029/2018EF001048.

Dash, S. K., & Mamgain, A. (2011). Changes in the frequency of different categories of temperature extremes in India. Journal of Applied Meteorology and Climatology, 50(9), 1842–1858. https://doi.org/10.1175/2011jamc2687.1.

De, U. S., Rajiv Kumar Dube, and GS Prakasa Rao. "Extreme weather events over India in the last 100 years." J. Ind. Geophys. Union 9.3 (2005): 173-187.

De, U. S., Singh, G. P., & Rase, D. M. (2013). Urban flooding in recent decades in four mega cities of India. Retrieved December 8, 2021, from http://iguonline.in/journal/Archives/17-2/4usde.pdf.

Demographia World Urban Areas. Demographia. (2021, June 1). Retrieved December 8, 2021, from http://www.demographia.com/db-worldua.pdf.

Diwakar, P. (2021). Spaces at Risk. Critical Disaster Studies, 97.

GUHATHAKURTA, P., SREEJITH, O. P., & MENON, P. A. (2011). Impact of climate change on extreme rainfall events and flood risk in India. Journal of Earth System Science, 120(3), 359–373. https://doi.org/10.1007/s12040-011-0082-5

Gupta, A. K., & Nair, S. S. (2011). Urban floods in Bangalore and Chennai: risk management challenges and lessons for sustainable urban ecology. Current Science, 100(11), 1638–1645. http://www.jstor.org/stable/24077767

Hall, A. (2014, December 19). Projecting regional change.science.org. Retrieved December 11, 2021, from https://www.science.org/doi/10.1126/science.aaa0629.

Homm, Sebastian & Bohle, Hans-Georg. (2012). "India's Shenzhen" – A miracle? Critical reflections on New Economic Geography, with empirical evidence from peri-urban Chennai. Erdkunde. 66. 281-294. 10.2307/41759100.

Jeganathan, A., Andimuthu, R., & Kandasamy, P. (2021). Challenges in Chennai City to cope with changing climate. European Journal of Climate Change, 3(1), 33–43. https://doi.org/10.34154/2021-ejcc-0017/euraass.

K. R. Sperber and H. Annamalai, "Interannual Variability of the Annual Cycle of Monsoon Rainfall and Projections of Future Climate" 2016 (December 1, 2016): A22D-02, https://ui.adsabs.harvard.edu/abs/2016AGUFM.A22D..02S.

Kotkin, J. (2012, July 11). The next decade's fastest-growing cities. Forbes. Retrieved December 1, 2021, from https://www.forbes.com/2010/10/07/cities-china-chicago-opinions-columnists-joel-kotkin_slide.html?sh=354028676 2bf.

Krishnamurthy, L., Vecchi, G. A., Yang, X., van der Wiel, K., Balaji, V., Kapnick, S. B., Jia, L., Zeng, F., Paffendorf, K., & Underwood, S. (2018). Causes and probability of occurrence of extreme precipitation events like Chennai 2015. Journal of Climate, 31(10), 3831–3848. https://doi.org/10.1175/jcli-d-17-0302.1.

Krishnamurthy, R., & Desouza, K. C. (2015). Chennai, India. Cities, 42, 118–129. https://doi.org/10.1016/j.cities.2014.09.004.

Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., & Chakraborty, S. (2020). Assessment of Climate Change over the Indian Region. Springer Open.

Malakar, K and Mishra, T (2017), "Assessing Socio-Economic Vulnerability to Climate Change: A City-Level Index-Based Approach", Climate and Development, 9(4), pp. 348–363.

Manohar, L. & K.T. Muthaiah. Towards resilience in Chennai. International Planning History Society Proceedings (Floods and Infrastructure), vol. 17, No. 3 (2016):252-260.

Mishra, A. (2014). Temperature rise and trend of cyclones over the eastern coastal region of India. Journal of Earth Science & Climatic Change, 05(09). https://doi.org/10.4172/2157-7617.1000227.

Pallavi Tiwari.(2019). Dynamics of Peri Urban areas of Indian Cities.International Journal of Scientific & Engineering Research Volume 10.

Praveen, D., Ramachandran, A., Jaganathan, R., & E Krishnaveni and K Palanivelu. (2016, February 13). Projecting droughts in the purview of climate change under RCP 4.5 for the coastal districts of South India. SRS Journal. Retrieved December 14, 2021, from https://indjst.org/articles/projecting-droughts-in-the-purview-of-climate-change-under-rcp-45-for-the-coastal-districts-of-south-india.

Prince Frederick, "On World Oceans Day, Naturalists Unveil Chennai's Marine Biodiversity," The Hindu, June 8, 2021, sec. Society, https://www.thehindu.com/society/on-world-oceans-day-naturalists-unveil-chennais-marine-biodiversity/article34758946.ece.

Rajeevan, M., Unnikrishnan, C. K., Bhate, J., Niranjan Kumar, K., & Sreekala, P. P. (2012). Northeast monsoon over India: Variability and prediction. Meteorological Applications, 19(2), 226–236. https://doi.org/10.1002/met.1322.

Rajkumar, R., Shaijumon, C. S., Gopakumar, B., & Gopalakrishnan, D. (2021). Recent patterns of extreme temperature events over Tamil Nadu, India. Climate Research, 84, 75–95. https://doi.org/10.3354/cr01655.

Ramachandran, A., Saleem Khan, A., Palanivelu, K., Prasannavenkatesh, R., & Jayanthi, N. (2017). Projection of climate change-induced sea-level rise for the coasts of Tamil Nadu and Puducherry, India using SimCLIM: A first step towards planning adaptation policies. Journal of Coastal Conservation, 21(6), 731–742. https://doi.org/10.1007/s11852-017-0532-6.

Roy, P. et al. (2018). Chennai: Urban Visions, Okapi Research and Advisory, Fields of View and Centre for Urbanisation, Buildings and Environment, IIT Madras, Funded by Tamil Nadu State Land Use Research Board, Cholamandalam Finance and Tata Trusts.

Shankar, D., Rehman, N. A., Sankar, S., Banu, A., & Sandhya, M. (2020). Chennai Water Crisis—Data Analysis. Intelligent Computing and Applications, 617–627. https://doi.org/10.1007/978-981-15-5566-4_56.

Tamil Nadu State Action Plan for Climate Change. (2017). OBSERVED CLIMATE AND CLIMATE CHANGE PROJECTIONS. Retrieved December 10, 2021, from https://www.forests.tn.gov.in/tnforest/app/webroot/img/document/Tamilnadu-Publications/2.pdf.

Verisk Maplecroft (2021), Environmental Risk Outlook 2021.

Wang, Y., He, C., & Li, T. (2018). Decadal change in the relationship between East Asian spring circulation and ENSO: Is it modulated by Pacific Decadal Oscillation? International Journal of Climatology, 39(1), 172–187. https://doi.org/10.1002/joc.5793

WMO. 2021. "Weather-related disasters increase over past 50 years, causing more damage but fewer deaths." World Meteorological Organization |. https://public.wmo.int/en/media/press-release/weather-related-disasters-increase-over-past-50-years-causing-more-damage-fewer.

Yaduvanshi, A., Nkemelang, T., Bendapudi, R., & New, M. (2021). Temperature and rainfall extremes change under current and future global warming levels across Indian climate zones. Weather and Climate Extremes,

31, 100291. https://doi.org/10.1016/j.wace.2020.100291