CLIMATE RISK ASSESSMENT AND ADAPTATION PLAN OF TAMIL NADU

WATER RESOURCES

Under

CLIMATE STUDIO

REPORT

2024

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

Prepared by
Centre for Climate Change and Disaster Management
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PREFACE

The Climate Risk Assessment and Adaptation Plan for Tamil Nadu – Water Resources is a testament to Tamil Nadu state unwavering commitment to addressing the urgent challenges posed by climate change with a particular focus on preserving our vital water resources. In a world where climate uncertainties continue to grow, it is essential that we act decisively and with foresight, ensuring that future generations inherit a sustainable and secure environment.

This plan is the result of a thorough and collaborative effort that brings together scientific research, data-driven analysis and the invaluable insights of various stakeholders. It captures the current and projected climate trends impacting Tamil Nadu water systems, offering a comprehensive understanding of the risks we face, such as droughts, floods and shifting rainfall patterns. Importantly, this document also lays the foundation for robust and forward-looking adaptation strategies, ensuring that our water management systems and river basins are equipped to withstand these challenges.

The State of Tamil Nadu, with its complex and diverse climatic zones, requires tailored strategies to address the unique vulnerabilities of each of its 17 river basins. This plan meticulously addresses these nuances, offering a clear and actionable path toward safeguarding our water resources. From strengthening water infrastructure to fostering community-driven adaptation initiatives, the recommendations outlined here represent a blueprint for a climate resilient future.

As we continue to face the consequences of a changing climate, the urgency to act is ever more apparent. This document serves not only as an assessment of risks but as a roadmap for how we can turn those challenges into opportunities—opportunities to innovate, collaborate and lead the way toward a climate-resilient Tamil Nadu.

Let us move forward with resolve and determination, committed to the task of building a future that is safe, sustainable and prosperous for every citizen of Tamil Nadu.

(P.Senthilkumar)

Thiru.A.R. Rahul Nadh I.A.S.,
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FOREWORD

In the face of an ever-changing climate, the management and preservation of water resources emerge as a major concern across the globe. As the impacts of climate change continue to unfold, it is imperative that we must equip ourselves with the knowledge, foresight and resilience to safeguard our precious water resources.

The Climate Risk Assessment and Adaptation Plan presented in this document represents a crucial milestone in our journey towards building a climate-resilient future, especially for the State of Tamil Nadu. By comprehensively examining the intricate interplay between climate dynamics and water availability, this plan offers invaluable insights into the challenges and opportunities that lie ahead.

In particular, the significance of this report is its in-depth assessment of drought and flood risks across the 17 river basins of Tamil Nadu. By identifying vulnerable areas and assessing the potential impacts on water availability and ecosystems, this assessment lays the groundwork for targeted adaptation strategies tailored to the unique needs of each basin. From promoting water conservation and sustainable water management practices to enhancing infrastructure resilience and fostering community engagement, these strategies will bring transformative changes.

I commend the dedication, expertise, and collaborative spirit of all those involved in the development of this plan. It is through such collective efforts that we can overcome the challenges posed by climate change and chart a course towards a more resilient and water- secure future for Tamil Nadu. As we embark on the journey outlined in this plan, let us remain steadfast in our commitment to innovation, inclusivity, and sustainability.

I extend my sincere gratitude to Dr.P.Senthilkumar, I.A.S., Principal Secretary to the Government, Environment, Climate Change and Forests Department for his valuable guidance and unwavering support in the successful operationalization of the Climate Studio.

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

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

(A.R. Rahul Nadh)

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

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

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

EXECUTIVE SUMMARY

Climate change, primarily driven by human activities such as burning fossil fuels and deforestation, alters global climate patterns. This change results in shifts in precipitation patterns, temperatures, and extreme weather events, significantly impacting water resources. IPCC AR6 report underscored the challenges to water security posed by climate change, including threats to availability and water-related hazards such as floods and droughts. Achieving the targets of SDG-6 (To ensure availability and sustainable management of water and sanitation for all) is essential for promoting sustainable development, protecting ecosystems, reducing inequalities, and advancing human health and well-being. India faces significant challenges related to water resources, exacerbated by climate change, population growth, urbanisation, and unsustainable water management practices. Some critical aspects of the Indian scenario regarding water resources are water stress, groundwater depletion, monsoon variability, extreme weather events, and adaptation strategies. In the current climate crisis, assessing the impact of climate change on water resources is not just essential; it's the need of the hour. Understanding these effects is crucial for informed decision-making and sustainable management of most precious resources.

Climate Studio at CCCDM

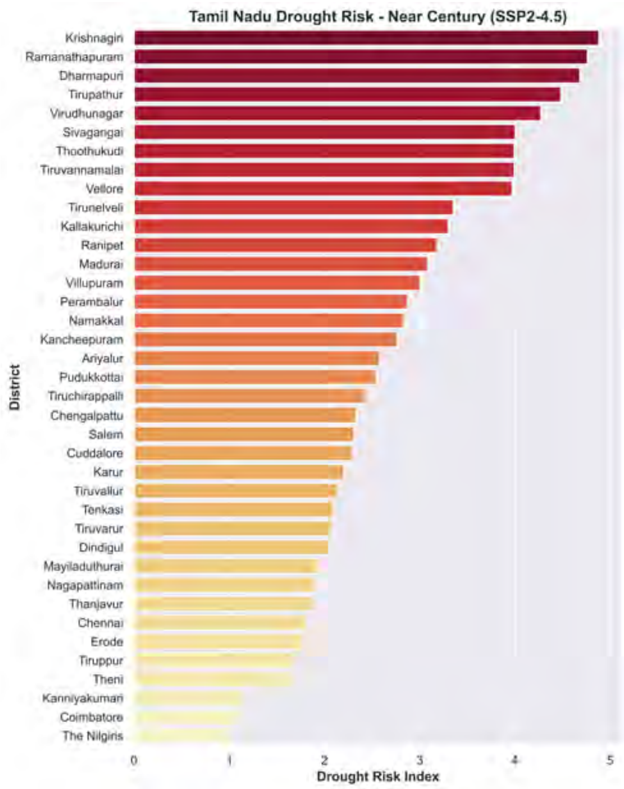
Embracing its commitment to the Nationally Determined Contribution (NDC), Tamil Nadu has emerged as a pioneer in developing adaptation strategies across sectors. Utilising the acclaimed IPCC framework on "Climate Change Risk Assessment," the Government of Tamil Nadu has established the 'Climate Studio' at the Centre for Climate Change and Disaster Management (CCCDM), Department of Civil Engineering, Anna University. This state-of-the-art facility, funded with Rs. 3.8 crores is equipped with high-performance computational resources and digital learning tools (financially supported by GIZ, Germany) to analyse global climate data at the cadastral level. The Climate Studio aims to provide updated high-resolution regional climate scenarios, assess climate change impacts on natural resources, develop multi-sectoral spatial information, and disseminate knowledge to stakeholders. Through capacity-building programs and workshops, over 250 sectoral officials and thousands of participants have been trained and sensitized, fostering a climate-resilient future for Tamil Nadu.

Water Resources Risk Assessment

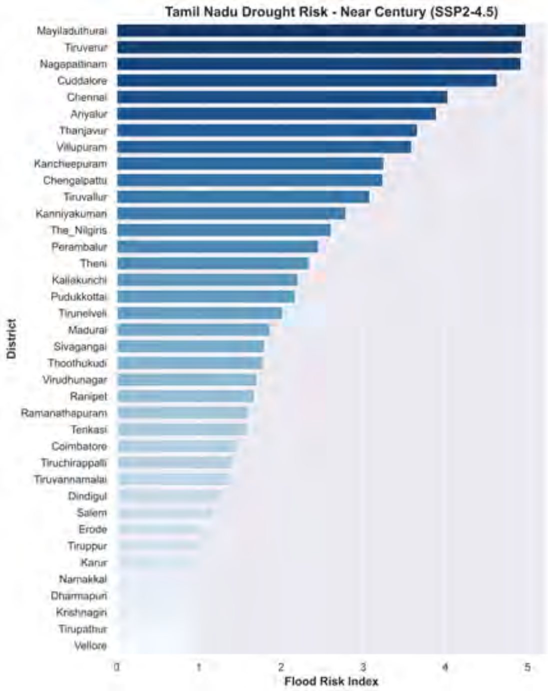
To have a clear sketch of the natural drainage system of Tamil Nadu at the river basin scale through the lens of climate change, each basin has been separately analysed and assessed through hydrological models as well as the IPCC risk framework from which the critical flood and drought risk basins were demarcated. The process-based hydrological model simulates hydrological components for the baseline and projected scenarios. The risk assessment is the combination of components such as hazard, vulnerability, and exposure, which means the inducing factors that are hazardous to the susceptible conditions prevailing over the place or thing. Therefore, this risk framework assesses the extent, intensity, frequency, and magnitude of flood and drought conditions in Tamil Nadu.

Flood and Drought prone areas of Tamil Nadu

The drought risk assessment has projected the magnitude and frequency of drought events to increase throughout the state. Over the next thirty years, drought events are expected to rise by 1.3 times. The districts of **Krishnagiri, Ramanathapuram, Dharmapuri, Tirupathur, and Virudhunagar may witness severe drought conditions approximately**



The flood risk assessment has projected the magnitude and frequency of climate extremes increasing in the future scenario in the coastal stretch. Coastal districts in Tamil Nadu, such as **Mayiladuthurai, Tiruvarur, Nagapattinam, Cuddalore, Chennai Ariyalur and Thanjavur** may witness frequent and intense rainfall events within shorter timeframes. Over the next thirty years, extreme rainfall events are expected to rise by 2.5 times, increasing the risk of severe flooding.



The overall flood risk of Tamil Nadu in terms of areal percentage has increased from 5.3% to 6.8%. Henceforth, to have a synergistic climate adaptation plan, the existing actions were sorted out for all the river basins that addressed flood and drought conditions. The degree to which an adaptation action is feasible and its possible extent have been considered for both the baseline conditions and future projected impacts in the water resources sector under IPCC AR6 climate scenarios.

Water Adaptation Actions

The adaptation measures identified were categorised according to the broad framework outlined by the IPCC, encompassing strategies such as

- **Rainwater harvesting,**
- **River/Canal restoration,**
- **Stormwater management**
- **Watershed management/ Catchment conservation**.

The identified actions were mapped based on the projected severity of droughts and floods in the basin. In addition to the existing practices, policymakers and stakeholders can implement the mapped actions to achieve the climate resilience of the basin. This comprehensive approach outlined in the plan underscores the importance of site-specific measures to effectively combat climate-related challenges in the region.

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Abbreviations

AR6	Assessment Report Six	LULC	Land Use Land Cover
BCM	Billion cubic metre	MC	Mid Century
CGWB	Central Groundwater Board	MCM	Million cubic metre
DEM	Digital Elevation Model	MFI	Modified Fournier Index
DHI	Drought Hazard Index	NC	Near Century
DRI	Drought Risk Index	NDVI	Normalized Difference Vegetation Index
DVI	Drought Vulnerability Index	PWD	Public Works Department
EC	End Century	R25	Number of heavy rainfall days above 25 mm
FHI	Flood Hazard Index	Rx1	Maximum 1-day rainfall amount
FRI	Flood Risk Index	SDI	Streamflow Drought Index
FVI	Flood Vulnerability Index	SDM	Statistical Downscaling Model
GDP	Gross Domestic Product	SPEI	Standardised Precipitation Evapotranspiration Index
GHG	Greenhouse gas	SRTM	Shuttle Radar Topography Mission
HRU	Hydrologic Response Unit	SSPs	Shared Socioeconomic Pathways
IMD	Indian Meteorological Department	SWAT	Soil and Water Assessment Tool
IPCC	Intergovernmental Panel on Climate Change	TMC	Thousand Million Cubic feet
ISRO	Indian Space Research Organization	WRD	Water Resources Department
NRSC	National Remote Sensing Centre	WRIS	Water Resource Information System

1. INTRODUCTION

Water is fundamental to all living organisms, and its security is essential in adapting and mitigating climate change. The recent increase in global warming due to anthropogenic activities affects the physical aspects of water security. Climate change affects critical hydrological cycle components such as precipitation, evapotranspiration, surface runoff, streamflow, and groundwater recharge. This departure in the hydrological cycle seriously impacts various sectors such as agriculture, energy, urban and peri-urban water security, and freshwater ecosystems.

Climate change projections show increased frequency, intensity, and duration of droughts in many regions, severely impacting water availability and agriculture (IPCC, 2021). Increased frequency and intensity of extreme weather events, including floods and storms, may damage water infrastructure and water quality degradation, affecting water availability and access for communities. Water scarcity and competition for water resources are expected to increase, particularly in areas with high population growth and limited water availability, leading to conflicts over water.

In the regional context, Extreme rainfall events and longer dry spells have been witnessed recently. The intensity of rainfall increased while the number of rainy days decreased in recent years; due to this dichotomy, the number of flood and drought events has risen in recent decades. Land use change has also accelerated in recent decades, and there is always a nexus between climate and land use change. Land use changes are key drivers of the loss and degradation of freshwater ecosystems. Demand for freshwater is anticipated to increase as most surface water bodies deteriorate due to overconsumption and pollutant contamination. As a result, the need for groundwater will be high. Increased precipitation intensity and paved surfaces alter the surface runoff, which decreases available rainfall augmentation. Water management strategies must address these complexities to ensure sustainable water resource management in the face of climate change.

According to the IPCC sixth assessment report (IPCC, 2021), the Asian region will likely experience more frequent and severe drought events in India's central and south-eastern parts. The report also indicates that extreme precipitation events, including flooding, are projected to increase in frequency and intensity across Asia, particularly in Southeast Asia.

1.1 State at Glance

The State of Tamil Nadu is situated in the southernmost part of the Indian Peninsula between the northern latitude of 8°05' and 13°35' and the eastern longitude of 76°15' and 80°20'. Tamil Nadu shares its border with the states of Kerala, Karnataka, Andhra Pradesh, and the union territory of Puducherry. In physiographical view, it is bounded by the Eastern Ghats on the north, by the Nilgiris and the Anamalai Hills on the west, by the Bay of Bengal on the east, by the Gulf of Mannar and the Palk Strait on the southeast, and by the Indian Ocean on the south. Significant parts of Tamil Nadu lie in the rain shadow region of the Western Ghats. Hence, Tamil Nadu does not benefit significantly from the Southwest Monsoon, which brings rainfall to significant parts of India. However, the State of Tamil Nadu has a substantial share of the Northeast Monsoon, where the state's agricultural cultivars depend on this post-monsoon period.

1.2 River Basins

River basins are essential natural resources that provide numerous socio-economic and ecological benefits to communities. However, they are vulnerable to the impacts of climate change, particularly concerning increased drought and flood risks. Assessing the potential effects of climate change on river basins is crucial for effective water resource management and adaptation planning.

The drainage system of Tamil Nadu can be grouped into 17 River Basins (127 sub-basins), most of which are water-stressed. Among the several rivers flowing through the state, the Cauvery River is the longest of all the rivers in Tamil Nadu. The total surface water potential of the State is 24,864 MCM. The State has 17 major river basins with 89 reservoirs and 41,948 tanks. The 17 River Basins Found in Tamil Nadu are Agniyar, Cauvery, Chennai, Gundar, Kallar, Kodaiyar, Nambiyar, Paravanar, Palar, Pambar & Kottakaraiyar, Parambikulam Aliyar Project (PAP), Pennaiyar, Tamiraparani, Varahanadhi, Vellar, Vaigai, Vaippar, and shown in Fig 1. Most rivers draining into Tamil Nadu originate from the Western and Eastern Ghats uplands.

Table 1 gives the name of the River Basins, its areal extent and surface water potential details. Among the 17 basins, the Cauvery River Catchment is the widest. Most of the surface water has already been tapped primarily for irrigation, which is the largest user. The total surface water potential of Tamil Nadu is shared by the tanks (40.7%), other states (30.6%), reservoirs (28.5%), and other storages (0.2%). The total surface water potential is higher in the Cauvery River basin (5,358 MCM), followed by the Palar River basin (1,393 MCM), Pennaiyar basin (1,319 MCM), and Chennai basin (1,062 MCM).

The total surface water potential of the State is 853 TMC (24160 MCM), including 261 TMC (7319 MCM) from neighbouring states. The surface water potential within the state resources is 592 TMC (16679 MCM) surface flow accounts for about half of the State’s total water potential. Most of the surface water has already been tapped primarily for irrigation, which is the largest user. The total surface water potential of Tamil Nadu is shared by the tanks (40.7%), other states (30.6%), reservoirs (28.5%), and other storages (0.2%).

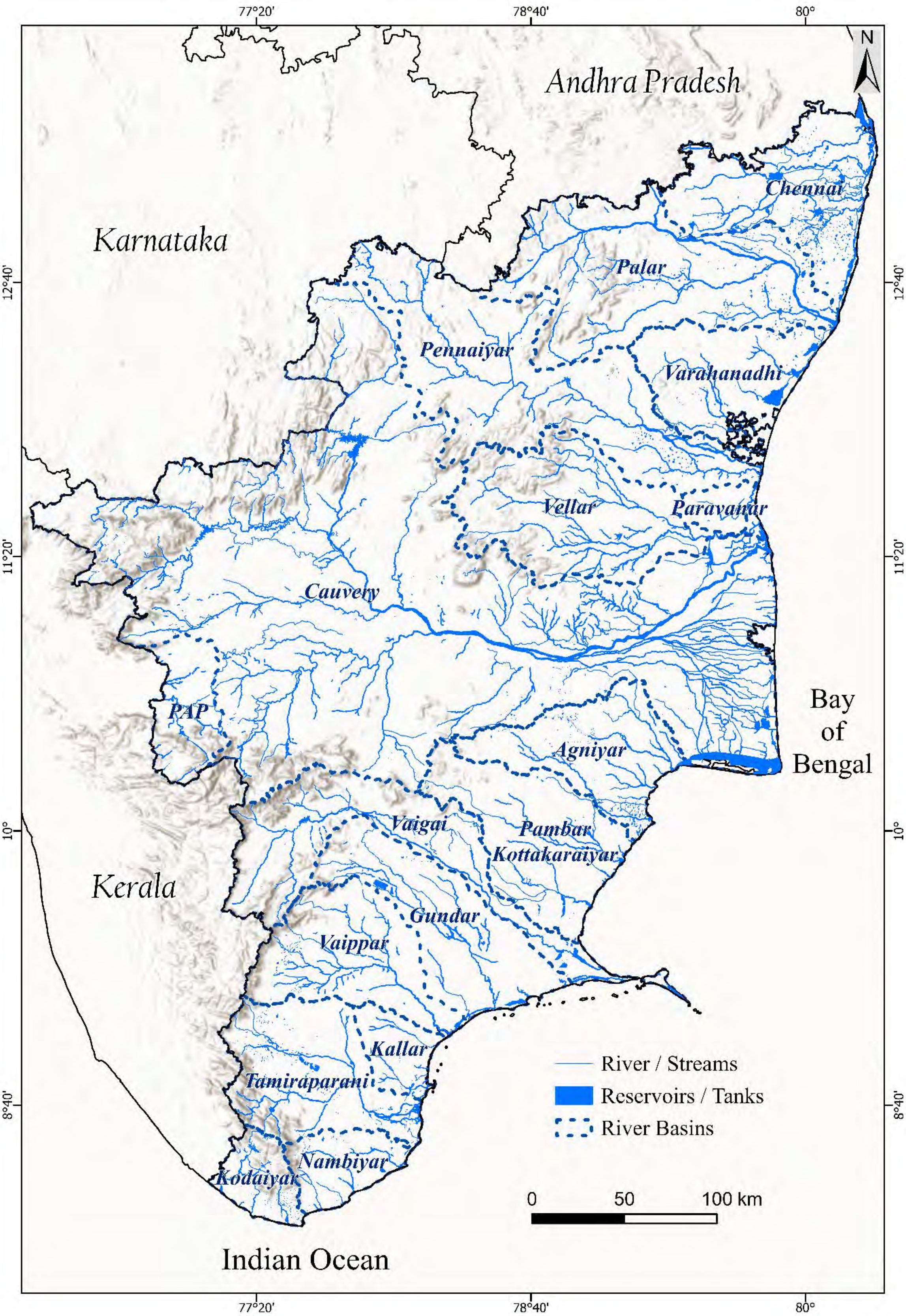


Fig. 1. River Basins of Tamil Nadu

Table 1. Tamil Nadu River Basins and its Surface Water Potential Details

Sl. No	River Basin	Area (km^2)	Surface Water Potential (MCM)
1	Agniyar	4702.13	637
2	Cauvery	47474.25	5358
3	Chennai	6123.11	1062
4	Gundar	5734.85	549
5	Kallar	1506.67	128
6	Kodaiyar	1618.87	916
7	Nambiyar	2000.75	203
8	Palar	10309.44	1393
9	Pambar Kottakaraiyar	5926.95	648
10	Parambikulam Aliyar Project (PAP)	2406.38	675
11	Paravanar	872.34	176
12	Pennaiyar	11375.56	1319
13	Tamiraparani	5717.21	883
14	Vaigai	6792.68	842
15	Vaippar	5320.17	715
16	Varahanadhi	4529.91	589
17	Vellar	7466.94	981

Source: Institute of Water Studies, WRD, Tamil Nadu (2018)

The total annual groundwater recharge of the state has been assessed as 21.11 BCM, and annual extractable groundwater resources as 19.09 BCM. The annual GroundWater Extraction is 14.43 BCM, and the Stage of GroundWater Extraction is 75.59 %. Out of 1166 assessment units (firkas), 360 units (30.87 %) have been categorised as 'Over Exploited', 78 units (6.69 %) as 'Critical', 231 units (19.81 %) as 'Semi-Critical', 463 units (39.71 %) as 'Safe' and 34 units (2.92 %) have been categorised as 'Saline'(CGWB,2022).

1.3 Overview of the Report

The water resource system of Tamil Nadu is intricately connected with the challenges posed by climate change. Adapting to the changing climate requires a comprehensive approach encompassing sustainable water resource management and conservation and integrating climate change considerations into planning and policy frameworks. By prioritising climate-resilient strategies, Tamil Nadu can enhance its water security, support sustainable development, and ensure the well-being of its people in the face of a changing climate.

In this context, examining how climate change affects Tamil Nadu's water resources in future climate projections is crucial. An effort has been made to comprehend its intricacies through the following steps:

- Development of hydrological models for the 17 River Basins of Tamil Nadu to simulate hydrological components under baseline (1985 - 2014) and future (2021 - 2050) SSP2-4.5 scenario.
- Evaluation of flood and drought risks across the 17 River Basins using the IPCC AR6 Risk framework to identify critical sub-basins.
- Development of appropriate adaptation strategies to address climate-related risks in future scenarios

2. TAMIL NADU CLIMATE PROFILE

Climate Change is “a change in the State of the climate that can be identified by changes in the mean and the variability of its properties and that persists for an extended period, typically decades or longer” (IPCC,2014). Anthropogenic climate change has been defined as “a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere (e.g., increase in greenhouse gases due to fossil fuel emissions) or surface characteristics (e.g., deforestation) and which is in addition to natural climate variability observed over comparable periods.”

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

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

The State receives most of its annual rainfall during October, November, and December (post-monsoon). It is contrary to the rest of the country, where the rainy season comprises the months of June, July, August, and September. The State is frequently subjected to extreme weather conditions, such as flooding in the coastal districts and severe droughts in the interior due to monsoon failure. This has an adverse effect on agricultural production. Drought, water depletion, soil erosion, seawater incursion, forest fire, species extinction and thermal discomfort are significant manifestations of climate change. Monsoon rains are the primary water source for irrigation, making its linkages with the agricultural sector very critical.

Since the last decade, the State has been facing a noticeably higher incidence of cyclonic events (Vardah 2016, Ockhi 2017 and Gaja 2018) and severe floods (2015 and 2017). This warrants immediate action to analyse and understand the current and future climate trends of the State. This Chapter dwells upon Tamil Nadu's historical climatic trends based on India Meteorological Data (IMD) data for 1985 – 2014 and future projections about the climate and related uncertainties.

2.1 Temperature

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

Maximum Temperature: It can be seen that the mean annual maximum temperature for Tamil Nadu is 32.5°C, with a range varying from 29.5°C to 33.4°C. It is also observed that for annual maximum temperature, the highest value is attained for the districts, viz., Chennai, Kancheepuram, Chengalpattu, Thiruvallur, Tiruvarur and Cuddalore, while the lowest value is attained for the Nilgiris district of Tamil Nadu.

Minimum Temperature: Mean annual minimum temperature is 22.6°C, varying from 19.4°C to 24.1°C. It is also seen that for annual minimum temperature, the highest value is attained for the district Tiruvarur, followed by Cuddalore, Mayiladuthurai and Nagapattinam, districts while the lowest value is attained for the district, Nilgiris: lying in Hilly Zone, for the period 1985-2014 (30 years). The annual average maximum and minimum temperature spatial variation of Tamil Nadu for the baseline period is given in Fig 2.

Maximum Temperature **Minimum Temperature**

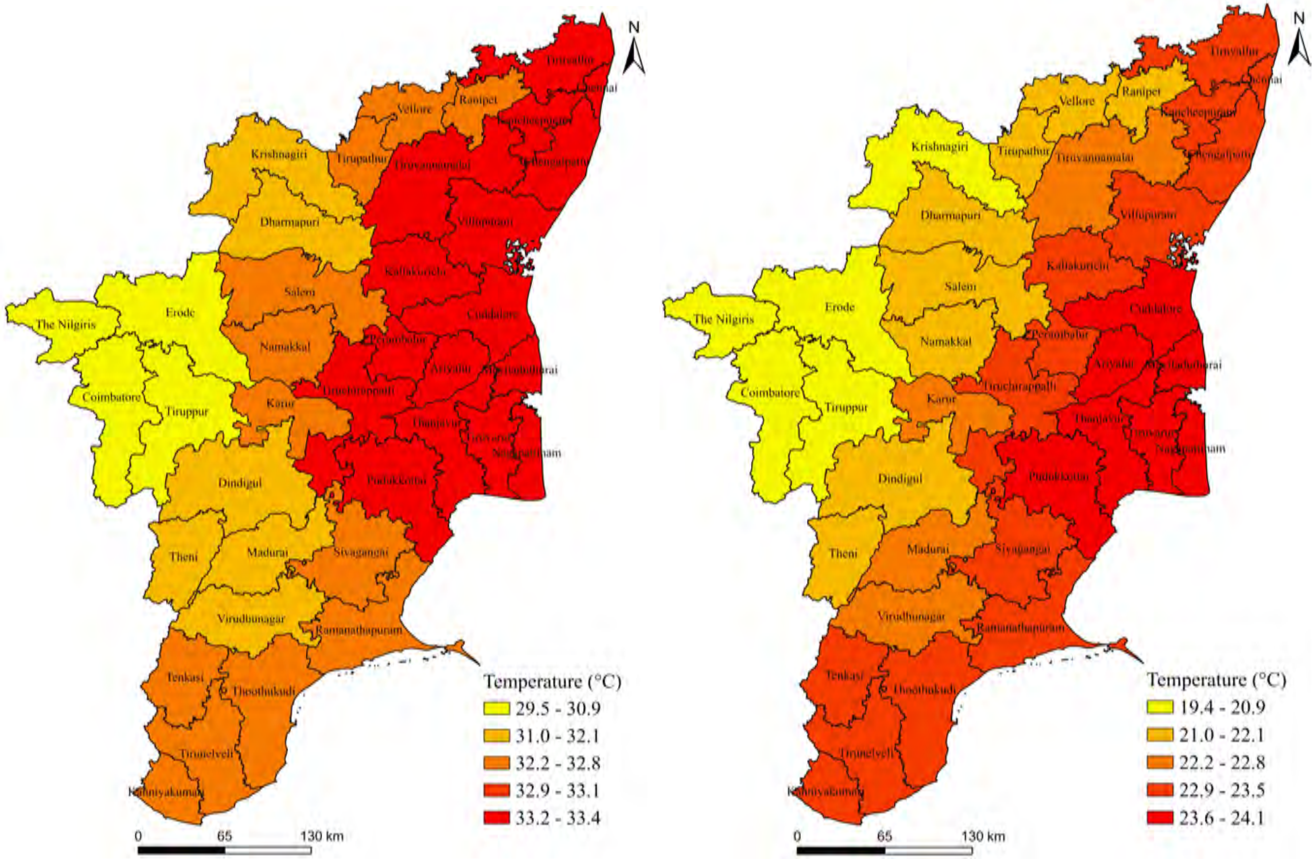


Fig. 2 Spatial Variation in Observed Annual Maximum and Minimum Temperature of Tamil Nadu (1985-2014)

2.2 Rainfall

The average annual rainfall of Tamil Nadu is 987 mm, within the district values ranging from 708 mm to 1406 mm over 30 years (1985-2014). As depicted in Fig 3, among all districts, The Nilgiris, Thiruvallur, Chennai, Kancheepuram, Chengalpattu, Cuddalore, Tiruvarur, Mayiladuthurai, and Nagapattinam receive the maximum average annual rainfall. In contrast, Erode, Tiruppur, Karur, Tenkasi, Thoothukudi, and Tirunelveli receive the lowest annual average rainfall.

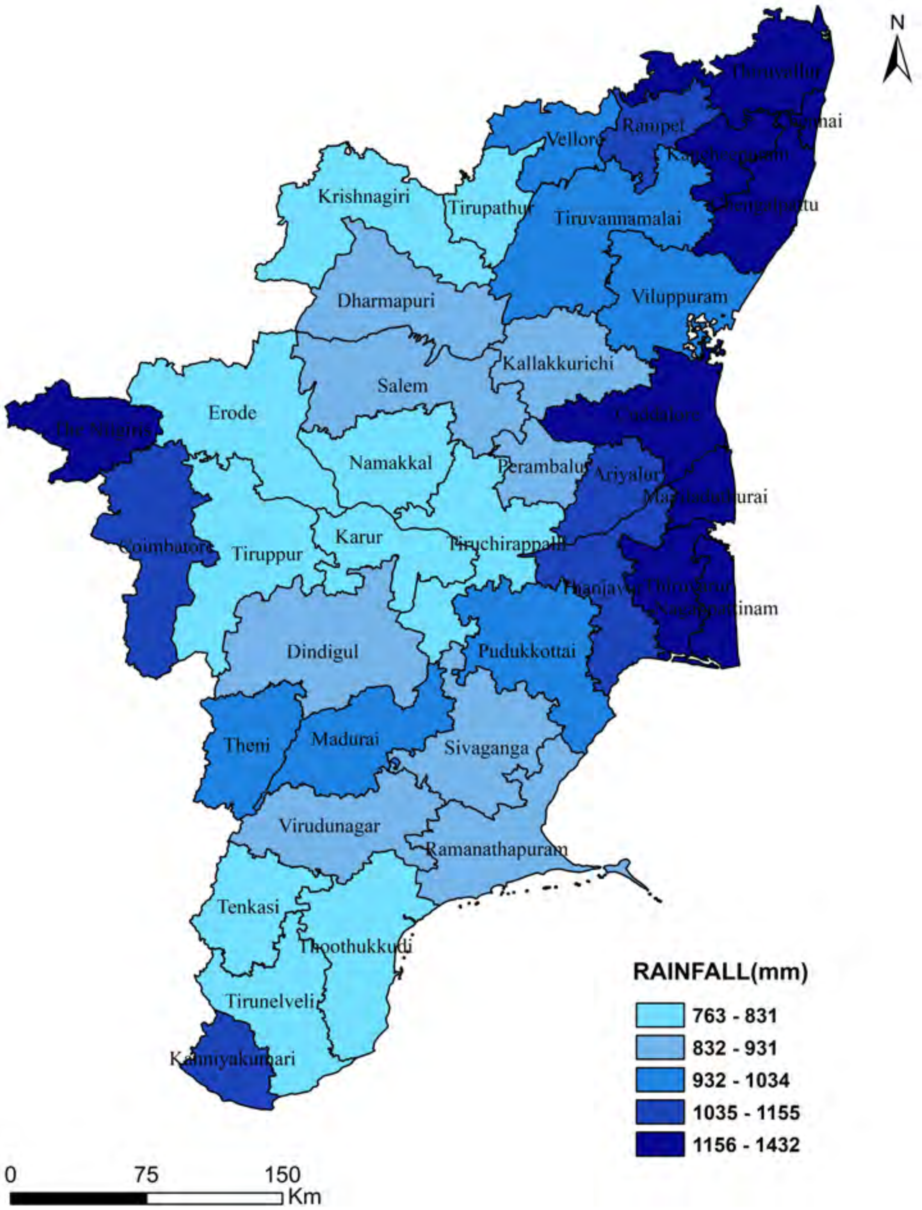


Fig. 3 Spatial Variation in Observed Annual Rainfall of Tamil Nadu (1985-2014)

2.3 Climate Change Scenario

Climate change is the long-term alteration in Earth's climate patterns, primarily caused by human activities. It is driven by releasing greenhouse gases (GHGs) into the atmosphere by burning fossil fuels. This process, known as global warming, leads to changes in temperature, precipitation, wind patterns, and other factors that affect the planet's climate system. The consequences of climate change are wide-ranging, impacting ecosystems, agriculture, water resources, and human health. Addressing climate change requires global cooperation, mitigation of GHG emissions, and adaptation measures to minimise its adverse effects. The temperature anomaly of Tamil Nadu is shown in Fig 4.

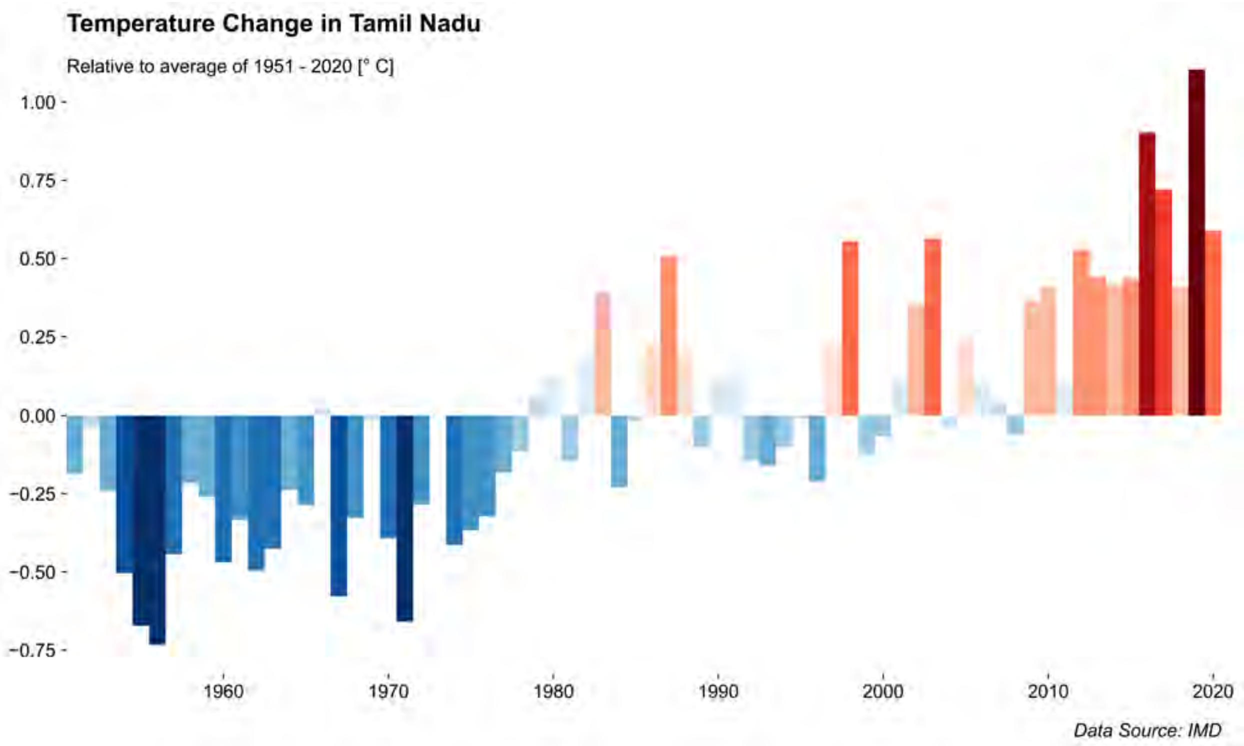


Fig. 4 Temperature Change in Tamil Nadu since 1951

2.3.1 Causes and Impacts of Climate Change

Climate change is primarily caused by human activities, including burning fossil fuels and deforestation, which release GHGs and alter the planet's carbon balance. The increased concentration of GHGs leads to the enhanced greenhouse effect, resulting in rising temperatures, changing precipitation patterns, extreme weather events, sea-level rise, loss of biodiversity, and negative impacts on human health, agriculture, and water resources. These interconnected impacts highlight the urgent need to reduce GHG emissions and implement adaptation strategies.

2.3.2 Climate Change Projections and Scenarios

Climate change projections and scenarios provide insights into future climate conditions. Climate models simulate the Earth's climate, considering factors such as GHG emissions, atmospheric composition, solar radiation, and land surface characteristics. These models generate projections of future climate conditions.

Scenarios like the Shared Socio-economic Pathways (SSPs) explore different future trajectories based on socio-economic factors. The SSPs categorise scenarios into SSP 1 - sustainability, SSP 2 - middle-of-the-road, SSP 3 - regional rivalry, SSP 4 - inequality, and SSP 5 - fossil-fueled development, representing different socio-economic and emission pathways. Fig 5 shows an SSP matrix that defines five possible SSPs in terms of various degrees of "challenges to adaptation" (or ability to deal with climate change that has already occurred) and "challenges to mitigation" (or ability to restrain the extent to which climate change will happen) as well as other features of socio-economic development.

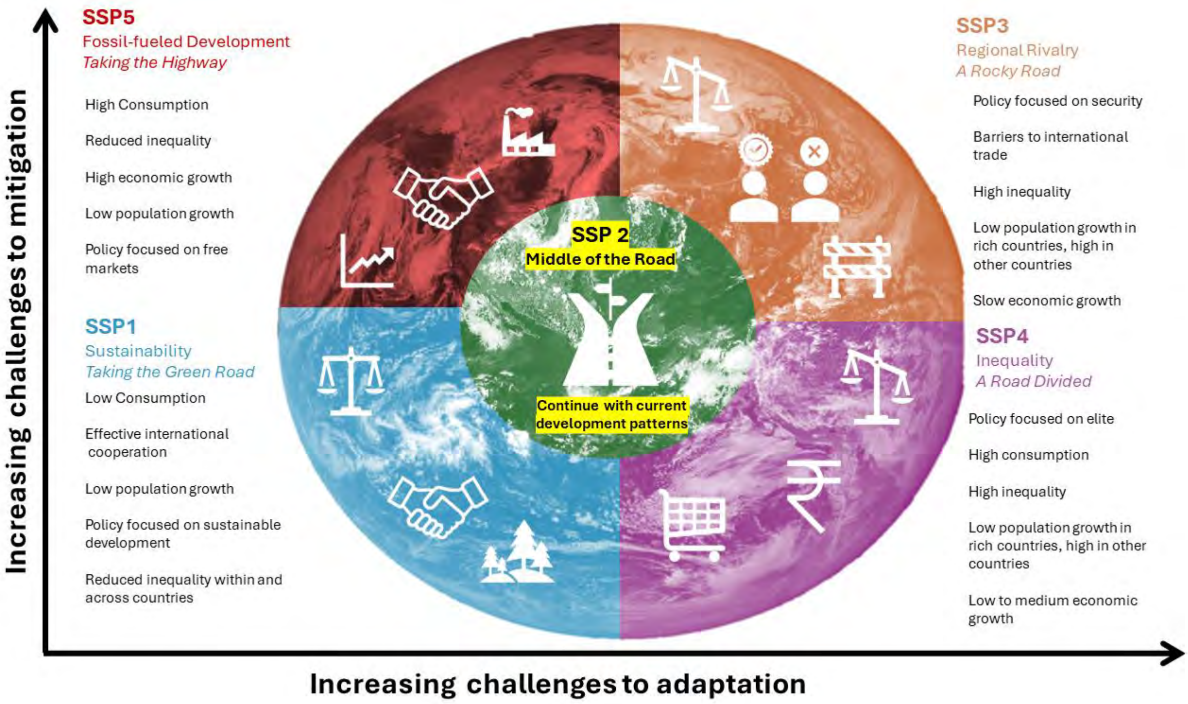


Fig. 5 SSPs mapped in the challenges to mitigation/adaptation space

2.3.3 Importance of Climate Change Projections and Scenarios

Climate change projections and scenarios help policymakers, scientists, and the general public understand potential impacts and plan for adaptation and mitigation. They assist in assessing risks and developing strategies based on socioeconomic choices. The recently released Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) incorporates the SSPs to explore different socio-economic development pathways and their associated climate change consequences. These scenarios enhance our understanding of the complex interactions between human activities and climate change, guiding decision-making processes for climate mitigation and adaptation.

Climate change is a global challenge requiring collective action to mitigate its effects and build resilience. Human activities, primarily burning fossil fuels, are the main drivers of climate change. The impacts of climate change are wide-ranging, affecting ecosystems, agriculture, water resources, and human well-being. Climate change projections and scenarios provide valuable insights into future climate conditions and assist in developing adaptation and mitigation strategies. The IPCC AR6 and the SSPs offer a range of scenarios representing different socio-economic and emission pathways, highlighting the importance of sustainable development and urgent actions to transition to a low-carbon economy. By understanding the causes, impacts, and potential future climate change conditions, we can make informed decisions to protect our planet and future generations.

The EC-Earth3 model is statistically downscaled using PyClim-SDM (Statistical Downscaling Model) from 100×100 km spatial resolution to 25×25 km spatial resolution for Tamil Nadu for the Shared Socio-economic Pathway scenario SSP2-4.5 (Mid Pathways) and SSP5-8.5 (Business as Usual) of IPCC AR6 and are projected for temperature and precipitation from 2021-2100.

Fig 6 and Fig 7 indicate the projected changes in annual maximum temperature by near, mid and end term under SSP2-4.5 and SSP5-8.5, respectively.

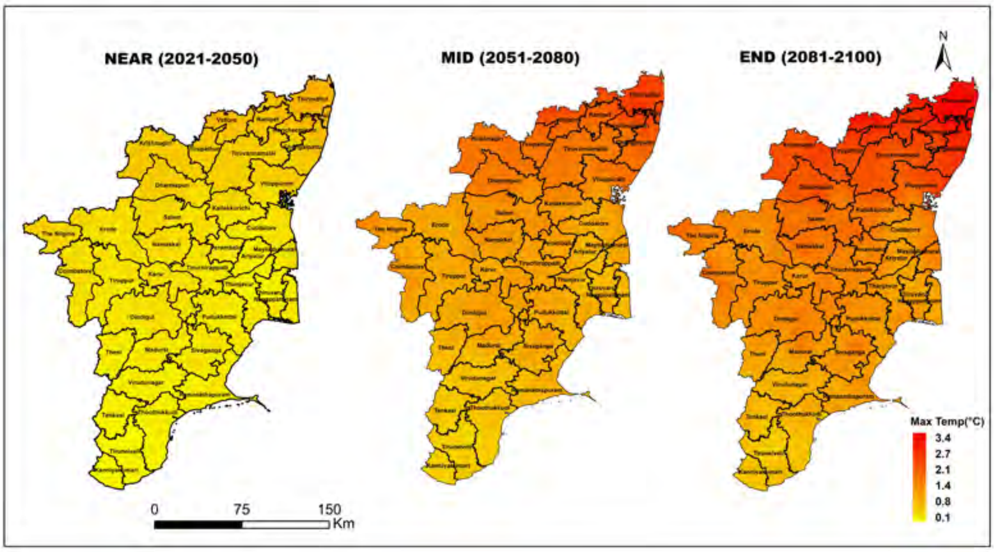


Fig. 6 Projected Changes in Annual Maximum Temperature by near century (NC), mid-century (MC) and end of century (EC) under SSP2-4.5

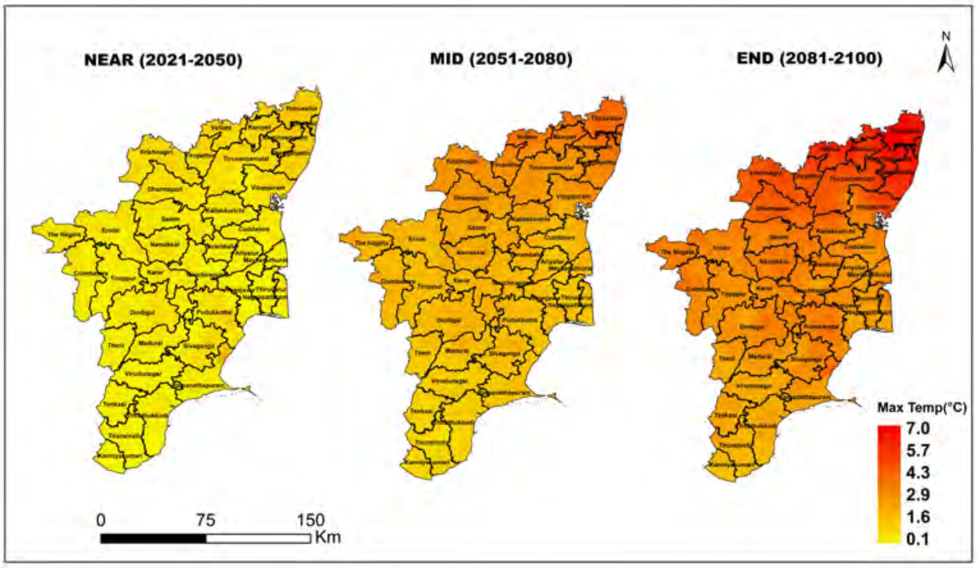


Fig. 7 Projected Changes in Annual Maximum Temperature by near century (NC), mid-century (MC) and end of century (EC) under SSP5-8.5

Table 2 indicates that the annual mean maximum temperature in the State may rise by up to 0.4 °C, 1.3°C and 1.7 °C in near-century, mid-century and end-century, respectively, under the SSP2-4.5 scenario and for the SSP5-8.5 scenario, the maximum temperature may rise by 0.6°C, 1.7 °C and 3.5°C by near-century, mid-century and end-century respectively.

The northern districts such as Chennai, Nagapattinam, Kanyakumari, and Mayiladuthurai are projected to have a maximum increase in temperature by the end of the century.

Table 2. Change in Annual Average Maximum Temperature

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

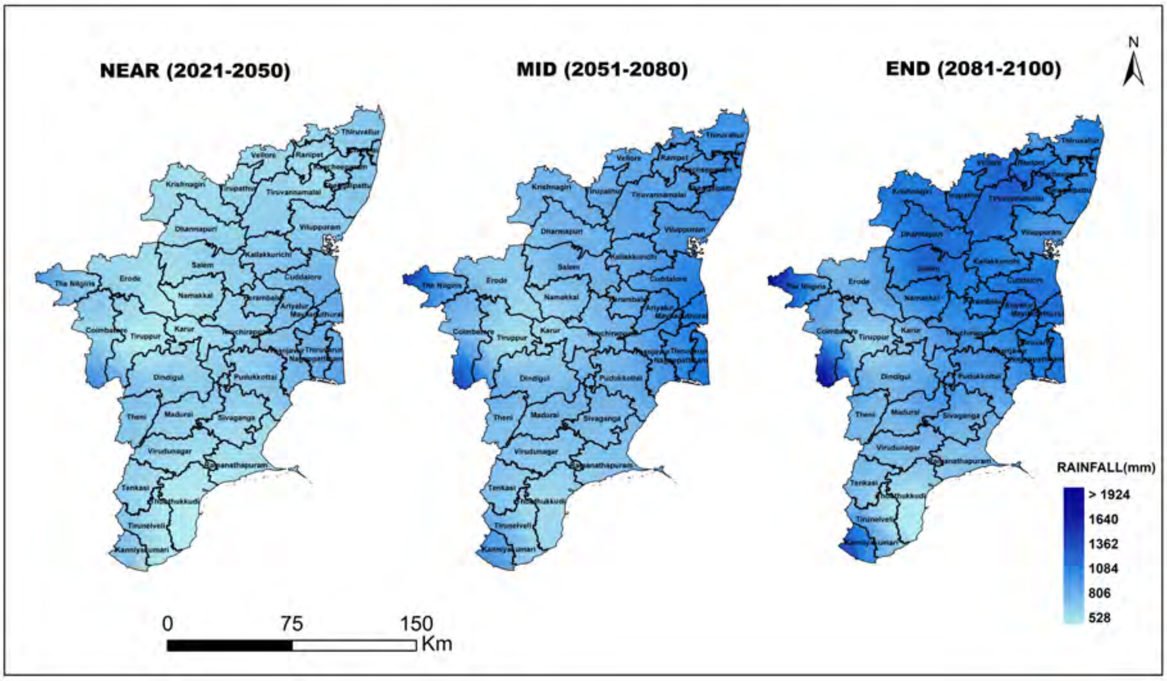


Fig. 8 Projected Average Annual Rainfall by near century (NC), mid-century (MC) and end century (EC) under SSP2-4.5

Table 3 indicates that the Average rainfall in Tamil Nadu State may increase marginally, by 4% towards the near century, 11% by the mid-century, and about 16% towards the end-century under the SSP2-4.5 scenario (Fig 8). Under the SSP5-8.5 scenario, the increase in rainfall is by 7% towards the near century, 18% in the mid-century, and 26% towards the end of the century (Fig 9).

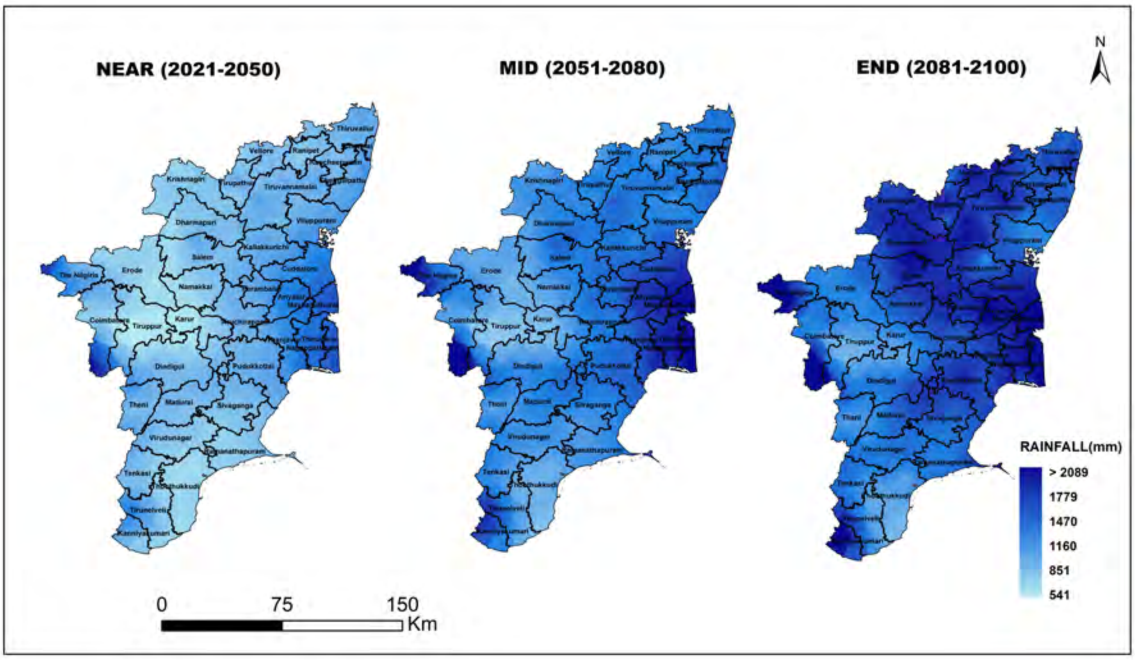


Fig. 9 Projected Average Annual Rainfall by near century (NC), mid-century (MC) and end century (EC) under SSP5-8.5

Table 3. Percentage Change in Annual Average Rainfall

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

> ***It is inferred that coastal districts such as Cuddalore, Nagapattinam, Kanyakumari, and Mayiladuthurai are projected to have a maximum increase in rainfall by the end of the century.***

3. WATER RESOURCES IMPACTS, VULNERABILITY AND RISKS OF CLIMATE CHANGE

The water resource system of Tamil Nadu is intricately linked with the impacts of climate change, making it a crucial area of concern for sustainable development and adaptation strategies. The State's water resources are vulnerable to the adverse effects of climate change, including altered precipitation patterns, rising temperatures, and increased frequency of extreme weather events. These changes pose significant challenges to the region's availability, quality, and management of water resources. Tamil Nadu relies heavily on surface water sources such as rivers, lakes, and reservoirs to meet its water needs. However, climate change-induced factors such as erratic rainfall patterns and prolonged droughts directly impact these surface water sources. Reduced rainfall and prolonged dry spells lead to lower water levels in rivers and lakes, affecting water availability for various sectors, including agriculture, industry, and domestic use. This situation is further exacerbated by increasing evaporation rates due to rising temperatures, resulting in accelerated water loss from reservoirs and water bodies.

The State's groundwater resources also face significant challenges due to climate change. Over-extraction of groundwater for agriculture, coupled with declining recharge rates caused by reduced rainfall, can lead to the depletion of aquifers and increased salinity intrusion in coastal areas. Additionally, sea-level rise associated with climate change threatens coastal groundwater resources, making them more vulnerable to contamination and saltwater intrusion. To address these challenges, Tamil Nadu has implemented various measures to enhance water resource management in the context of climate change. These initiatives include the construction of check dams, farm ponds, and small reservoirs to improve water storage capacity and recharge groundwater levels. Promoting water-efficient irrigation techniques, such as drip irrigation and sprinkler systems, aims to reduce water demand in agriculture. The State has also emphasised rejuvenating and conserving traditional water bodies like tanks and ponds to enhance water storage and recharge.

Furthermore, integrating climate change considerations in water resource planning and management is crucial. It involves assessing the potential impacts of climate change on water availability, identifying vulnerable areas, and developing strategies to adapt to changing conditions. It may include the development of climate-resilient water infrastructure, the implementation of water-saving measures, and the promotion of rainwater harvesting and watershed management practices.

3.1 Climate Risk Assessment

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

Hazard

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

Vulnerability

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

Exposure

Exposure can be understood as the presence or susceptibility of human and natural systems to the impacts and risks associated with climate change. Exposure often refers to areas or settings vulnerable to climate change's adverse effects. It encompasses potential harm or disruption to livelihoods, infrastructure, ecosystems, species, and socio-economic systems due to climate-related hazards and changes. Risk is assessed as a function of the interaction of climate hazards, vulnerability, and exposure.

Risk

The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from the potential impacts of climate change and human responses to climate change. "In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards". Hazards, exposure and vulnerability may each be subject to uncertainty in magnitude and likelihood of occurrence, and each may change over time and space due to socioeconomic changes and human decision-making. The climate change risk is understanding the sub-components that contribute to it (IPCC, 2022). The risk conceptualisation framework is shown in Fig 10.

Fig. 10 Conceptualization of Risk Framework - IPCC AR6

(Source: IPCC AR6 Report, WGII)

3.2 Existing Vulnerabilities of Tamil Nadu

Both floods and droughts have significantly impacted Tamil Nadu, affecting the state's economy, environment, and society. Floods often cause extensive damage to roads, bridges, buildings, and other infrastructure. It also results in the inundation of farmland, causing crop damage and sometimes leading to complete crop failure, directly impacting farmers' livelihoods and contributing to food shortages. Severe floods can lead to loss of lives and the displacement of people, especially residents in low-lying

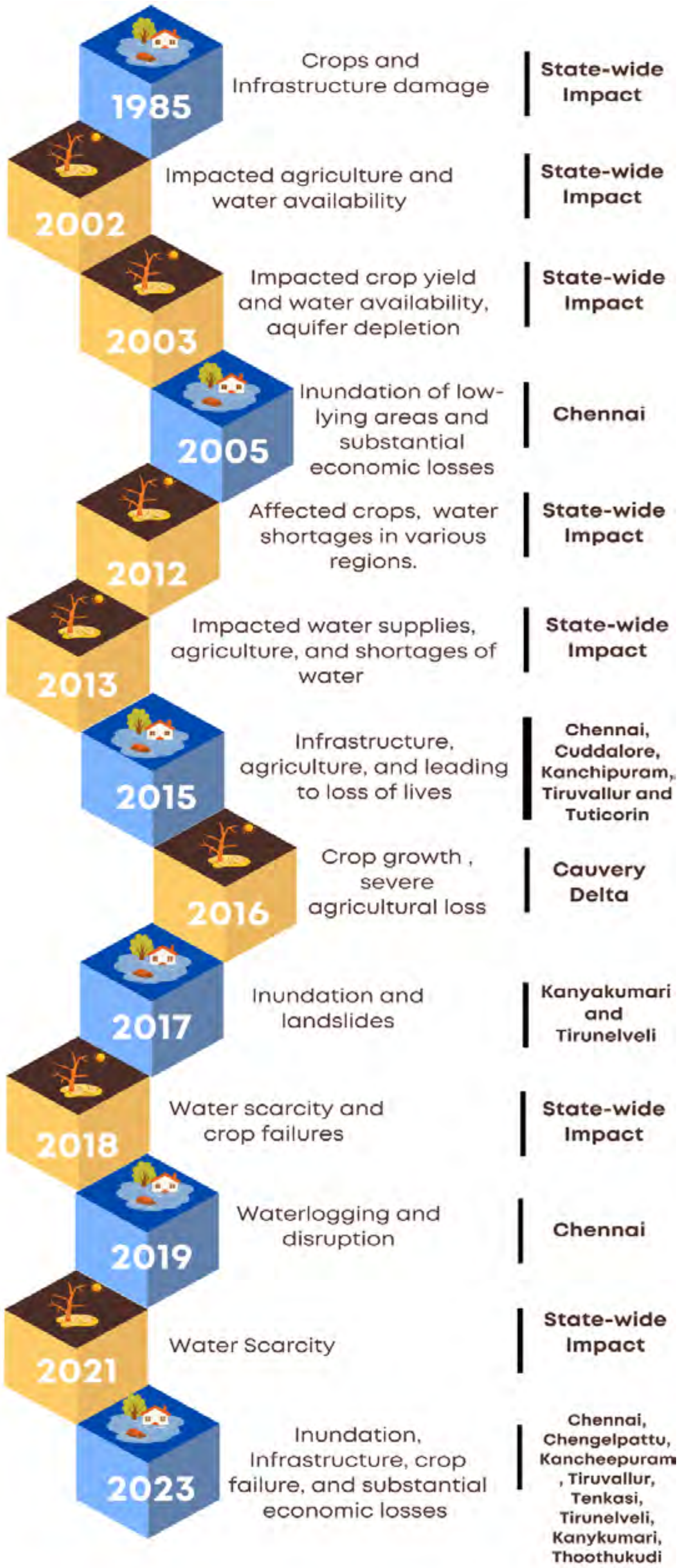


Fig 11. History of Flood and Drought Events in Tamil Nadu

areas, who are particularly vulnerable. The economic impact of floods includes not only the immediate costs of rescue and relief operations but also long-term effects on businesses, tourism, and overall economic productivity. Tamil Nadu's geographical positioning renders it one of India's most susceptible maritime states, particularly vulnerable to tropical cyclones and storm surges. Additionally, it frequently contends with severe weather phenomena, experiencing coastal flooding in various districts. According to the National Remote Sensing Centre (NRSC, 2023) report, flooding has impacted 24 districts, with an affected area spanning approximately 552,010 hectares between 1998 and 2022. Notable flood events occurred in 2007, 2008, 2009, 2010, 2012, 2015, and 2020.

Tamil Nadu, a coastal State in south India, is also prone to droughts. Droughts result in water scarcity, affecting irrigation and agricultural productivity. Reduced rainfall and depletion of water sources during droughts contribute to water shortages for domestic, agricultural, and industrial purposes. Farmers and those dependent on agriculture often face significant challenges during droughts. Droughts can contribute to economic slowdowns, particularly in agriculture-dependent regions like India. Drought conditions may contribute to health issues, including waterborne diseases and malnutrition, especially in vulnerable populations. To address these impacts, parts and the whole of Tamil Nadu, prone to floods and droughts, often implement measures such as early warning systems, improved water management, and infrastructure development to mitigate the effects of these natural disasters.

An assessment of droughts in Tamil Nadu from 1977 to 1991 reveals recurrent water shortages in significant parts of the State. The worst drought years in the past 32 years were identified as 1980, 1982, 1983, 1987, 1989, 2002, 2003, 2004, 2006 and 2009. The drought of 1980 destroyed the groundnut crop in over 1,00,000 hectares in the districts of Chengalpattu and Vellore (TNSAPCC).

An overview of past flood and drought events that affected Tamil Nadu has been shown in Fig. 11. This infers that the frequency of flood and drought events increases, intensifying their magnitude. Even before and after such events, mitigation efforts fall short of their intended objectives, primarily due to the unpredictability of climate change. Future projections on flood and drought events must be understood to address these issues. It is achieved through hydrological modelling for the baseline and future scenarios. The simulated hydrological components under baseline and future projections were further utilised to assess the frequency and magnitude of drought and flood events.

3.3 Hydrological Model Setup

SWAT is a semi-distributed, continuous-time and process-based eco-hydrological model used to simulate the hydrological variables at the watershed scale. SWAT is a widely adopted ecohydrological model for impact assessment under different future climate scenarios. SWAT model-derived outputs were widely used for assessing hydro-climatic extreme events such as floods and drought (Tan et al., 2020).

In this study, SWAT+, a restructured version of SWAT, is used to simulate the hydrological variables (Bieger et al., 2017). SWAT+ is more flexible and user-friendly for modifying the spatial interactions and processes within a watershed (Pulighe et al., 2021). Based on the topography and stream network, the SWAT+ model divides a catchment into subbasins. The land areas within a subbasin are represented in SWAT+ by one or more Landscape Units (LSUs), which are subdivided into hydrological response units (HRUs) representing different combinations of soil types, land use and slope. The hydrological simulation of the model relies on the water balance equation of the soil profile which consider the various processes such as precipitation, surface runoff, evapotranspiration, lateral flow across channel, infiltration, and groundwater flow (Arnold et al., 1998; Gassman et al., 2014).

The SCS curve number and Penmann Monteith method were adopted to simulate surface runoff and potential evapotranspiration. The data used for the SWAT+ model setup is given in Table 4.

Table 4 Data and its source used for SWAT+ model setup

Data Type	Source
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission (SRTM)
Land-use/Land-cover (LULC)	National Remote Sensing Centre (NRSC)
Soil	Tamil Nadu Agricultural University
Climate Data (Daily)	IMD (Rainfall & Temperature), Tamilnadu PWD Observatories
River Discharge (Monthly)	India-Water Resource Information System (WRIS)

3.4 Drought

Drought is a naturally occurring event characterised as an extended period of dryness over a prolonged period and a broad region. Droughts pose a significant hazard to health, agriculture, economies, energy, and the ecosystem. The IPCC AR6 report projects that drought risk is expected to increase across many world regions in the coming decades, especially in areas already vulnerable to droughts. According to the report, it is highly likely that some areas, including the Mediterranean, western North America, and southern Africa, will experience an increase in the frequency and intensity of droughts. Additionally, droughts will likely become more severe in some regions, such as Central Europe and South America, and probably more frequent in other areas, such as East Africa and northeastern Brazil. The report also suggests that many regions, including South Asia, will likely experience more frequent drought events. These projections highlight the urgent need for effective drought management and adaptation strategies to minimise the impacts of droughts on people, economies, and ecosystems. The primary cause of droughts in South Asia is the deficiency of the summer monsoon season, which is crucial for the survival of millions of individuals in the area and contributes around 80% of the yearly rainfall. According to the IPCC AR6 Assessment, recurrent drought incidents are probable in India's central and south-eastern regions.

Drought is categorised into four major types: meteorological drought (rainfall below average level), agricultural drought (soil moisture below threshold), hydrological drought (departure in storage and runoff) and socioeconomic drought (economic shortfall in the water supply).

3.4.1 Drought Hazard

The term hazard refers to potential events, either naturally occurring or caused by human activities, that have the potential to cause harm to different areas, either individually or in combination (Wilhite & Buchanan-Smith, 2005). The likelihood and severity of a hazard can be estimated by analysing the frequency and intensity of the events. The IPCC AR6 defines drought hazard as the potential occurrence of drought events that can lead to adverse consequences. Drought hazard is characterised by a deficiency in precipitation over a prolonged period, resulting in a shortage of water supply. It is one of the three components contributing to drought risk, exposure, and vulnerability.

Drought hazard is computed based on the intensity and probability of drought events. Drought indices help to quantify and characterize drought events under changing climatic conditions, which aids in water resources management. The Drought Hazard Index (DHI) has emerged as a reliable tool to provide quantitative information about an area's vulnerability to drought, taking into account its spatial extent, frequency, and severity. Physically-based hydrological models are used to assess water balance components at the sub-basin level of each river basin for future SSP scenarios. The simulated hydrological features are further used to compute the Drought Hazard Index at the sub-basin scale, as shown in Fig 12.

Drought Indices, such as the Standardised Precipitation Evapotranspiration Index (SPEI), and the Streamflow Drought Index (SDI), has adopted to evaluate the frequency and intensity of drought events under baseline and future period.

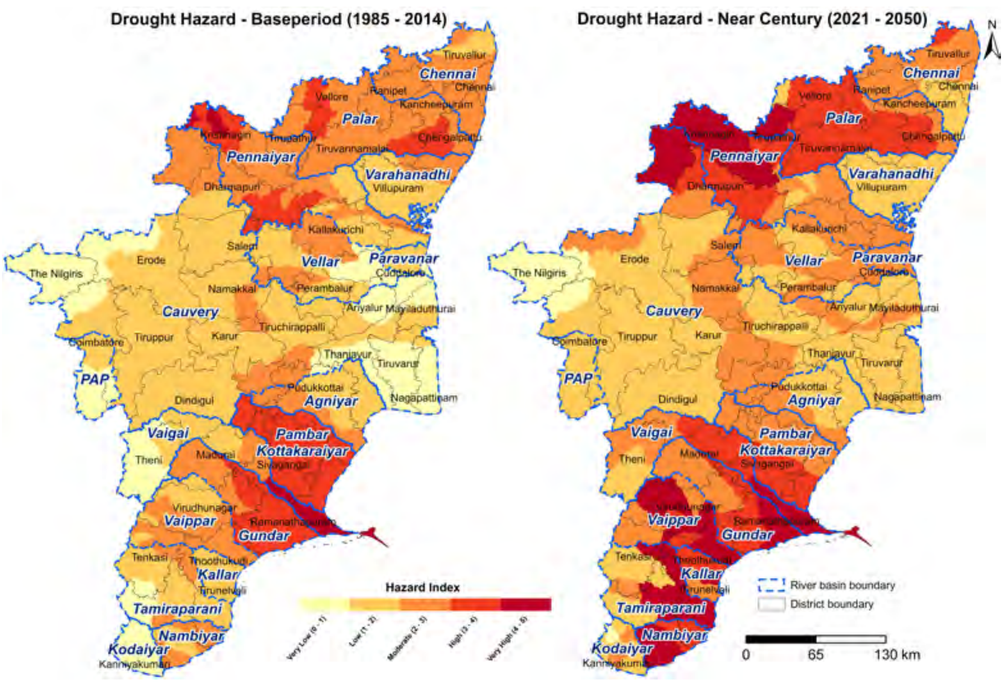


Fig. 12 Drought Hazard Index Spatial Distribution of Tamil Nadu during the base period and Near Century (2021 -2050) under SSP2-4.5 Scenario

3.4.2 Drought Vulnerability

Drought vulnerability refers to the propensity of a system or population to suffer negative impacts when exposed to drought events. It is determined by the sensitivity, adaptive capacity, and exposure of the system or population to drought (IPCC, 2021). Vulnerability assessment is essential for designing effective drought management and adaptation strategies (Pulido-Velazquez et al., 2020).

It is a comparative assessment that reflects the extent to which system is susceptible to damage due to drought events. The drought vulnerability indicators considered in this study considered multiple dimensions such as Social, Economic, Physical, Environmental and Farming practices (Hagenlocher et al. 2019).The drought vulnerability indicators considered are normalised and weighted sum to compute the drought vulnerability index (DVI), as shown in Fig 13.

> *Drought Vulnerability Indicators include Agricultural Productivity, Soil, Land Use Land Cover (LULC), Groundwater category assessment, Rural Population, GDP, Irrigation Index, Literacy Rate, Population Density, and Poverty head count.*

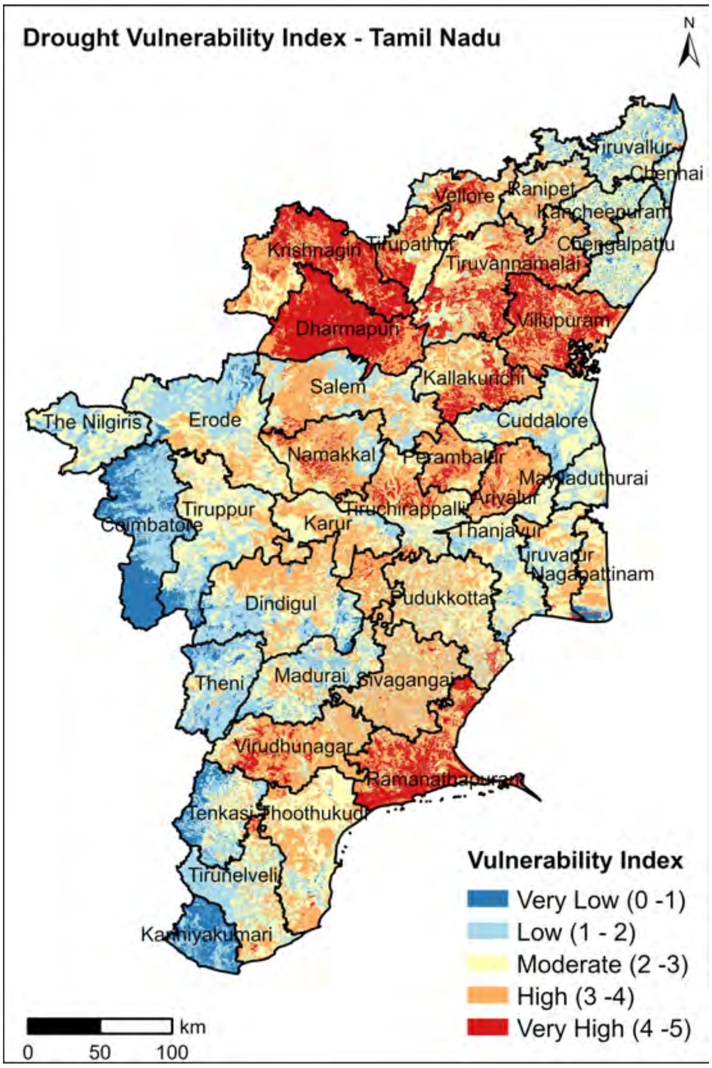


Fig. 13 Drought Vulnerability Index Spatial Distribution of Tamil Nadu

3.4.3 Drought Risk

Drought risk refers to the chance of adverse outcomes or the possibility of damages arising from several factors. These factors include the potential occurrence of drought events (drought hazard), the people, their livelihoods, and assets in regions where droughts might occur (drought exposure), and the vulnerability of the exposed entities hit by a drought event (drought vulnerability) (Cardona et al., 2012). The hazard and vulnerability information computed in the form of the Drought Hazard Index (DHI) and Drought Vulnerability Index (DVI), respectively, are combined to evaluate the Drought Risk Index (DRI). The framework to assess drought risk index is shown in Fig 14.

The frequency and magnitude of drought events have shown a significant increase, varying widely across different basins, by two-fold for the Nambiyar basin. In addition, over the next thirty years, the Pennaiyar, Palar, Gundar, and Vaippar basins may experience five to seven severe drought events, which are expected to significantly impact the ecosystem. The areal extent of drought risk increasing the SSP2-4.5 scenario compared with the baseline is shown in Fig 15.

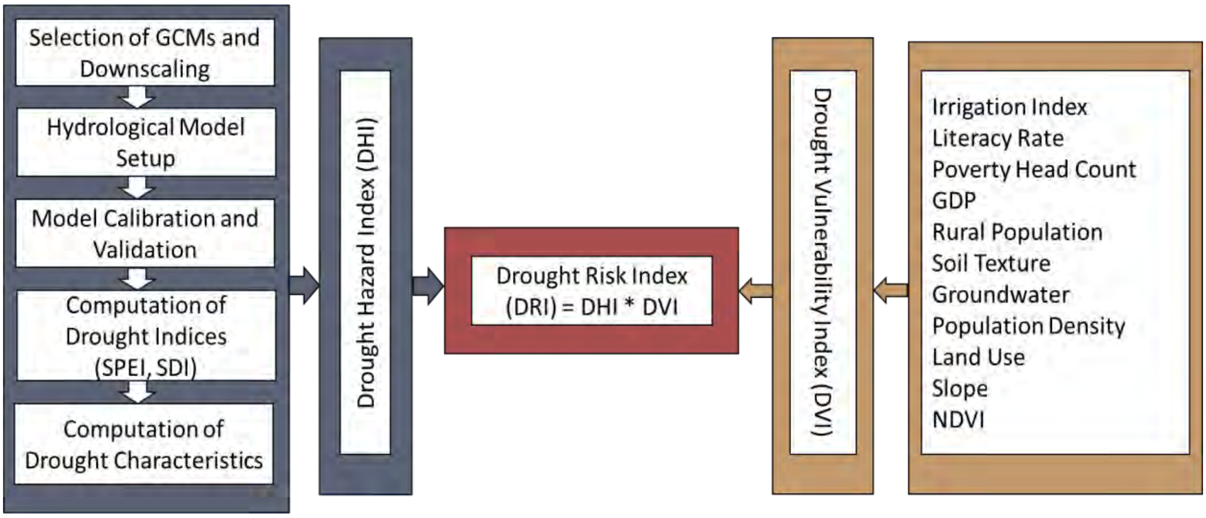


Fig. 14 Framework to assess Drought Risk Index for Baseline and Near-century

The drought risk spatial distribution of Tamil Nadu under the baseline and SSP2-4.5 scenario for the near century period is shown in Fig 16, and the areal percentage of Tamil Nadu's drought risk pattern is shown in Fig 15. Identifying regions characterised by homogeneous vulnerability and risk levels through regionalisation presents an integrated approach to addressing drought risk management on a broader scale. By analysing the complex interplay between climatic factors, socio-economic vulnerabilities, and environmental conditions, decision-makers can prioritise resource allocation and implement targeted measures to mitigate drought risk and enhance resilience in areas identified as high-risk. This comprehensive strategy ensures that interventions are tailored to the specific needs of each region, thereby maximising effectiveness in managing drought-related challenges and safeguarding communities and ecosystems against the impacts of water scarcity.

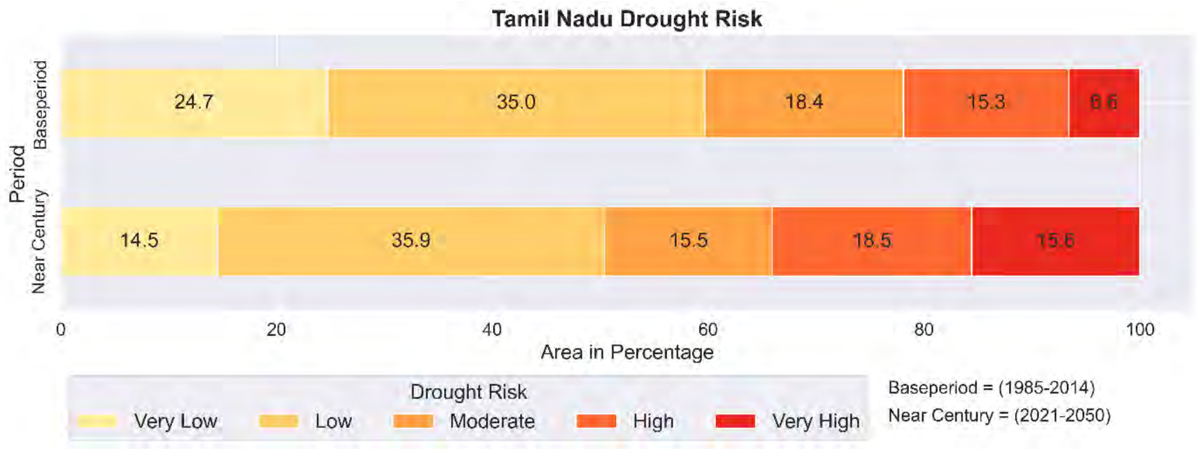


Fig 15. Drought risk index areal extent variation of Tamil Nadu under baseline and future SSP2-4.5 scenario

The overall drought risk of Tamil Nadu in terms of areal percentage has likely to increase from 6.6% to 15.6% base model. Districts such as Ramanathapuram, Dharmapuri, Krishnagiri, Tiruvannamalai, Thoothukudi, and Virudhunagar are projected to have Very high Drought Risk in the near century period.

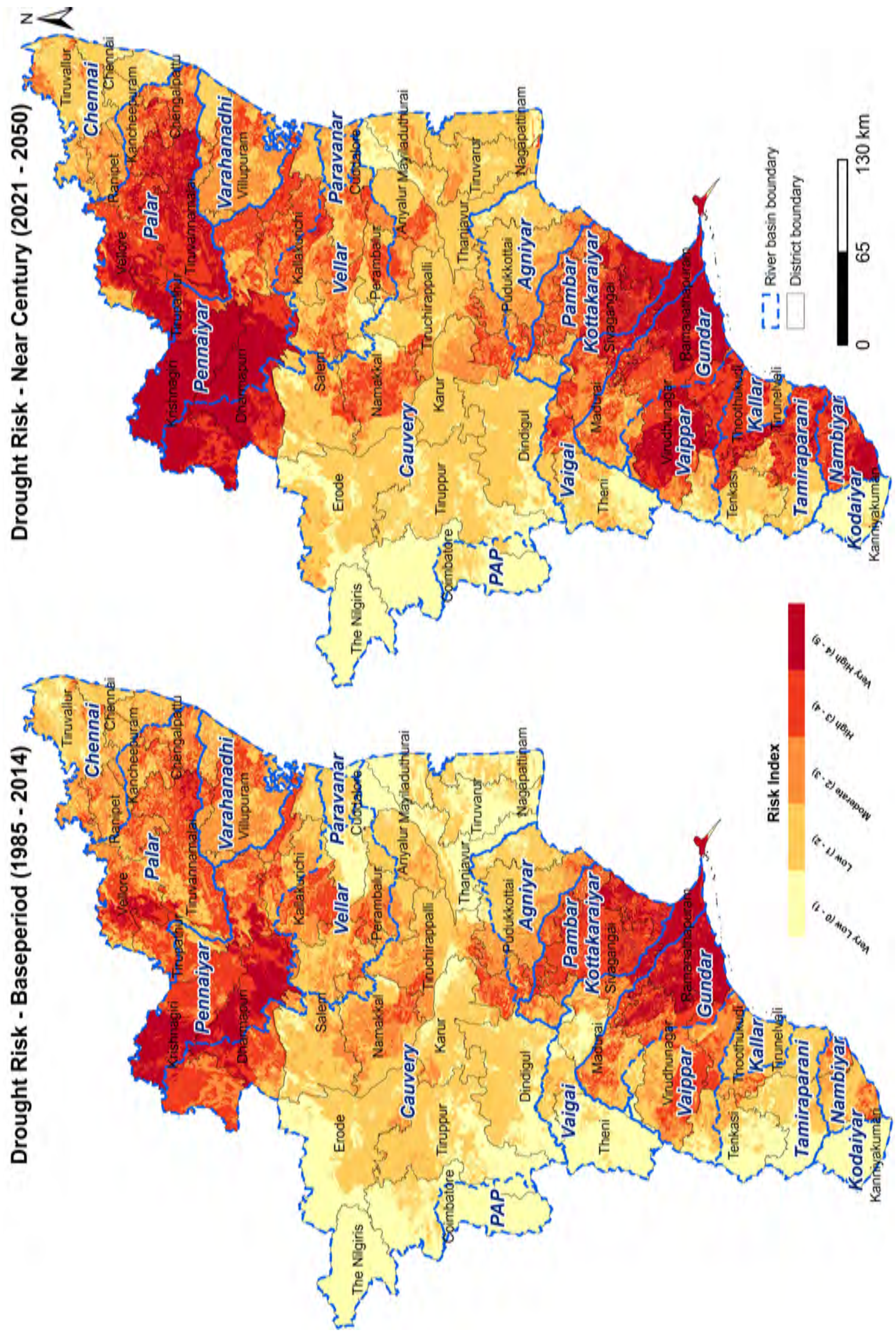


Fig. 16 Drought Risk Spatial Distribution of Tamil Nadu River Basins during the Baseline and Near Century (2021 -2050) under SSP2-4.5 Scenario

3.5 Flood

Floods are the inundation of normally dry land and are classified into types (e.g., pluvial floods, flash floods, river floods, groundwater floods, surge floods, and coastal floods) depending on the space and time scales. Floods are a complex interplay of hydrology, climate, and human management, and the relative importance of these factors varies for different flood types and regions. Floods pose a severe and frequent threat in various parts of the world, often resulting in substantial economic losses and loss of human life. Flooding is especially harmful in developing countries due to low levels of flood protection.

The number of studies on flood trends has increased since AR5, and there were also new analyses after the release of SR1.5 (Berghuijs et al., 2017; Bloschl et al., 2019; Gudmundsson et al., 2019); hydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales, making it difficult to synthesise at the global and sometimes regional scales. According to the IPCC AR6 report, flood risk refers to the probability of harmful consequences or likelihood of losses resulting from interactions between the potential occurrence of flood hazard (i.e., extreme precipitation or river flow), exposure of people, assets and ecosystems to the hazard, and the vulnerability of the exposed elements to flood impacts. Natural and human-induced factors influence flood risk and can vary spatially and temporally (IPCC, 2021).

3.5.1 Flood Hazard

The IPCC AR6 report defines flood hazard as the potential occurrence of extreme precipitation or river flow that can cause flooding and lead to negative consequences. Various factors can influence flood hazards, such as climate change, land-use change, and water management practices (IPCC, 2021). Flood hazard assessment is an essential component of flood risk management, and it involves

> *Runoff coefficient, Modified Fournier Index (MFI), Rx1day (maximum 1-day rainfall amount), and R25mm (number of heavy rainfall days above 25 mm), are the effective, dynamic and influencing parameters in determining the frequency and magnitude of flood events were adopted to quantify FHI.*

estimating the probability and magnitude of flood events (Pappenberger et al., 2020).

Hydrological models are mathematical formulations that can determine the volume of runoff leaving a watershed from the rainfall received by the watershed. A flood hazard model can be developed to incorporate all effective criteria for identifying flood hazard areas. The Flood Hazard Index (FHI) calculation helps demarcate the severity and extent of flood events, as represented in Fig 17 on spatio-temporal scales.

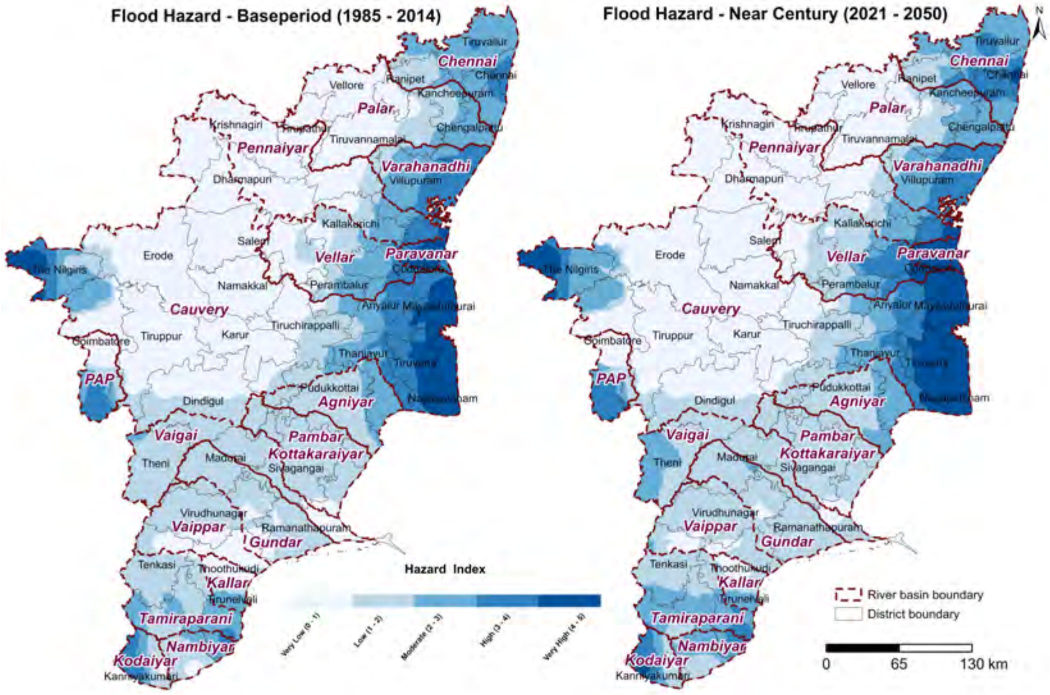


Fig. 17 Flood Hazard Index Spatial Distribution of Tamil Nadu during the base period and Near Century (2021 -2050) under SSP2-4.5 Scenario

3.5.2 Flood Vulnerability

Flood vulnerability assessment is critical for designing effective flood risk management and adaptation strategies (Pescaroli & Alexander, 2016). The vulnerability indicators method was adapted to use available data to provide a logical image of the place's vulnerability. This method is widely used in flood vulnerability studies and is preferred by policymakers for its clarified vulnerability image over space. This depiction aims to prioritise measures and plan for the risk response in specified regions. The IPCC AR6 report defines flood vulnerability as the propensity or susceptibility of exposed elements, such as people, assets, and ecosystems, to be adversely affected by a flood hazard. Flood vulnerability

> *Flood vulnerability indices play a vital role, and the factors that influence the extent of the flood are slope, elevation, drainage distance, land use, land cover, population density, and GDP per capita income.*

is influenced by various factors, such as social, economic, and environmental conditions and exposure to flood hazards (IPCC, 2021).

These parameters are crucial in assessing flood vulnerability, which acts as the carriers of the flood, as the spatial extent of its magnitude and frequency are represented in Fig 18.

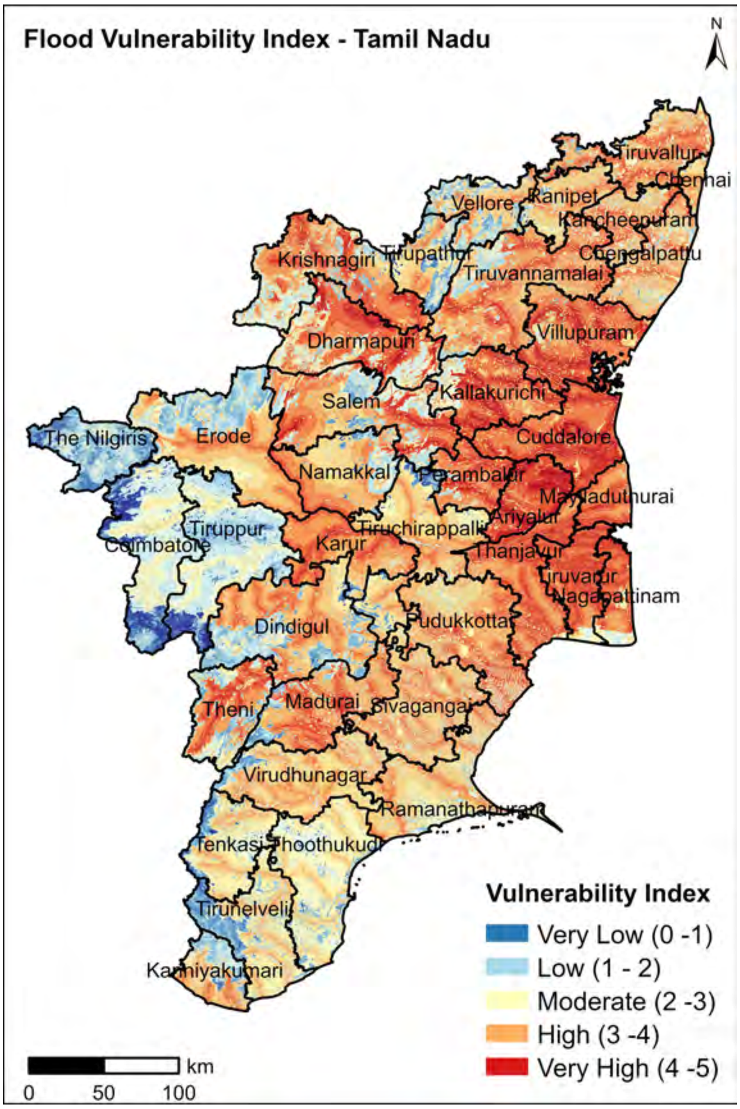


Fig. 18 Flood Vulnerability Index Spatial Distribution of Tamil Nadu

3.5.3 Flood Risk

Flood Risk Index (FRI) combines three interacting components: climate-related hazards (including hazardous events and trends), the vulnerability of human and natural systems, and exposure to places and settings that could be adversely affected. To appropriately assess the complex phenomenon of flood risk, well-approved methodologies and novel representations must be used to construct risk and vulnerability indices. Subsequently, regionalising areas of homogenous vulnerability and risk levels will result in an integrated approach. The IPCC AR6 report defines flood risk as the combination of the probability or likelihood of a flood hazard occurring and the consequences or impacts that result from that hazard. The framework to assess the Flood risk index is shown in Fig 19.

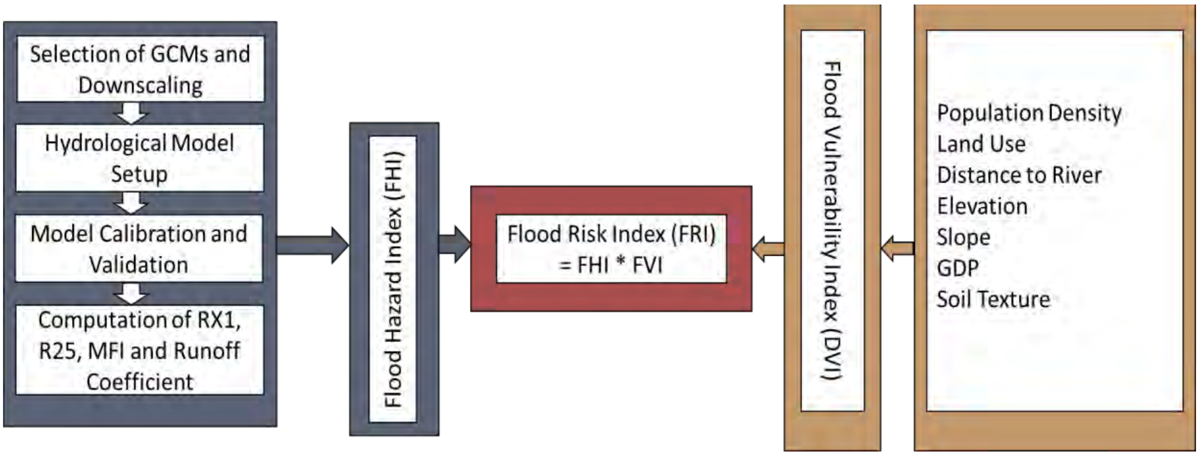


Fig. 19 Framework to assess Flood Risk Index for Baseline and Near-century

Flood risk is influenced by various factors, including climate change, land use, and socio-economic development, and can be spatially and temporally variable (IPCC, 2022). Effective flood risk management strategies require understanding flood risk and its drivers (Merz et al., 2014).

Fig 20 displays the spatial distribution of flood risk in Tamil Nadu under the SSP2-4.5 scenario for the near century. The flood risk assessment has projected the magnitude and frequency of climate extremes increasing in the future scenario in the coastal stretch. Paravanar basin may experience very high chances of getting one day extreme rainfall, whereas the Kodaiyar basin may witness maximum extreme rainfall events in the future. Varahanadhi, Chennai, and Vellar basins may experience frequent intense rains in short periods.

The flood risk of the Tamil Nadu region for the future SSP scenario shows an increase in flood risk; compared with the baseline, 6.8% of the state experience very high flood risk under the SSP2-4.5 scenario. The extent to which flood risk increases the SSP2-4.5 scenario compared to the baseline is shown in Fig 20. This suggests certain regions are more vulnerable to flood hazards and may suffer serious consequences. Effective flood risk management requires understanding flood risk drivers like the above factors. By analysing flood risk and its components, policymakers and stakeholders may devise tailored measures to minimise and adapt to floods in vulnerable areas.

Identifying areas with homogeneous vulnerability and risk levels through regionalisation provides an integrated approach to addressing flood risk management at a broader scale. By considering the interactions between climate-related hazards, vulnerability, and exposure, decision-makers can prioritise resources and implement targeted measures to reduce flood risk and enhance resilience in the identified high-risk areas.

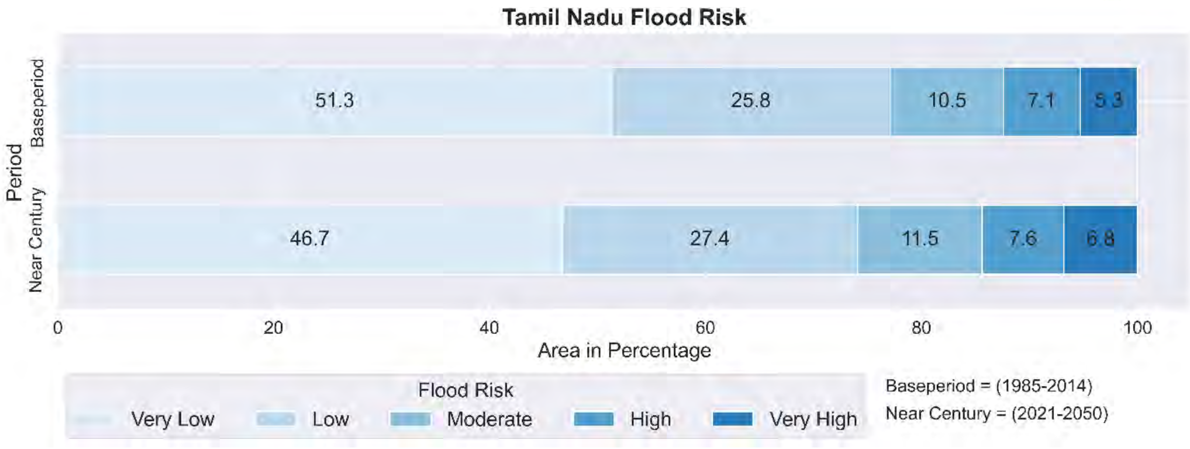


Fig. 20 Flood risk index areal extent variation of Tamil Nadu under baseline and future SSP2-4.5 scenario

> *The overall flood risk of Tamil Nadu in terms of areal percentage has likely to increase from 5.3% to 6.8%. Mayiladuthurai, Tiruvarur, Nagapattinam, Cuddalore, and Chennai are anticipated to have significant flood risks in Tamil Nadu in the near century. Over the next thirty years, extreme rainfall events are expected to rise two and a half fold, increasing the risk of severe flooding.*

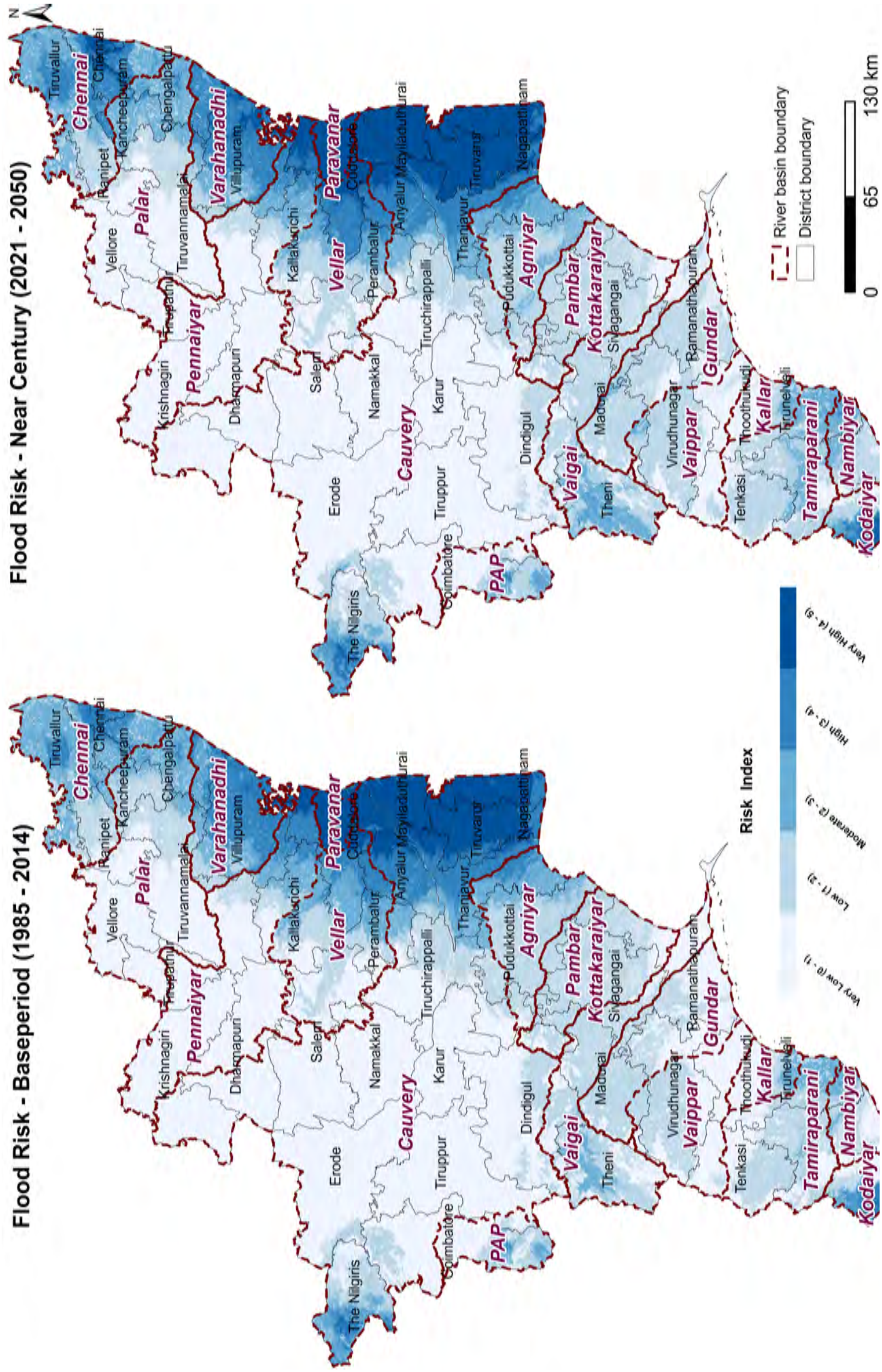


Fig. 21 Flood Risk Spatial Distribution of Tamil Nadu River Basins during the Baseline and Near Century (2021 -2050) under SSP2-4.5 Scenario

4. DROUGHT AND FLOOD RISK ASSESSMENT OF 17 RIVER BASINS OF TAMIL NADU

Based on the IPCC Risk framework, the 17 River basins of Tamil Nadu assessed for the flood and drought risk. The key inference of Risk assessment for the near century under SSP2-4.5 scenario is discussed below.

4.1 Agniyar River Basin

Agniyar river basin is one of the major east-flowing rivers of Tamil Nadu, which has a conical or triangular-shaped watershed boundary, as represented in Fig 22. The Cauvery Basin is bound to this basin in the northwestern part, and the Pambar Kottakaraiyar Basin is in the south. In contrast, the river flows into Palk Strait and Palk Bay in the southeastern direction. The basin lies in between the latitude from 9°55’00” to 10°45’00” and longitude from 78°15’00” to 79°30’00”. The basin is divided into three prominent rivers, and its sub-basins are Agniyar, Ambuliyar, and South Vellar. It has a total area of about 4702.13 km^2. The Administrative boundary that falls under this basin is some of the districts, namely, Pudukottai and Thanjavur, in the majority, while the minimal parts of Trichy, Dindigul and Sivangangai were in it.

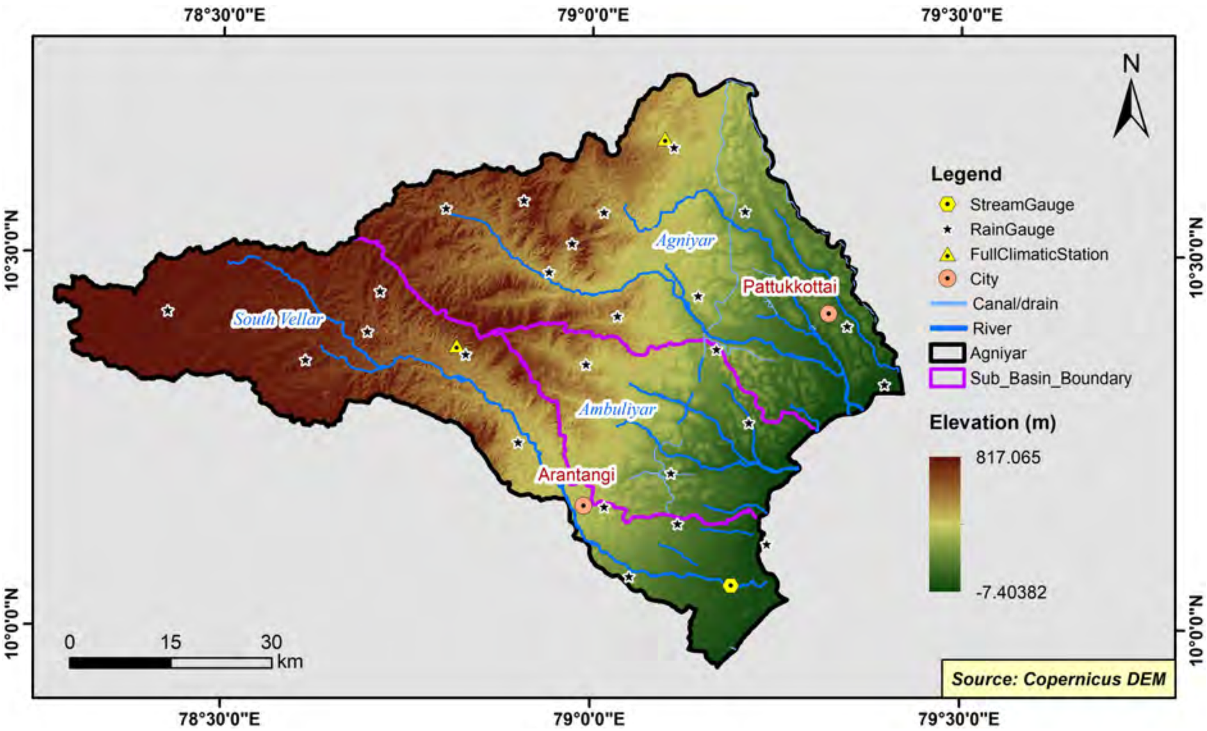


Fig. 22 Agniyar Basin Index map

Agniyar basin is a non-forested catchment that has an elevation of 817.065 m above MSL, and the slope ranges between 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as given in Table 5 below.

Table 5. Hydro-Meteorological Observatories for Agniyar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Agniyar	11	1	-
2	Ambuliyar	4	-	-
3	South Vellar	10	1	1

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy loam (30%), clay (14%), sandy clay loam (11%), sandy clay (10%), loamy sand (5%), silty clay loam (3%), sand (2%), and silty clay (1%). This basin entirely falls under the agro-climatic zone of the Cauvery delta region. Henceforth, the primary land use of the Agniyar River basin is agricultural land (75.68%), built-ups (7.9%), forestland (2.73%), wasteland (1.7%) and wetland (0.73%). The waterbodies of this basin are covered by only 11.61% as a whole.

4.1.1 Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 Risk assessment framework, the climate risks such as flood and drought for the Agniyar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). The spatial distribution of drought and flood risk of the Agniyar River basin is shown in Figs 23 and 24.

In drought risk assessment, the critical sub-basin of Agniyar River is South Vellar, which will intensify in the near century. The base period witnessed four drought years, while projections for the near century indicate an increase to 5 drought years. Additionally, the drought magnitude, 4.8 during the base period, is anticipated to rise to 5.9. Specifically, in the Agniyar, South Vellar sub-basin is expected to undergo six drought years with a magnitude of 7 in the future scenario.

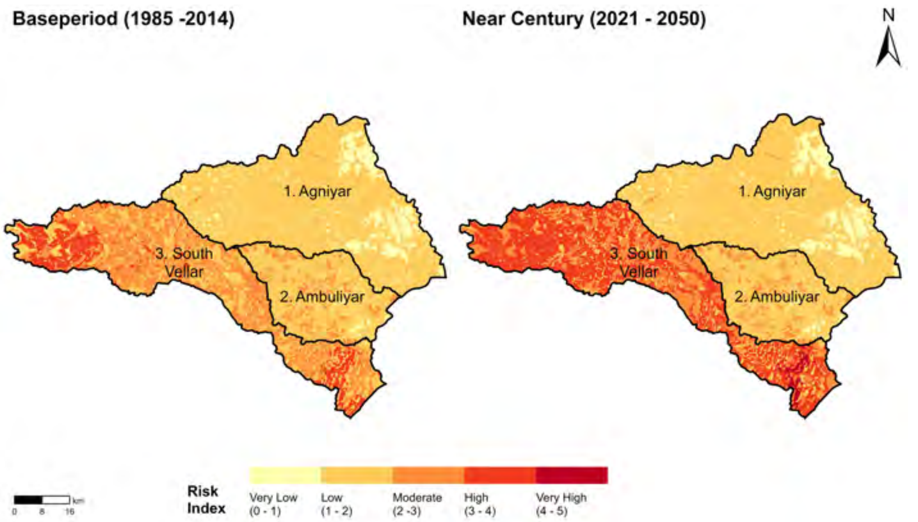


Fig. 23 Drought Risk Spatial Distribution of Agniyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

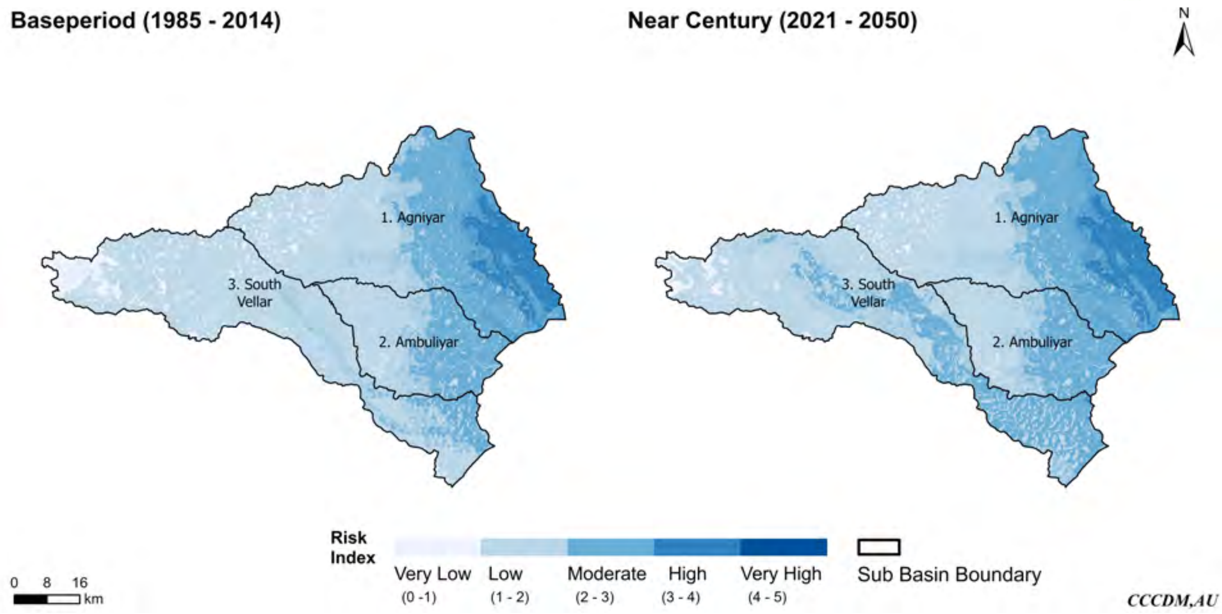


Fig. 24 Flood Risk Spatial Distribution of Agniyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario.

In flood risk assessment, the critical sub-basin of the Agniyar River Basin is Agniyar. The Agniyar basin is expected to experience a 42.6% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 59.2%. More specifically, within the Agniyar sub-basin, there is an anticipated increase of 44.3% in extreme rainfall events and a 50.3% increase in extreme rainfall days.

The subbasin ranking based on the drought and flood risk assessment is shown in Fig 25. and the most critical subbasin to be prioritised for future adaptation work is given in Table 6.

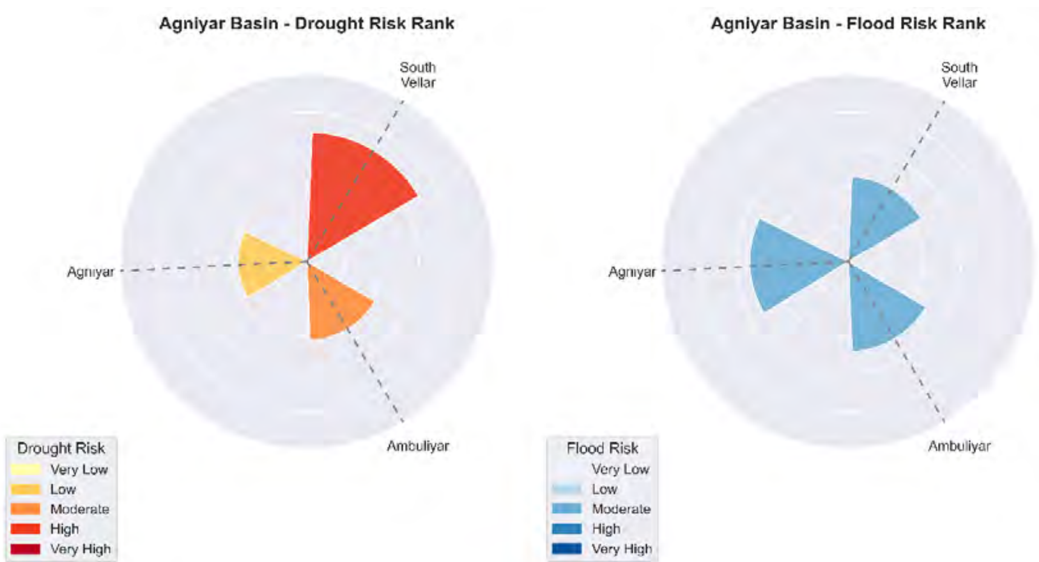


Fig. 25 Drought and Flood Risk Ranking for Agniyar Sub-basins

Table 6. Drought Risk and Flood Critical Sub-Basins of Agniyar River Basin under SSP2-4.5 scenario during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Agniyar (3)	4663	South Vellar	Agniyar

(**SSP2-4.5 Scenario during Near Century (2021 - 2050)*)

The overall drought risk is expected to increase from baseline to future in which the drought classification has a more significant shift from low (8.73%) and medium (5.81%) class in baseline to high (13.89%) and very high (0.83%) class in future. The overall flood risk slowly increases from baseline to future periods. The very low (3.1%) and low (5.4%) class of flood risk in baseline has a shift to the medium (8.6%) class in the future period. The areal extent of drought and flood risk for the baseline and future scenarios is given in Figs 26 and 27.

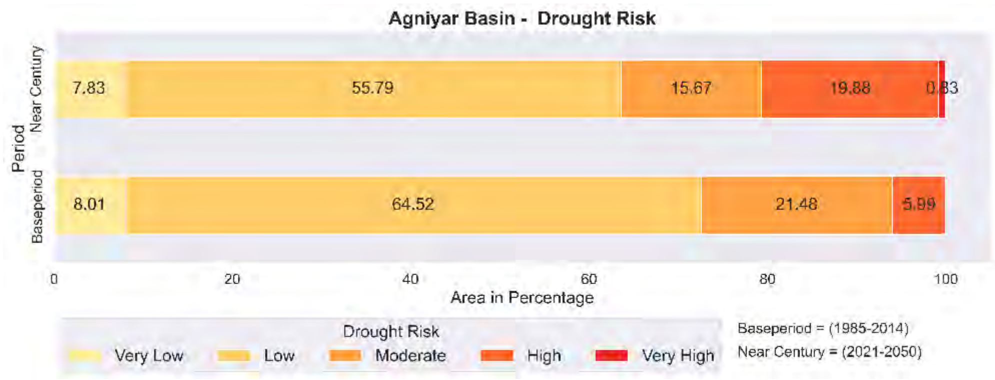


Fig. 26 Areal percentage of Drought Risk Assessment for Agniyar River Basin

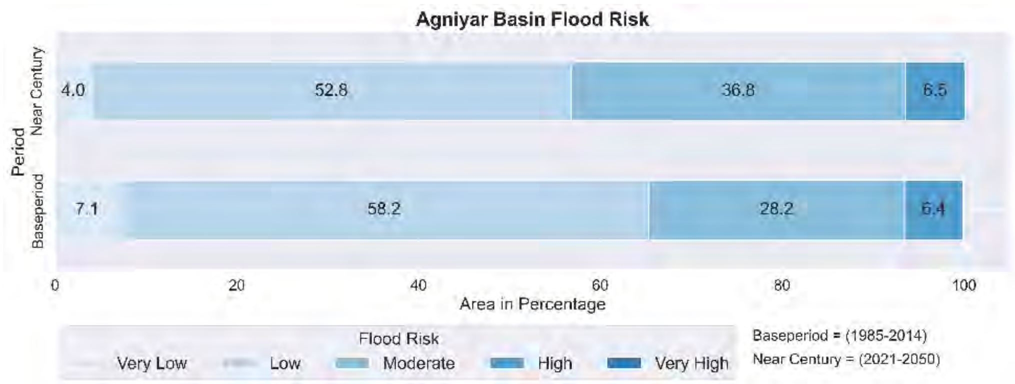


Fig. 27 Areal percentage of Flood Risk Assessment for Agniyar River Basin

According to the climate risk assessment, the Agniyar basin is not very prone to flooding but intensifies for drought conditions in future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. In addition, the TN-PWD Water Resources Department (WRD) had a new proposal on linking the rivers of Cauvery (Kattalai Barrage) and South Vellar, one of the subbasins of Agniyar River in phase – I, for which 59% of the works were completed in construction of the new canal. Upon executing this project, the Agniyar basin will be sufficient to withhold future climate extremes of flood and drought.

4.2 Cauvery River Basin

The Cauvery River basin serves as the primary eastward-flowing river in Tamil Nadu, effectively dividing the state into northern and southern regions through its watershed boundary, represented in Fig 28. This basin is surrounded by the Pennaiyar and Vellar rivers in the northern part, while the Parambikulam Aliyar, Vaigai, Gundar, Pambar, Kottakaraiyar, and Agniyar basins border its southern areas. The river eventually empties into the Bay of Bengal. Geographically, the basin boundary ranges between the latitudes of 10°9' to 13°30'N and longitudes of 75°27' to 79°54'E. This basin is further divided into 18 significant rivers and sub-basins, including Chinnar, Dodda Halla, the stretch from Mettur Reservoir to the Noyel Confluence, Palar Dodda Halla, Moyar, Upper and Lower Bhavani, Noyel, Tirumanimuttar, Amaravati, Karaipottanar, Ayiaar, Pungar (upper Coleroon), Ponnaniyar, Nandiyar-kulaiyar, Marudaiyar, Lower Coleroon, and the Cauvery Delta. Collectively, these sub-basins encompass a total area of approximately 47,474.25 square kilometres. Administratively, the districts falling within this basin include Nilgiris, Erode, Thirupur, Karur, Namakkal, Dindigul, Trichy, Salem, Ariyalur, Mayiladuthurai, Thanjavur, Thiruvarur, and Nagapattinam. Additionally, smaller portions of Coimbatore, Krishnagiri, Dharmapuri, Perambalur, Cuddalore, and Pudukottai are also part of this basin's jurisdiction.

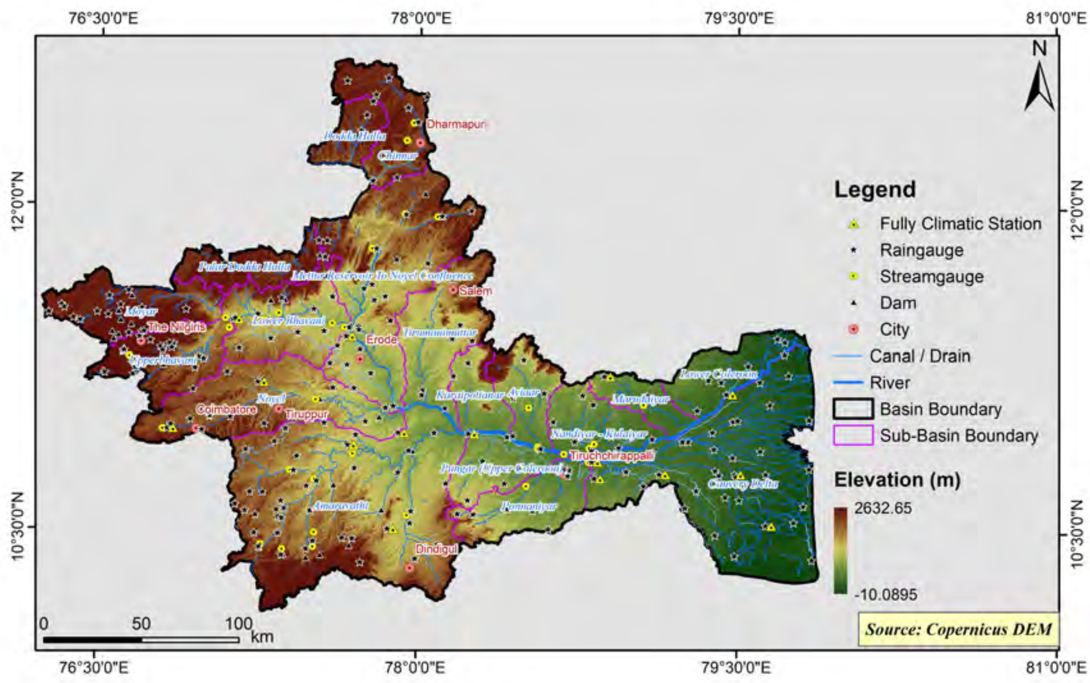


Fig. 28 Cauvery Basin Index map

The Cauvery basin is a perennial stream, and its catchment is in Karnataka. Tamil Nadu has an elevation of 2632.65 m above MSL, and the slope ranges between 0 and 35. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin in Tamil Nadu, as shown in Table 7.

Table 7. Hydro-Meteorological Observatories for Cauvery River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Chinnar	8	-	2
2	Dodda Halla	3	-	-
3	Mettur Reservoir to Noyel Confluence	26	1	3
4	Palar Dodda Halla	3	-	-
5	Moyar	13	-	1
6	Upper Bhavani	21	-	1
7	Lower Bhavani	15	1	4
8	Noyel	16	2	2
9	Tirumanimuttar	7	-	-
10	Amaravati	40	3	8
11	Karaipottanar	4	-	-
12	Ayiaar	3	-	2
13	Pungar	6	1	2
14	Ponnaniyar	11	-	2
15	Nandiyar-kulaiyar	7	-	2
16	Marudaiyar	2	1	1
17	Lower coleroon	7	-	-
18	Cauvery Delta	34	6	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (24%), sandy loam (24%), clay (14%), sandy clay (11%), clay loam (11%), loamy sand (6%), and 1% of equal proportion on loam, sand, silty clay and silty clay loam. This basin entirely falls under the agro-climatic zone of the Western, Northwestern, Cauvery Delta and Hilly regions. Henceforth, the primary land use of the Cauvery River basin is agricultural land (68.61%), forestland (15.78%), built-ups (7.74%), wasteland (3.3%), and wetland (0.94%). The waterbodies of this basin are covered by 3.64% as a whole, and the Pichavaram and Point Calimere are the well-known mangrove wetlands of Tamil Nadu, India.

4.2.1 Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Cauvery basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 29 and 30 illustrate the spatial distribution depicting the drought and flood risk within the Cauvery River basin.

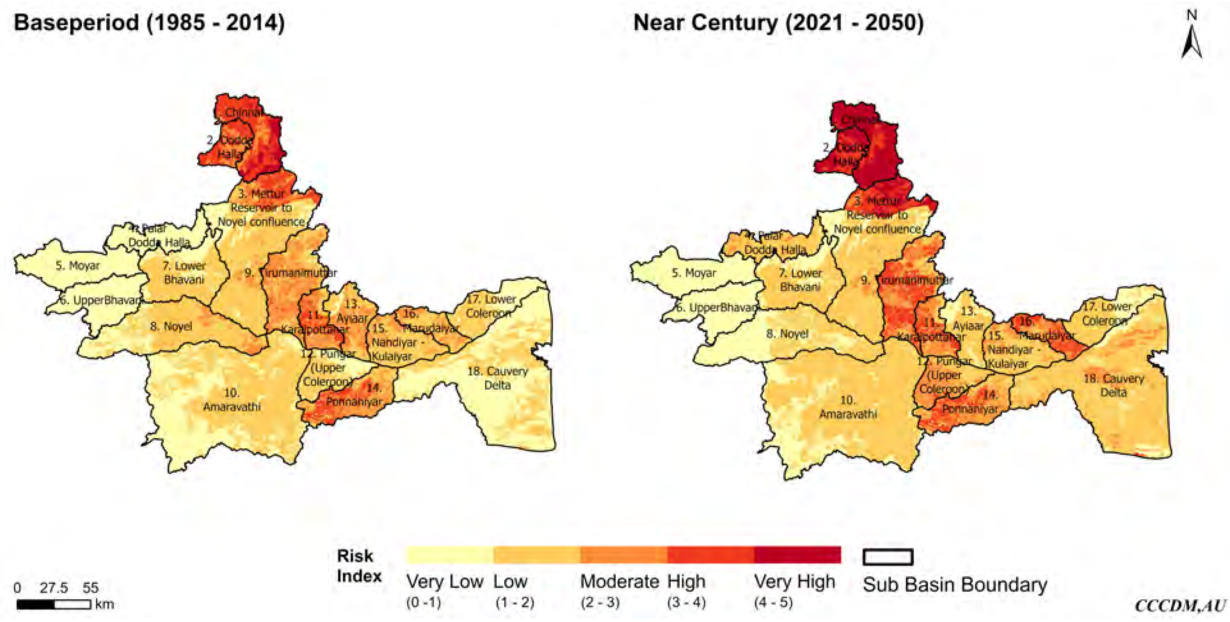


Fig. 29 Drought Risk Spatial Distribution of Cauvery River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

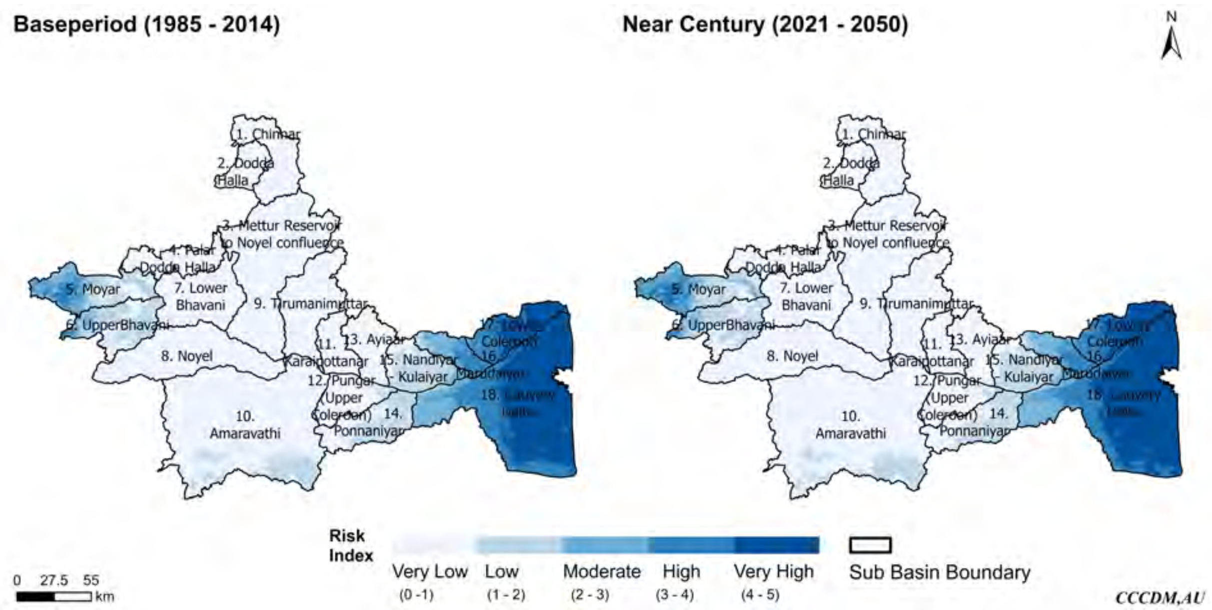


Fig. 30 Flood Risk Spatial Distribution of Cauvery River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, the critical sub-basins of the Cauvery River are Chinnar, Dodda Halla, and Mettur Reservoir to Noyel Confluence, which intensify similarly. During the base period, there were four drought years, and projections for the near century suggest continuing this pattern. Moreover, the expected drought magnitude was 4.4 in the base period, which is projected to increase to 5.5 in the future. Specifically, within the Cauvery Basin, the Chinnar sub-basin is anticipated to experience six drought years with a magnitude of 8 in the future scenario.

In flood risk assessment, the critical sub-basins of the Cauvery River are Lower Coleroon and Cauvery Delta, which intensify similarly. One-day extreme rainfall occurrences (RX1) are projected to rise by 47.9% in the Cauvery basin, while the number of extreme rainfall days (R25) is projected to increase by 79.1%. More precisely, it is anticipated that there will be a 21.6% rise in the frequency of extreme rainfall days and a 31.1% increase in extreme rainfall events in Lower Coleroon within the Cauvery basin.

Fig 31 displays the ranking of subbasins according to their assessment of drought and flood risks. Additionally, Table 8 presents the most crucial subbasin for prioritising future adaptation efforts.

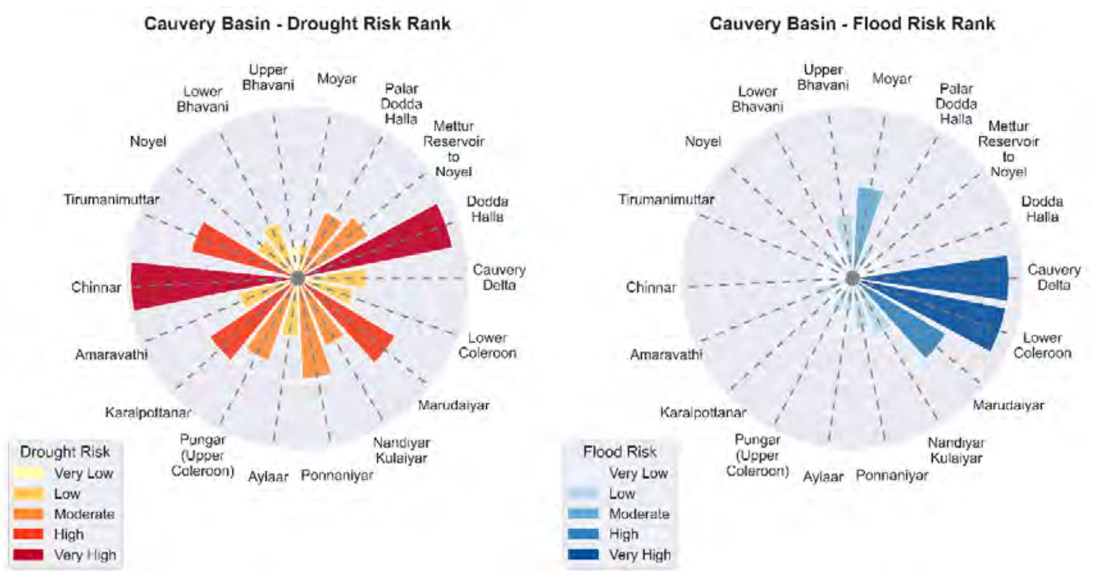


Fig. 31 Graphical Representation of Drought and Flood Risk for Cauvery Sub-basins

Table 8. Drought Risk and Flood Risk Critical Sub-Basins of Cauvery River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km²)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Cauvery (18)	47501	Chinnar, Dodda Halla, Mettur Reservoir to Noyel Confluence	Cauvery Delta, Lower Coleroon, Moyar

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to future in which the drought classification has a more significant shift from very low (14.28%) and medium (1.18%) class in baseline to low

(10.23%) and very high (4.33%) class in future. The overall flood risk remains the same for both baseline and future periods. The very low (0.3%) and high (0.9%) class of flood risk in baseline has a meagre shift to a very high (1.3%) class in the future period. Figs 32 and 33 provide information about the extent of drought and flood risk in terms of area for both the baseline and future scenarios.

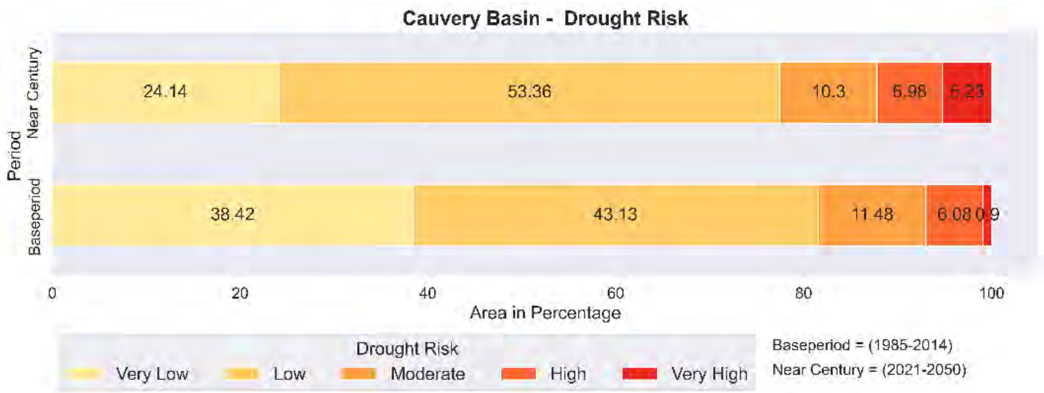


Fig. 32 Areal percentage of Drought Risk Assessment for Cauvery River Basin

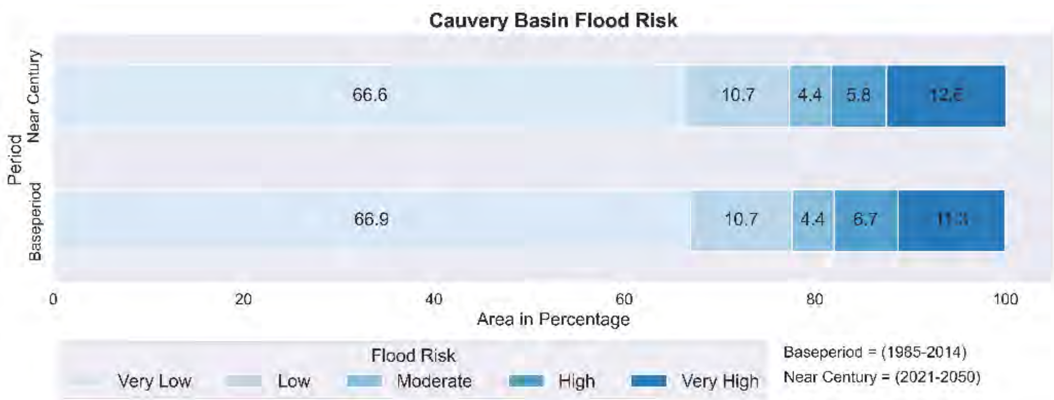


Fig. 33 Areal percentage of Flood Risk Assessment for Cauvery River Basin

According to the climate risk assessment, the Cauvery Basin is more prone to flood intensity and reduced drought conditions in future projections. It continues to be in the same area extent using climate extremes. The Cauvery River originates in Karnataka and drains into Tamil Nadu entirely as there is a Cauvery water issue, which is an inter-state dispute. The adaptation measure is somewhat complex, but the adaptive framework is more feasible sub-basin-wise. As part of climate-adaptive measures, this basin must be extended, renovated, and modernised (ERM) by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) existing works are;

1) Inter-linking of Peninsular Rivers, viz., Mahanadi - Godavari - Krishna - Pennar - Palar - Cauvery - Vaigai – Gundar link as flood carriers

2) Cauvery Delta Desilting Works

3) Canal Automation by Decision Support System (DSS) for efficient water management in the Grand Anicut System

4) Nadanthai Vaazhi Cauvery Project – Massive river rejuvenation programme

5) The Asian Development Bank (ADB) assisted the Climate Change Adaptation Programme in the Cauvery Delta (Phase-I), which was completed for six rivers in the Vennar and Cauvery sub-basins, for which monitoring and verification are in progress.

Upon execution of the projects mentioned above, the Cauvery basin, to some extent, can face future climate extremes of flood and drought. In addition, this basin is more likely to have faster socioeconomic growth and exceptionally rapid urbanisation. Therefore, the Cauvery River basin needs site-specific climate adaptation measures to face the future challenges of extremes.

4.3 Chennai River Basin

The Chennai river basin is a significant east-flowing river system in Tamil Nadu, characterised by its fan-shaped watershed boundary and represented in Fig 34. It is surrounded by the administrative boundary of Andhra Pradesh to the north and west, with the Palar basin bordering its southern region. The river ultimately flows into the Bay of Bengal to the east. Geographically, the basin's boundaries span from latitude 12°30'00" to 13°35'00" N and longitude 79°15'00" to 80°22'30"E.

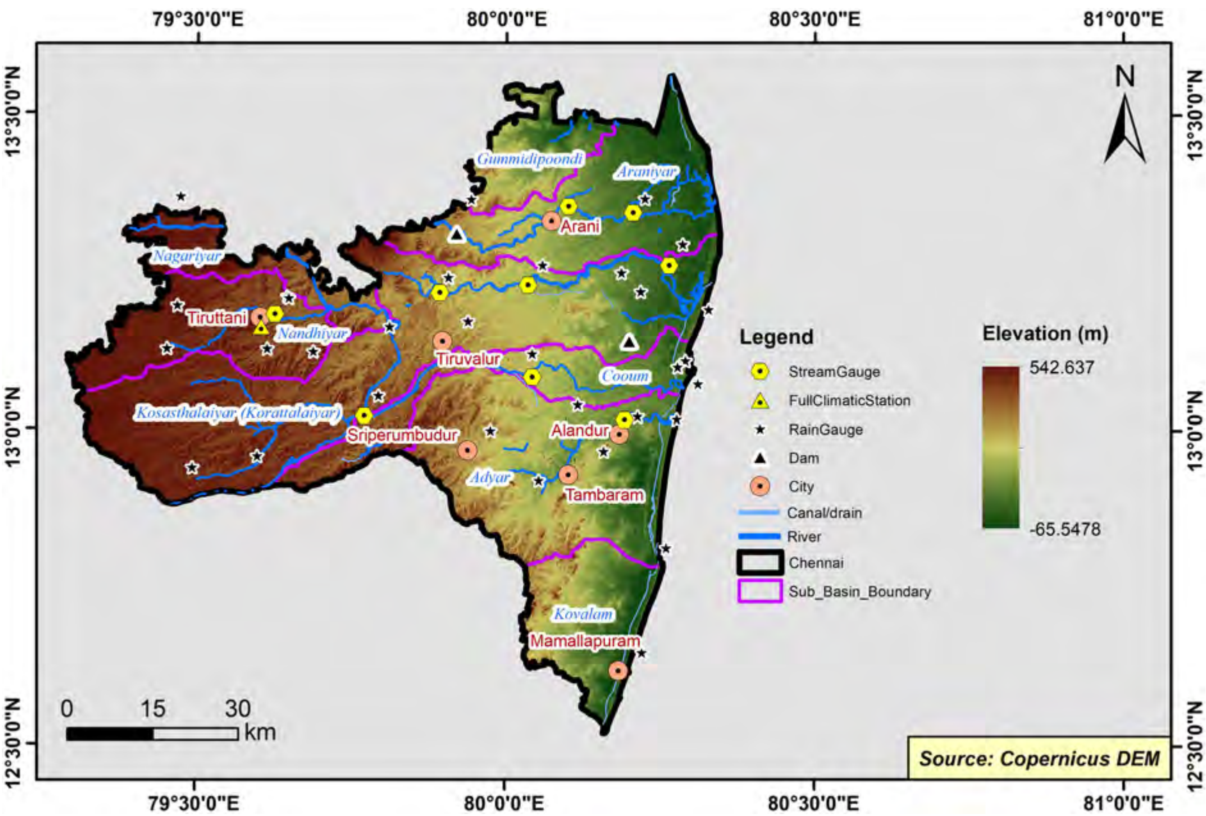


Fig. 34 Chennai Basin Index Map

Within the Chennai river basin, there are eight prominent rivers and their associated sub-basins, namely Nagariyar, Nandhiyar, Gummidipoondi, Araniyar, Kosasthalaiyar, Cooum, Adyar, and Kovalam, covering a total area of approximately 6,123.11 square kilometres. Administratively, this basin encompasses several districts, primarily Chennai and Thiruvallur, with smaller portions of Ranipet, Kancheepuram, and Chengalpattu falling within its jurisdiction.The Buckingham Canal is a natural freshwater navigation canal connecting the Coromandel Coast of India. Of its total length of 257 km, Tamil Nadu claims about 163 km, beginning from Chennai and extending to Cuddalore, with 31 km of the canal running through the Chennai river basin. Notable water resources for Chennai city are primarily supplied by the Poondi (Sathyamurthy) Reservoir, Sholavaram Lake, Red Hills Lake, and Chembarambakkam Lake.

Chennai basin is a non-forested catchment with an elevation of 542.637 m above MSL, and the slope ranges between 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 9 below. The soil texture of the basin consists of sandy loam (20.79%), sandy clay loam (15.41%), clay (13.8%), sandy clay (11.32%), loamy sand (6.83%), clay loam (5.39%), sand (2.7%), and silty clay (0.98%). This basin entirely falls under the agro-climatic zone of the Northeastern region. Henceforth, the major land use of the Chennai river basin is agricultural land (56.02%), built-ups (21.39%), wasteland (4.6%), forestland (3.47%), and wetland (2.42%). The waterbodies of this basin are covered by only 12.09% as a whole.

Table 9. Hydro-Meteorological Observatories for Chennai River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Nagariyar	1	-	-
2	Nandhiyar	6	1	1
3	Gummidipoondi	1	-	-
4	Araniyar	3	-	2
5	Kosasthalaiyar	14	-	3
6	Cooum	4	-	2
7	Adyar	7	-	1
8	Kovalam	1	-	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

Drought and Flood Risk Assessment

Based on IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought for the Chennai basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 35 and 36 depict the spatial distribution of the drought and flood risk in the Chennai river basin.

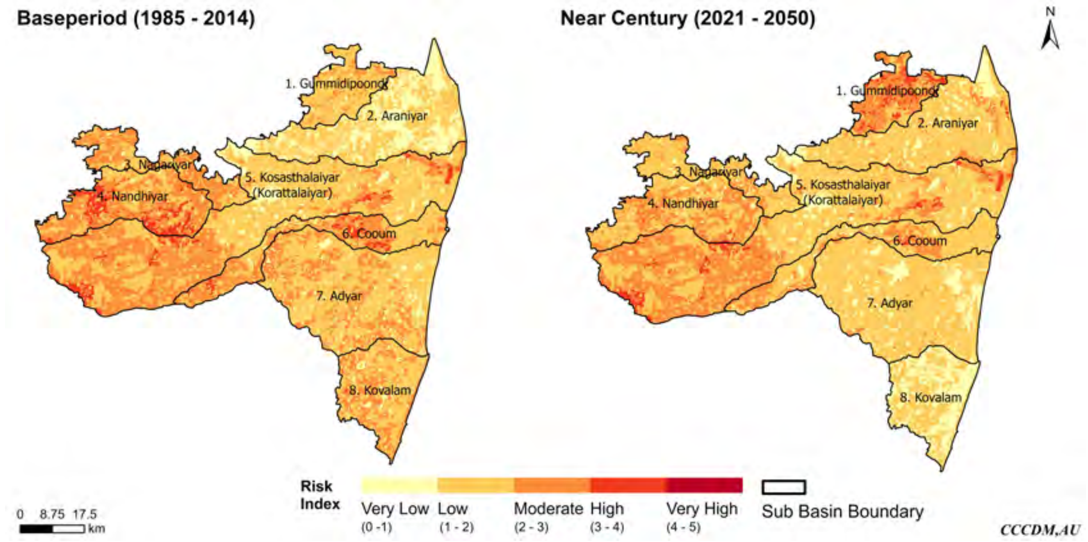


Fig. 35 Drought Risk Spatial Distribution of Chennai River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

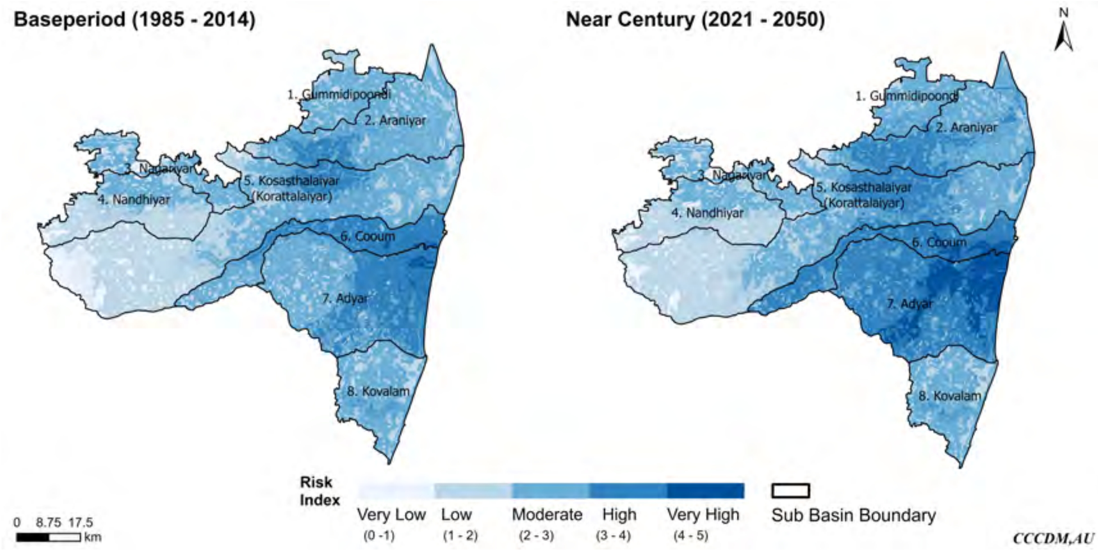


Fig. 36 Flood Risk Spatial Distribution of Chennai River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, Gummidipoondi and Kosasthalaiyar are the critical sub-basins for the Chennai River at baseline and will remain the same in the future. In the base period, they witnessed four drought years, while projections for the near century indicate an increase to 5 drought years. Additionally, the drought magnitude, which was 5.2 during the base period, is anticipated to rise to 6.7. Specifically, within the Chennai Basin, Gummidipoondi is expected to undergo six drought years with a magnitude of 9 in the future scenario.

In flood risk assessment, the critical sub-basin of Chennai River is colour and Adyar, which intensifies similarly. The Chennai basin is expected to experience a 30.8% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 60.9%. More specifically, within the Adyar sub-basin, there is an anticipated increase of 33.9% in extreme rainfall events and a 47.9% increase in extreme rainfall days. According to assessments of the hazards of drought and flooding, Fig 37 shows the subbasin's rankings. Table 10 also lists the most critical subbasin for ranking future adaptation efforts.

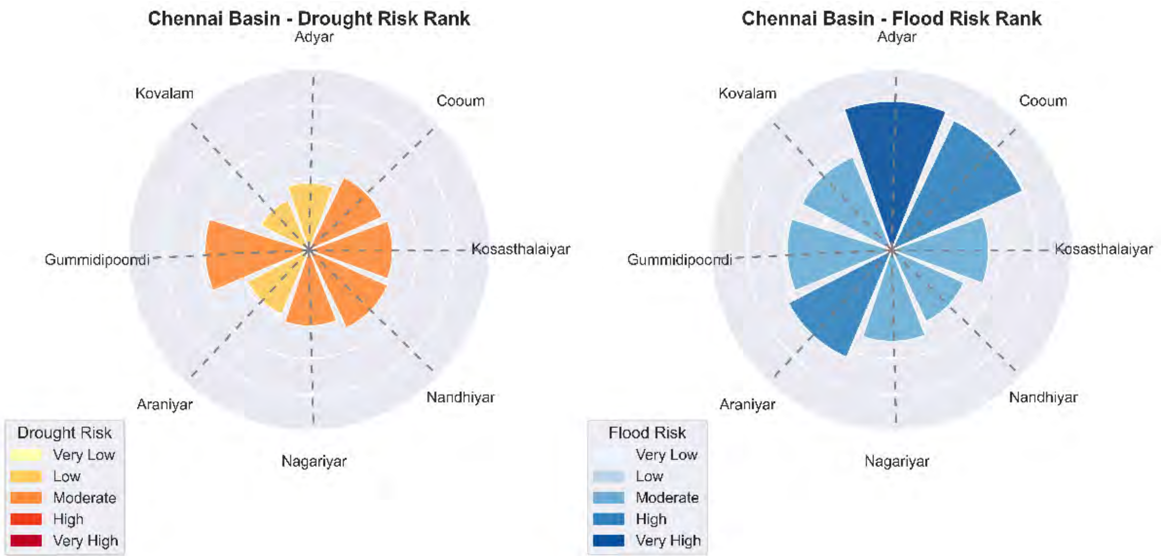


Fig. 37 Graphical Representation of Drought and Flood Risk for Chennai Sub-basins

Table 10. Drought Risk and Flood Risk Critical Sub-Basins of Chennai River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km²)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Chennai (8)	6122	Gummidipoondi, Kosasthalaiyar	Cooum, Adyar

(**SSP2-4.5 Scenario durning Near Century (2021 - 2050)*)

The overall drought risk is reduced from baseline to future, in which the drought classification has a more significant shift from high (1.03%) and medium (8.82%) classes in baseline to low (8.44%) and very low (1.41%) class in future. The overall flood risk is increasing tremendously from the baseline to future periods. The very low (2.2%), low (5.2%) and medium (8.1%) class of flood risk in baseline has a more significant shift to the high (10.3%) and very high (5.1%) class in a future period. Figs 38 and 39 indicate the risk area for both the baseline and the future scenarios' droughts and floods of the Chennai river basin.

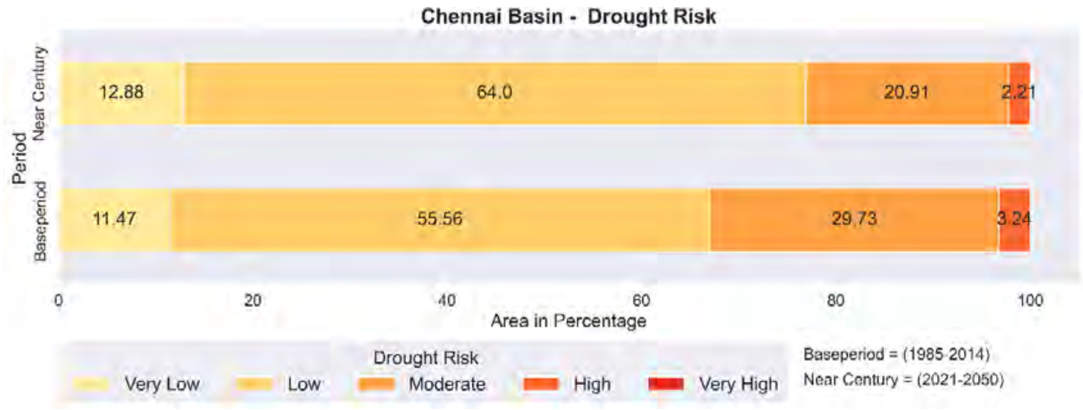


Fig. 38 Areal percentage of Drought Risk Assessment for Chennai River Basin

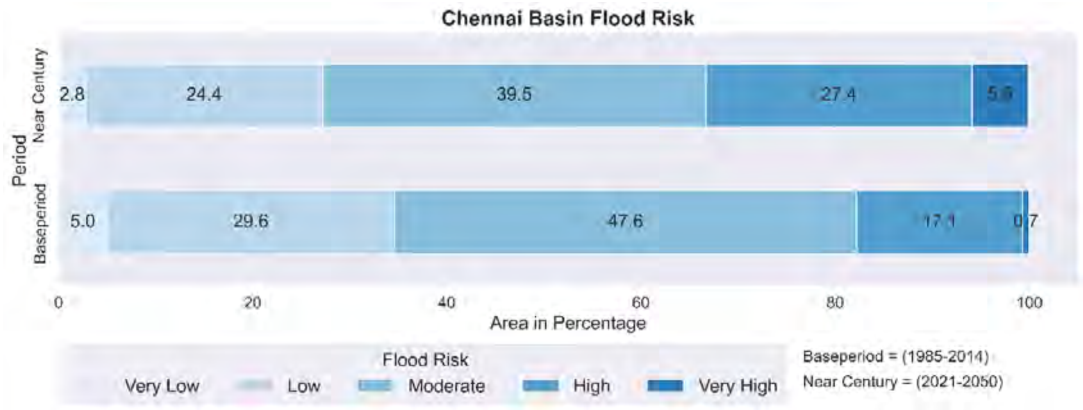


Fig. 39 Areal percentage of Flood Risk Assessment for Chennai River Basin

According to the climate risk assessment, the Chennai basin is less prone to drought and increased flood intensity for future projections. It is continuously expanding and contracting flood and drought intensity to an extent by means of climate extremes. As part of climate-adaptive measures, this basin has to be conserved, restored, and monitored, as well as its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) execution works are;

Tamil Nadu - Satellite-Based Water Bodies Information, Monitoring and Protection System (TN-SWIP), especially for Chennai.

1. The primary water resources of the Chennai basin are Cholavaram Tank and Poondi Reservoir, which will be augmented by increasing their capacity; meanwhile, the desolation of Chembarambakkam Tank will also be executed.

2. Preparing a detailed project evaluation for a pilot project in Chennai, including flood mitigation and climate change, and the supply of additional water to Chennai City is in progress.

3. Adyar and Cooum River restoration works by desilting and widening the river mouth

4. Demarcation of Buckingham Canal, which lost its width over the period

5. Rehabilitation and Renovation of existing tanks, Flood mitigation works

7. New sluices, cut and cover channels were proposed in and around the Chennai basin

Upon execution of the listed projects, the Chennai basin will have the capacity to withstand future climate extremes of flood and drought. Furthermore, the flood pattern is being intensified in future projections. In addition, Chennai is considered a hotspot of rapid economic growth in industrialisation and urbanisation, and the climate adaptation framework is necessary to avoid loss and damage caused by extreme events.

4.4 Gundar River Basin

The Gundar river basin is a significant east-flowing river system in Tamil Nadu, characterised by its cylindrical-shaped watershed boundary and represented in Fig 40. The Vaigai basin surrounds it to the northwestern part and the Vaippar basin to the south, with the river ultimately flowing into the Palk Strait and Palk Bay in the southeastern direction. Geographically, the basin's boundaries range from latitude 9°05'00" to 10°03'00" and longitude 77°35'00" to 78°35'00". Within the Gundar river basin, there are nine prominent rivers and their respective sub-basins, including Upper Gundar, Therkar, Kanal Odai, Gridhamal, Paralaiyar, Lower Gundar, Utharakosamangaiyar, Palar, and Vembar, collectively covering a total area of approximately 5,734.85 square kilometres. This basin includes several districts, primarily Madurai, Virudhunagar, and Ramanathapuram, with smaller parts of Sivagangai and Thoothukudi falling within its jurisdiction.

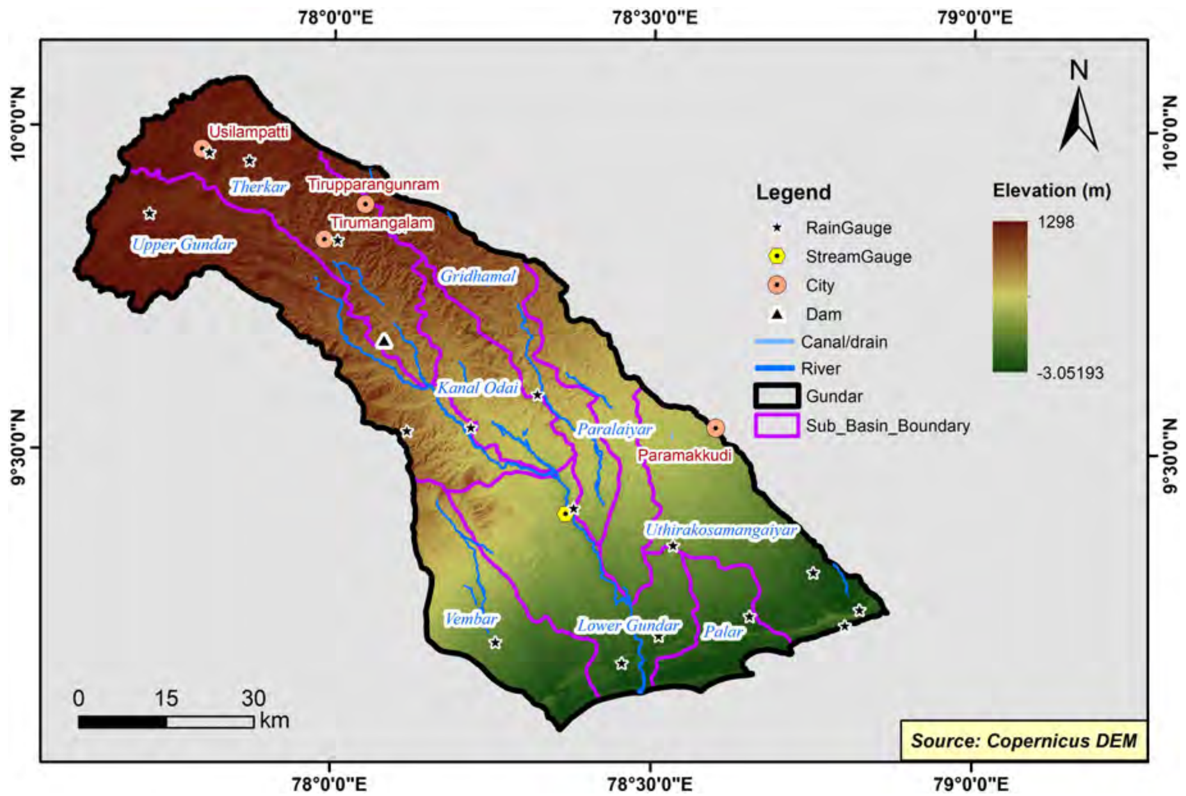


Fig. 40 Gundar Basin Index map

Gundar basin originates from the Eastern Ghats and forested catchment with an elevation of 1298 m above MSL, and the slope ranges between 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 11 below.

Table 11. Hydro-Meteorological Observatories for Gundar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Upper Gundar	3	-	-
2	Therkar	3	-	-
3	Kanal Odai	1	-	
4	Gridhamal	1	-	-
5	Paralaiyar	-	-	-
6	Lower Gundar	3	-	1
7	Utharakosamangaiyar	4	-	-
8	Palar	1	-	-
9	Vembar	1	-	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (22.77%), sandy loam (22.17%), clay (14.25%), sandy clay (12.67%), clay loam (10%), sand (4.31%), and loamy sand (3.68%). This basin entirely falls under the agro-climatic zone of the southern region. Henceforth, the primary land use of the Gundar River basin is agricultural land (79.03%), built-ups (4.1%), wasteland (3.82%), forestland (2.38%), and wetland (0.74%). The waterbodies of this basin are covered by only 9.94% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Gundar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). The spatial distribution of drought and flood risk of the Gundar River basin is shown in Figs 41 and 42.

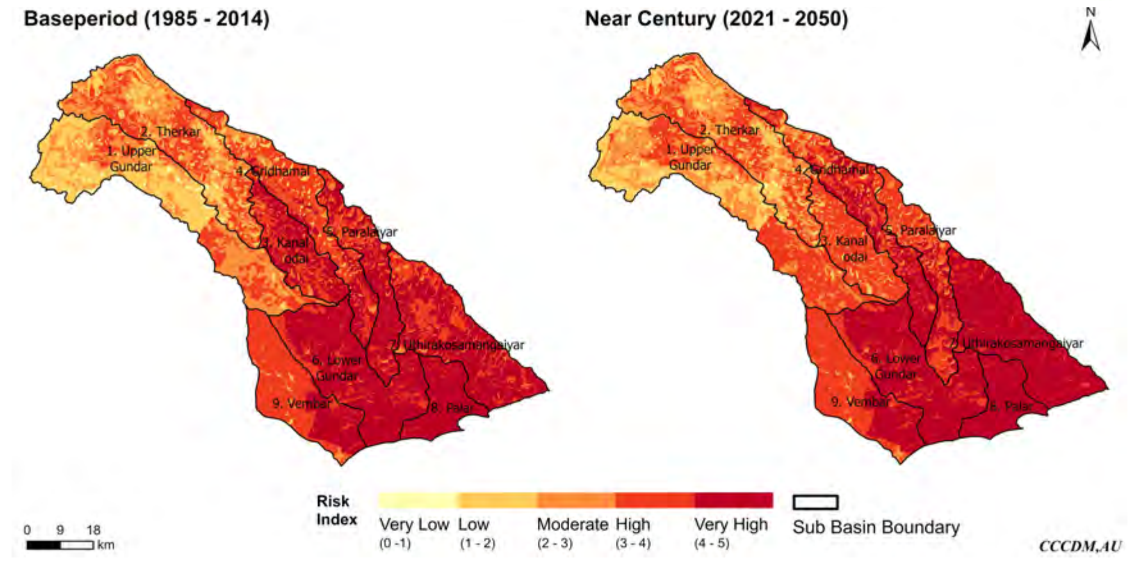


Fig. 41 Drought Risk Spatial Distribution of Gundar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

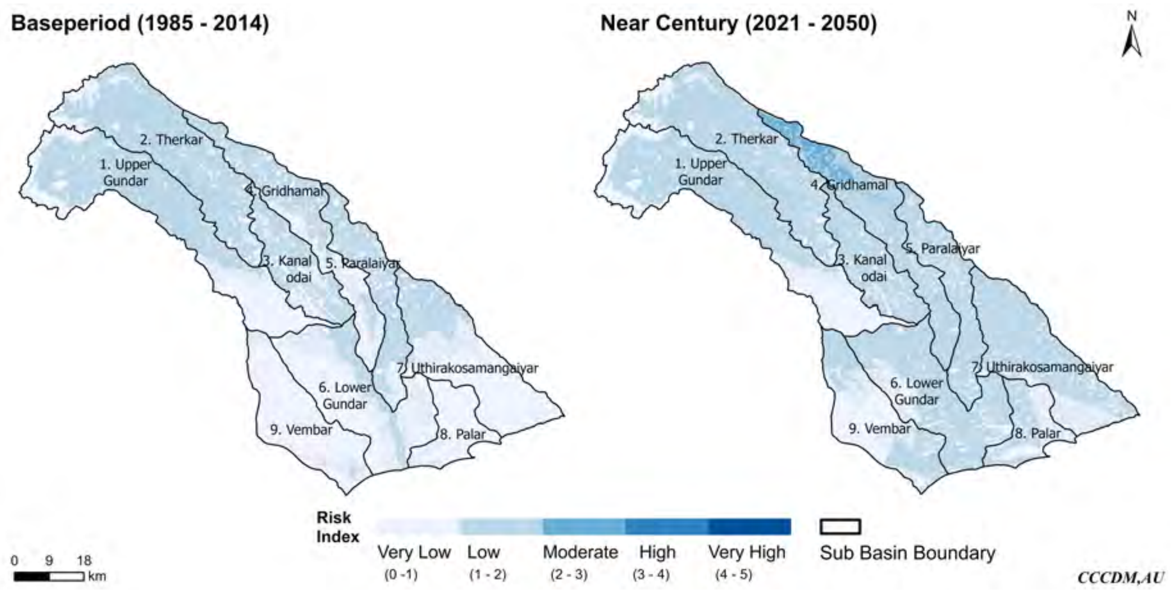


Fig. 42 Flood Risk Spatial Distribution of Gundar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, the critical sub-basins of the Gundar River are Uthirakosamangaiyar, Palar, Vembar, Lower Gundar, Kanal Odai and Paralaiyar. In contrast, it gets intensified in the same except for Kanal Odai and Paralaiyar but has a shift to the Gridhamal sub-basin. In the base period, we witnessed five drought years, while projections for the near century indicate an increase to 7 drought years. Additionally, the drought magnitude, 6.3 during the base period, is anticipated to rise to 9.2. Specifically, in the Gundar, the Palar sub-basin is expected to undergo eight drought years with a magnitude of 11 in the future scenario.

In flood risk assessment, there is no critical subbasin for Gundar River at the baseline, and it will remain the same. The Gundar basin is expected to experience a 61.7% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 115.2%. More specifically, within the Gridhamal sub-basin, there is an anticipated increase of 53.7% in extreme rainfall events and a 111.8% increase in extreme rainfall days. The subbasin ranking based on the drought and flood risk assessment is shown in Fig 43, and the most critical subbasin to be prioritised for future adaptation work is given in Table 12.

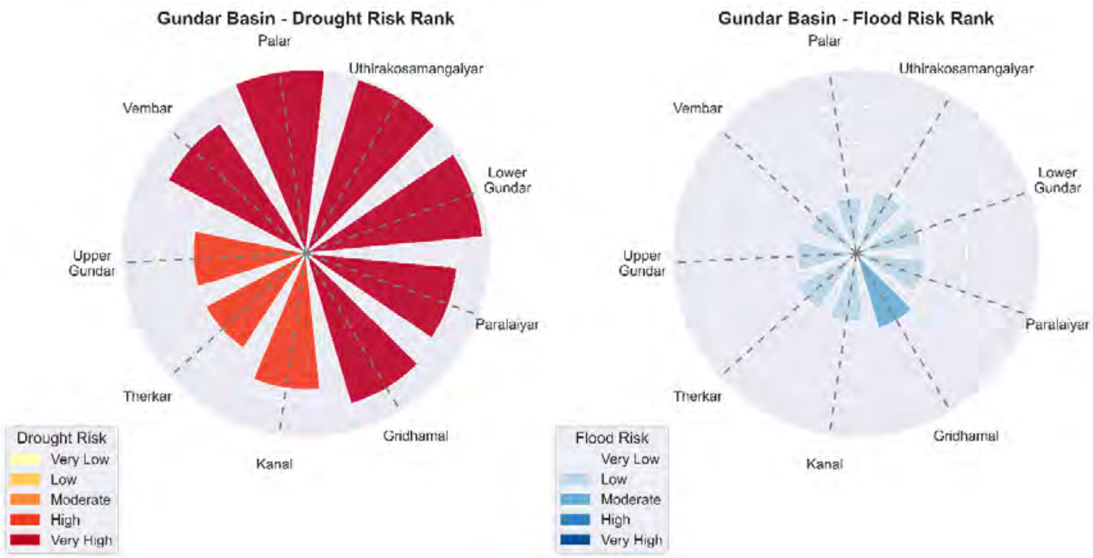


Fig. 43 Graphical Representation of Drought and Flood Risk for Gundar Sub-basins

Table 12. Drought Risk and Flood Risk Critical Sub-Basins of Gundar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Gundar (9)	5740	Uthirakosamangaiyar, Palar, Vembar, Lower Gundar, Gridhamal	-

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from low (2.54%), medium (0.78%) and very high (0.6%) class in baseline to high (4.25%) class in future. The overall flood risk remains the same for both baseline and future periods. The medium (8.6%) class of flood risk in baseline has a shift to low (5.4%) and very low (3.1%) in future periods. The areal extent of drought and flood risk for the baseline and future scenarios is given in Figs 44 and 45.

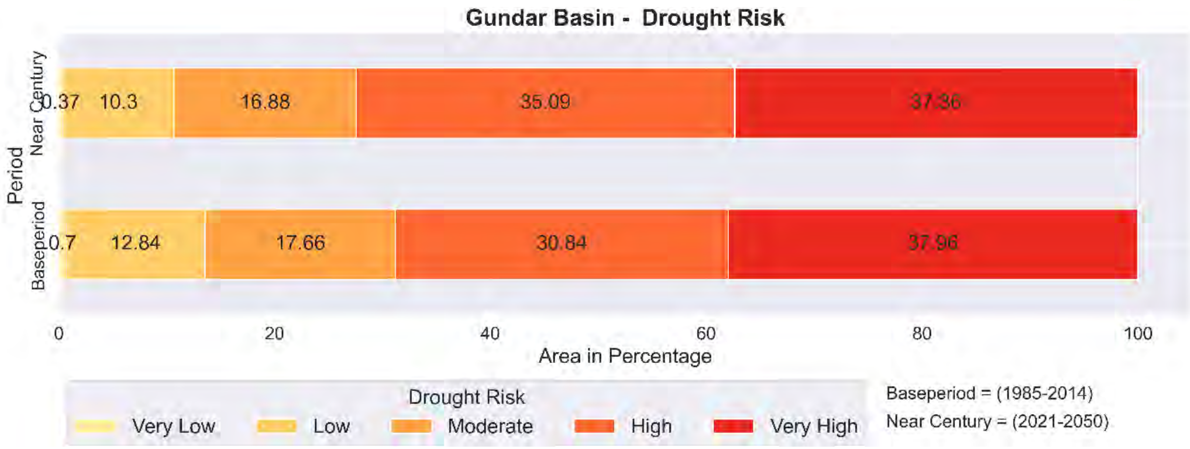


Fig. 44 Areal percentage of Drought Risk Assessment for Gundar River Basin

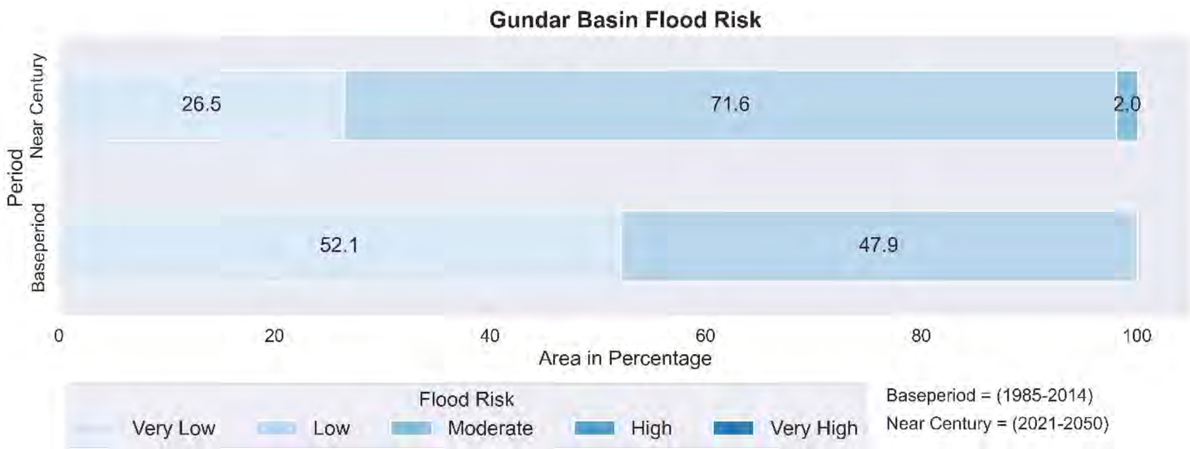


Fig. 45 Areal percentage of Flood Risk Assessment for Gundar River Basin

According to the climate risk assessment, the Gundar basin is not flood-prone but has drought intensity in future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. In addition, the TN-PWD Water Resources Department (WRD) had a new proposal on linking the Gundar River with Cauvery and Vaigai to meet the irrigation demand, which is to be implemented in Phase III. On execution of this project, the Gundar basin will meet the demand on irrigation demand and withstand the future climate extremes of flood and drought. In addition, there is a need to frame future climate adaptive measures that are site-specific to meet the water demand during dry seasons by improving the surface and groundwater scales.

4.5 Kallar River Basin

The Kallar River basin is a significant southeast-flowing river system in Tamil Nadu, characterised by its box-shaped watershed boundary and represented in Fig 46. It is surrounded by the Vaippar basin to the northwestern part and the Tamiraparani basin to the south, with the river ultimately flowing into the Gulf of Mannar in the southeastern direction. Geographically, the basin's boundaries range from latitude 8°41'00" to 9°10'30" and longitude 77°48'00" to 78°15'00". Within the Kallar river basin are three prominent rivers and their respective sub-basins, including Kallar, Challikulamar, and Korampallam, collectively covering a total area of approximately 1,506.67 square kilometres. Administratively, this basin falls within the jurisdiction of the Thoothukudi district.

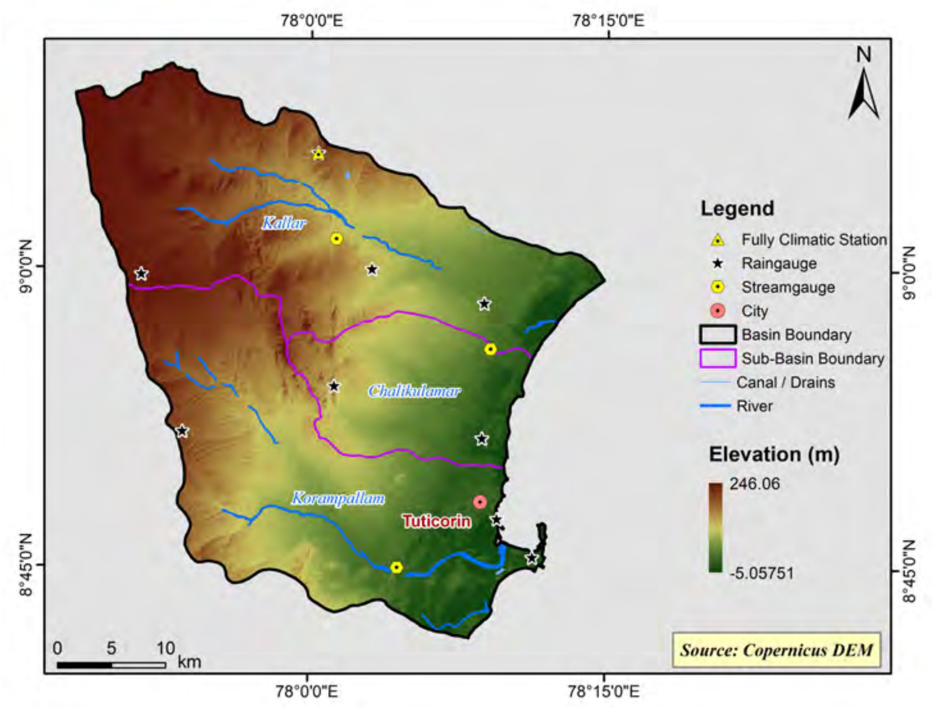


Fig. 46 Kallar River Basin Index map

Kallar basin is a small and non-forested catchment with an elevation of 246.06 m above MSL, and the slope ranges between 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 13 below. The soil texture of the basin consists of sandy clay (21.27%), sandy loam (20.63%), clay loam (18.13%), sandy clay loam (17.64%), clay (6.98%), loamy sand (4.85%), and sand (3.57%). This basin entirely falls under the agro-climatic zone of the southern region. Henceforth, the major land use of the Kallar River basin is agricultural land (81.25%), built-ups (6.17%), wetland (4.55%), wasteland (1.86%), and forestland (1.19%). The waterbodies of this basin are covered by 4.97% as a whole.

Table 13. Hydro-Meteorological Observatories for Kallar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Kallar	4	1	1
2	Challikulamar	2	-	1
3	Korampallam	3	-	1

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Kallar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 47 and 48 illustrate the spatial distribution depicting the drought and flood risk within the Kallar River basin.

In drought risk assessment, the critical sub-basins of the Kallar River are Kallar and Chalikulamar, which will intensify only in the future. The base period witnessed four drought years, while projections for the near century indicate an increase to 7 drought years. Additionally, the drought magnitude, which was 4.8 during the base period, is anticipated to rise to 8.9. Specifically, in the Kallar, Chalikulamar sub-basin is expected to undergo eight drought years with a magnitude of 11 in the future scenario.

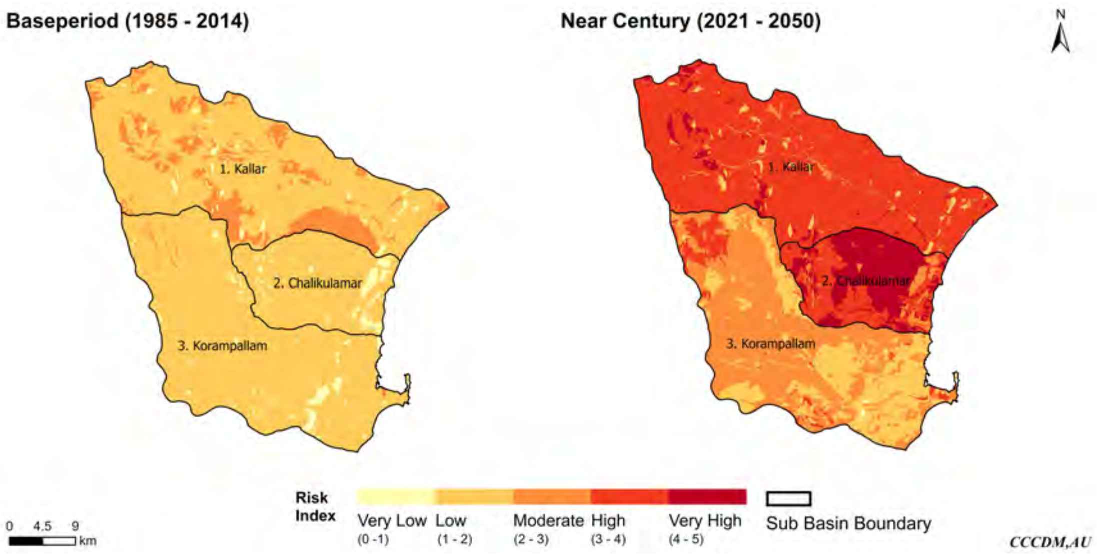


Fig. 47 Drought Risk Spatial Distribution of Kallar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

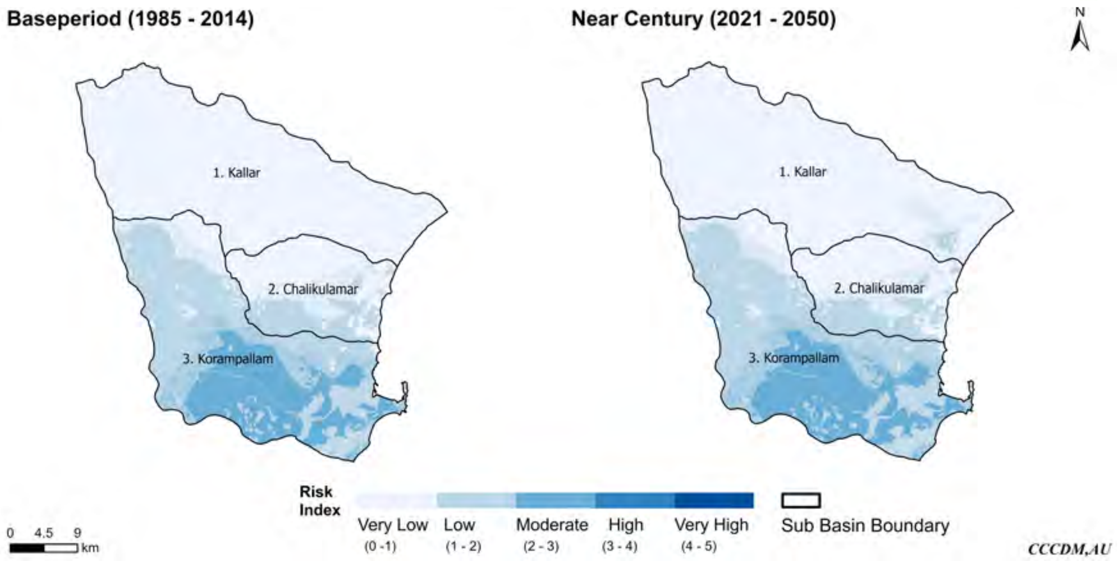


Fig. 48 Flood Risk Spatial Distribution of Kallar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In flood risk assessment, there is no critical subbasin for Kallar River at the baseline, and it will remain the same. The Kallar basin is expected to experience an 83.7% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 142.4%. More specifically, within the Korampallam sub-basin, there is an anticipated increase of 89% in extreme rainfall events and a 120.2% increase in extreme rainfall days. Fig 49 displays the ranking of subbasins according to their assessment of drought and flood risks. Additionally, Table 14 presents the most crucial subbasin for prioritising future adaptation efforts.

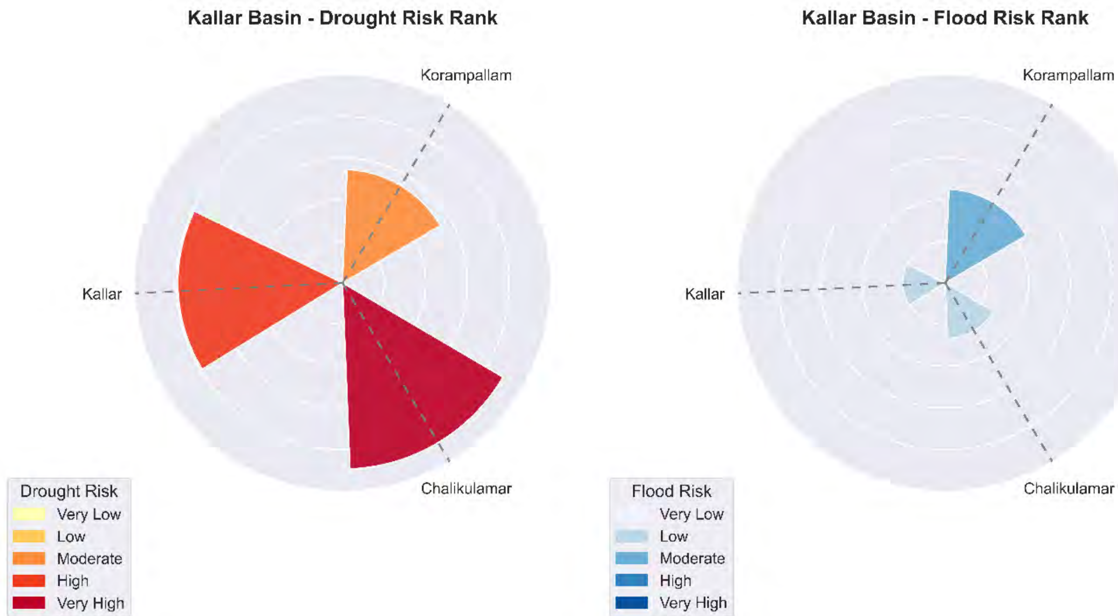


Fig. 49 Graphical Representation of Drought and Flood Risk for Kallar Sub-basins

Table 14. Drought Risk and Flood Risk Critical Sub-Basins of Kallar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Kallar (3)	1507	Chalikulamar	-

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from very low (3.56%) and low (72.83%) class in baseline to medium (17.49%), high (48.94%) and very high (9.82%) class in future. The overall flood risk remains the same for both baseline and future periods. The very low (0.9%) class of flood risk in baseline has shifted to low (0.9%) in the coming period. Figs 50 and 51 provide information about the extent of drought and flood risk in terms of area for both the baseline and future scenarios.

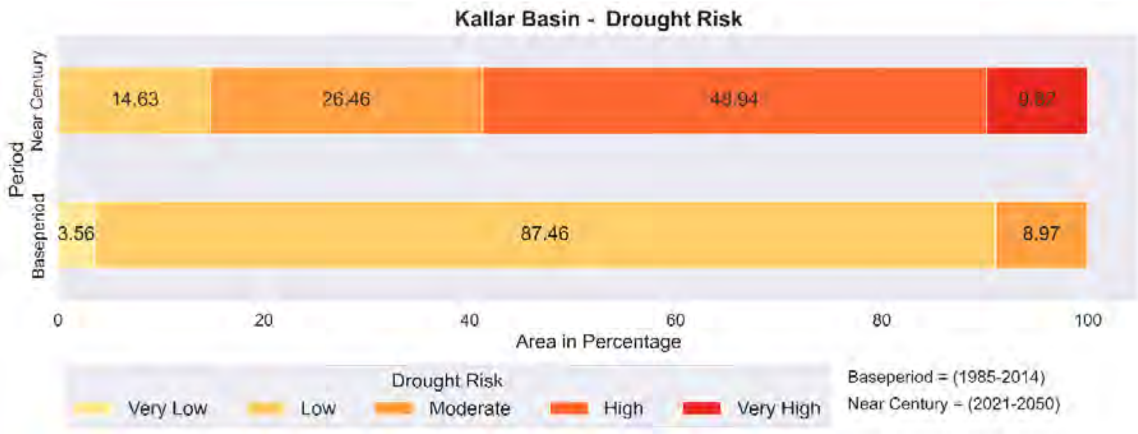


Fig. 50 Areal percentage of Drought Risk Assessment for Kallar River Basin

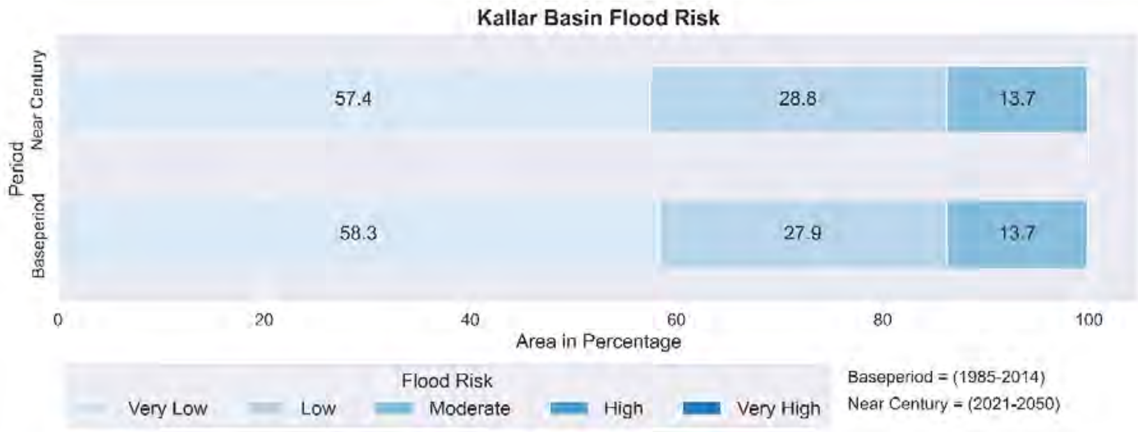


Fig. 51 Areal percentage of Flood Risk Assessment for Kallar River Basin

Based on the climate risk assessment, the Kallar basin is not prone to flood but has drought intensity in future projections. It continues to have the same characteristics in terms of climate extremes.

As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. In addition, the TN-PWD Water Resources Department (WRD) had a new proposal on linking the Malattar River under the Kallar basin with the Tamiraparani River to meet domestic and irrigation demands. Upon executing this project, the Kallar basin will meet the water demand and withstand future climate extremes of drought conditions. In addition, there is a need to frame future climate adaptive measures that are site-specific to meet the water demand during dry seasons by improving the surface and groundwater scales.

4.6 Kodaiyar River Basin

The Kodaiyar river basin is a unique south-flowing river system in Tamil Nadu, characterised by its triangular-shaped watershed boundary and represented in Fig 52. It is surrounded by the Tamiraparani and Nambiyar basins to the northern part and the Western Ghats to the west, with the river ultimately flowing into the Arabian Sea in the southern direction. Geographically, the basin's boundaries range from latitude 08°04’34” to 08°34’35” and longitude 77°05’53” to 77°35”39”.

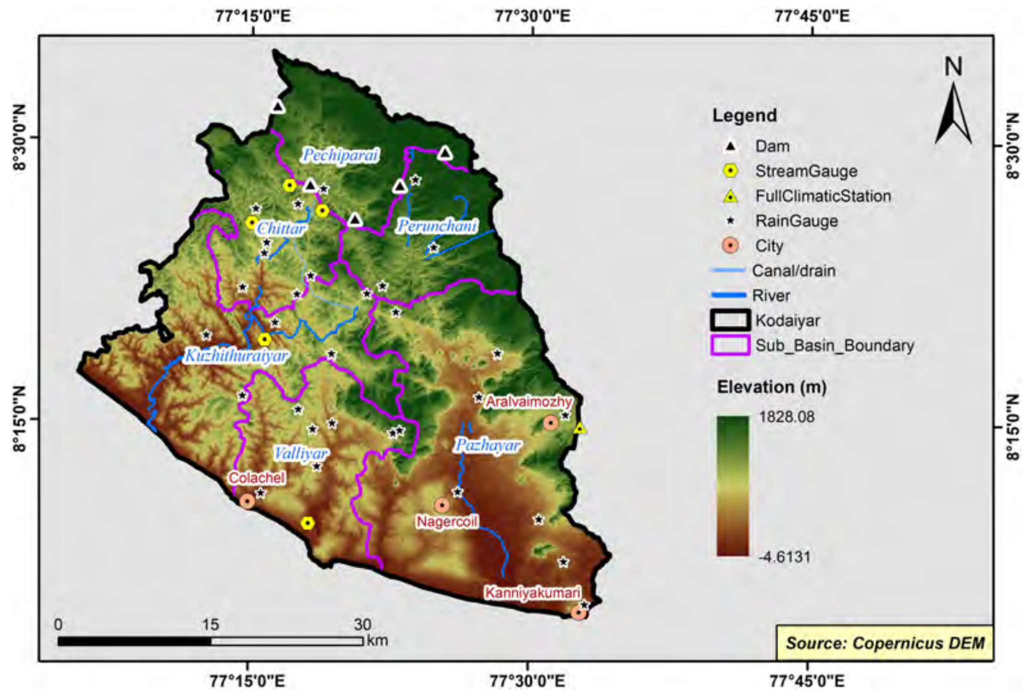


Fig. 52 Kodaiyar River Basin Index Map

Within the Kodaiyar river basin, there are six prominent rivers and their respective sub-basins, including Pechiparai, Chittar, Perunchani, Kuzhithuraiyar, Valliyar, and Pazhaiyar, collectively covering a total area of approximately 1,618.87 square kilometres. Administratively, this basin falls within the jurisdiction of the Kanyakumari district, with smaller parts of Tirunelveli included within its boundaries. Kodaiyar basin originates from the Western Ghats and densely forested catchment that has an elevation of 1828.08 m above MSL, and the slope ranges between 0 and 35. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 15 below.

Table 15. Hydro-Meteorological Observatories for Kodaiyar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Pechiparai	1	-	-
2	Chittar	7	-	3
3	Perunchani	3	-	-
4	Kuzhithuraiyar	5	-	1
5	Valliyar	6	-	1
6	Pazhaiyar	8	1	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (44.45%), clay (33.41%), sandy clay (23.83%), sandy loam (17.52%), sand (5.74%), loamy sand (5.1%), clay loam (0.18%) and loam (0.03%). This basin entirely falls under the agro-climatic zone of high rainfall region. Henceforth, the major land use of the Kodaiyar River basin is agricultural land (48.19%), forestland (24.62%), built-ups (18.36%), wasteland (4.35%), and wetland (0.44%). The waterbodies of this basin are covered by nearly 4.04% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Kodaiyar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 53 and 54 depict the spatial distribution of the drought and flood risk in the Kodaiyar River basin.

In drought risk assessment, there is no critical sub-basin under the Kodaiyar River for both the baseline and the future. The base period witnessed three drought years, while projections for the near century indicate an increase to 4 drought years. Additionally, the drought magnitude, which was 3.4 during the base period, is anticipated to rise to 5.3. Specifically, in the Agniyar, the Valliyar sub-basin is expected to undergo six drought years with a magnitude of 7 in the future scenario.

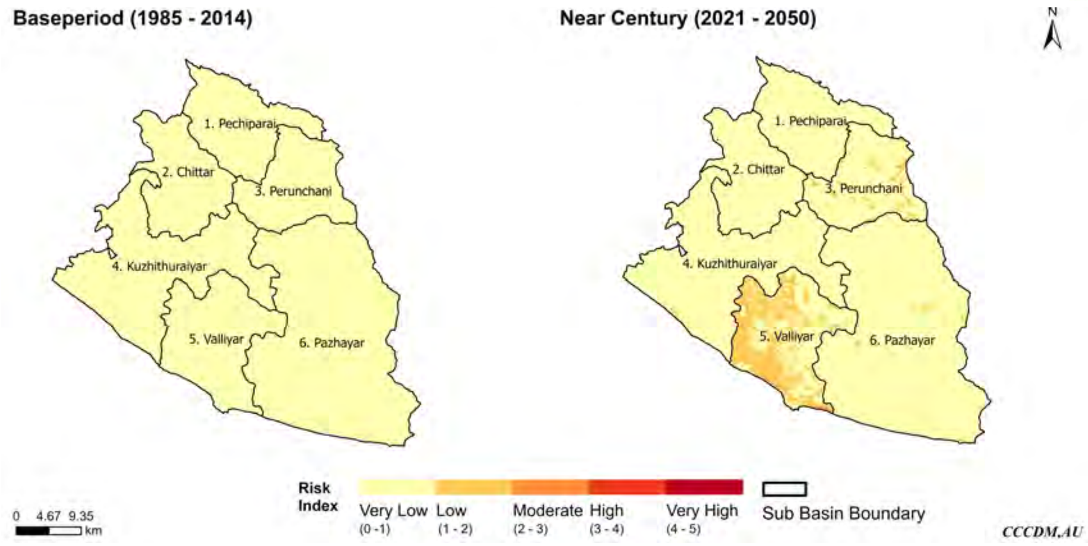


Fig. 53 Drought Risk Spatial Distribution of Kodaiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

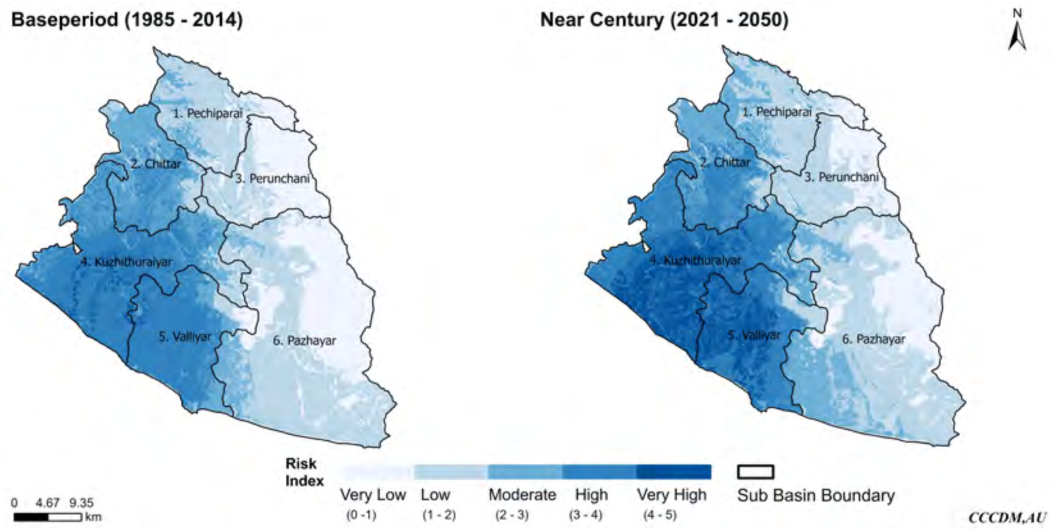


Fig. 54 Flood Risk Spatial Distribution of Kodaiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In flood risk assessment, the critical sub-basin for Kodaiyar River is Kuzhithuraiyar in baseline and remains the same in addition to the Valliyar sub-basin in the future. The Kodaiyar basin is expected to experience a 32.5% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 175.4%. More specifically, within the Kuzhithuraiyar sub-basin, there is an anticipated increase of 18.6% in extreme rainfall events and a 165.9% increase in extreme rainfall days.

According to assessments of the hazards of drought and flooding, Fig 55 shows the subbasin's rankings. Table 16 lists the subbasin most important for ranking future adaptation efforts.

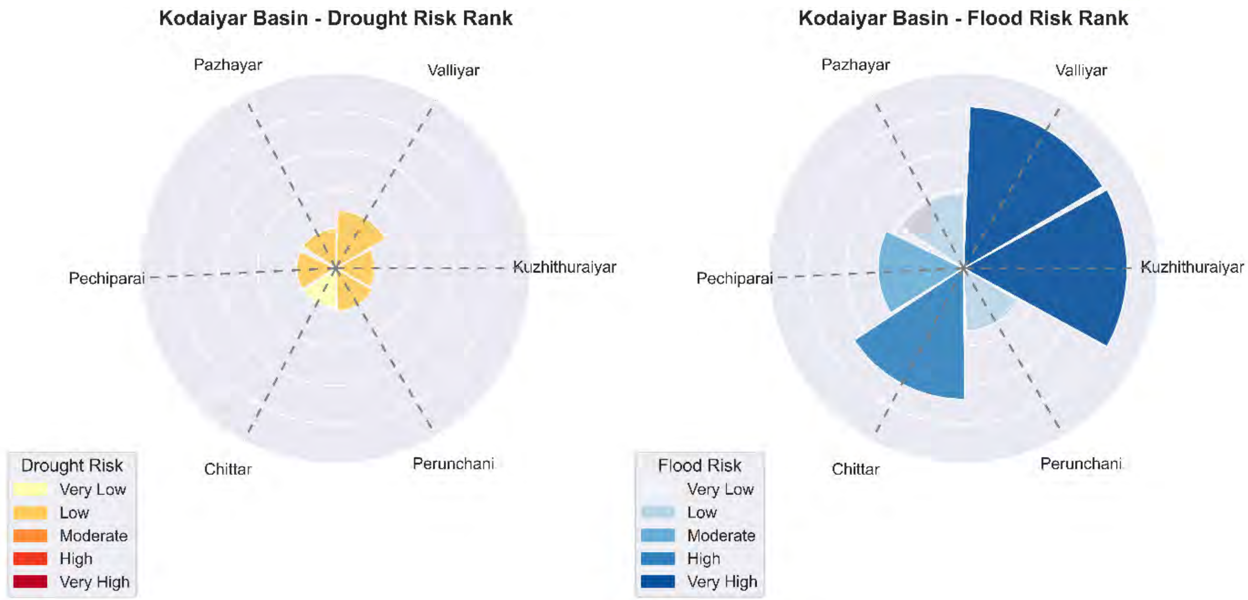


Fig. 55 Graphical Representation of Drought and Flood Risk for Kodaiyar Sub-basins

Table 16. Drought Risk and Flood Risk Critical Sub-Basins of Kodaiyar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Kodaiyar (6)	1620	-	Kuzhithuraiyar, Valliyar

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to the future, in which the drought classification shifts from a very low class in baseline to a low (7.7%) class in the future. The overall flood risk intensifies from the baseline to future periods. The very low (8.15%) and high (3.8%) class of flood risk in baseline has a shift to low (0.5%), medium (0.9%) and very high (10.5%) in future periods. Figs 56 and 57 indicate the risk area for both the baseline and the future scenarios' droughts and floods of the Kodaiyar river basin.

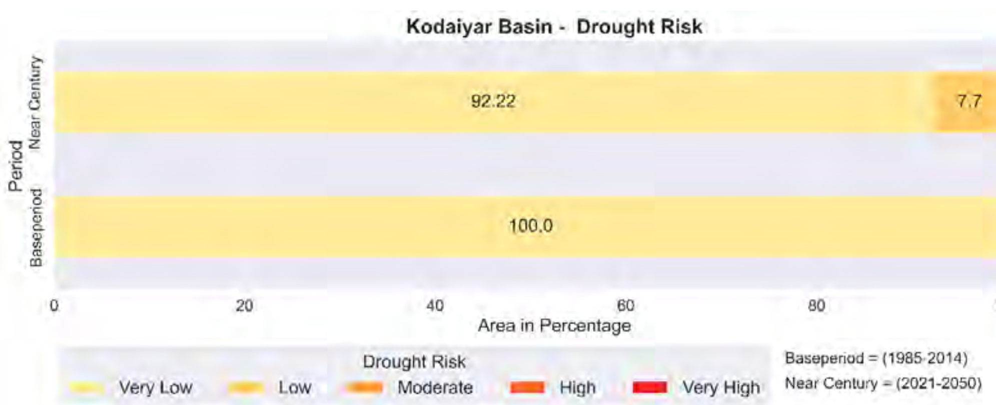


Fig. 56 Areal percentage of Drought Risk Assessment for Kodaiyar River Basin

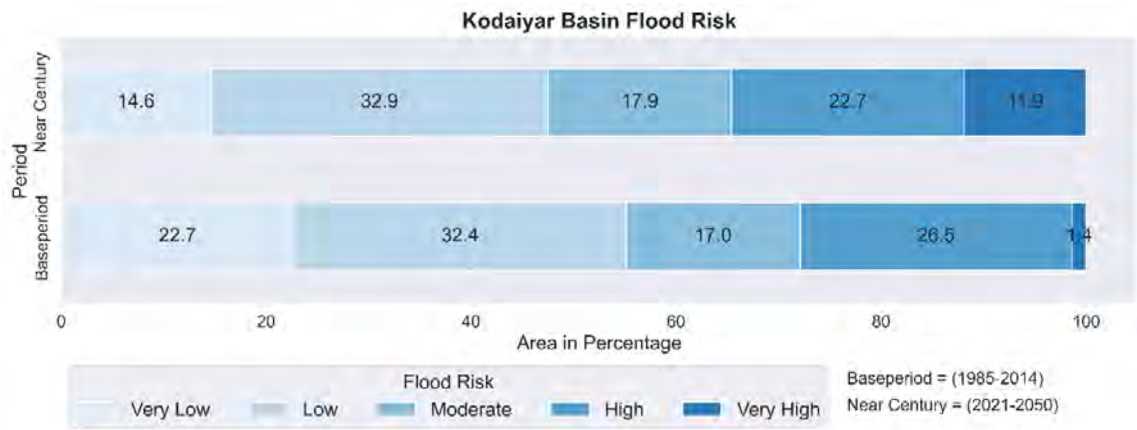


Fig. 57 Areal percentage of Flood Risk Assessment for Kodaiyar River Basin

According to the climate risk assessment, the Kodaiyar basin is not drought-prone but has flood intensity in future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) had proposed desilting works, permanent restoration works on flood damages for the Kanyakumari district were sanctioned and in progress and a proposal for an automated community micro-irrigation system in the Kodaiyar basin. Upon executing this project, the Kodaiyar basin can withstand future climate extremes of flood and drought. The addition of more water harvesting structures will conserve the watersheds of the Kodaiyar basin.

4.7 Nambiyar River Basin

The Nambiyar river basin is one of the south-east flowing rivers in Tamil Nadu, characterised by its conical-shaped watershed boundary and represented in Fig 58. The Western Ghats surround it to the west, the Tamiraparani river basin to the northern part, and the Kodaiyar river basin to the south. The river ultimately flows into the Palk Strait and the Bay of Bengal in the eastern direction. Geographically, the basin's boundaries range from latitude 08°08'00" to 08°33'00" and longitude 77°28'00" to 78°15'00". Within the Nambiyar River basin are three prominent rivers and their respective sub-basins, including Karumeniyar, Nambiyar, and Hanumanadhi, collectively covering approximately 2,000.75 square kilometres. This basin falls within the jurisdiction of the Tirunelveli district, with smaller parts of Thoothukudi included within its boundaries.

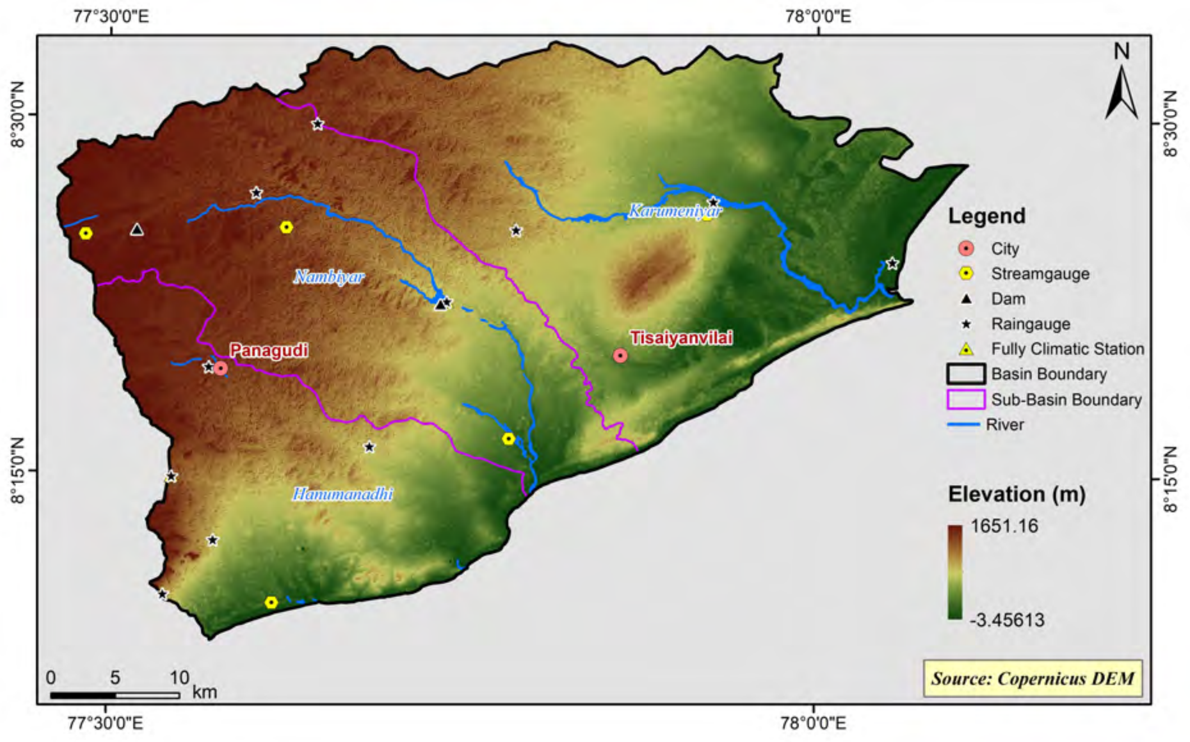


Fig. 58 Nambiyar River Basin Index map

Nambiyar basin is a non-forested catchment with an elevation of 1651.16 m above MSL, with a slope of 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 17 below.

Table 17. Hydro-Meteorological Observatories for Nambiyar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Hanumanadhi	5	-	1
2	Nambiyar	3	-	3
3	Karumeniyar	3	-	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of clay (22.36%), sandy clay (21.56%), sandy clay loam (21.01%), sandy loam (18.4%), clay loam (4.56%), sand (1.45%), and loamy sand (1.12%). This basin entirely falls under the agro-climatic zone of the southern region. Henceforth, the major land use of the Nambiyar River basin is agricultural land (70.69%), wasteland (7.82%), built-ups (6.12%), forestland (5.74%), and wetland (0.21%). The waterbodies of this basin are covered by 9.41% as a whole.

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Nambiyar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). The spatial distribution of drought and flood risk of the Nambiyar River basin is shown in Figs 59 and 60.

In drought risk assessment, the critical sub-basin for Nambiyar River is Hanumanadhi and Karumeniyar in baseline and shifts to increase in density of drought to all the sub-basins such as Hanumanadhi, Nambiyar and Karumeniyar in the future. The base period witnessed four drought years, while projections for the near century indicate an increase to 8 drought years. Additionally, the drought magnitude, which was five during the base period, is anticipated to rise to 11.5. Specifically, in the Nambiyar, the Hanumanadhi sub-basin is expected to undergo ten drought years with a magnitude of 13.5 in the future scenario.

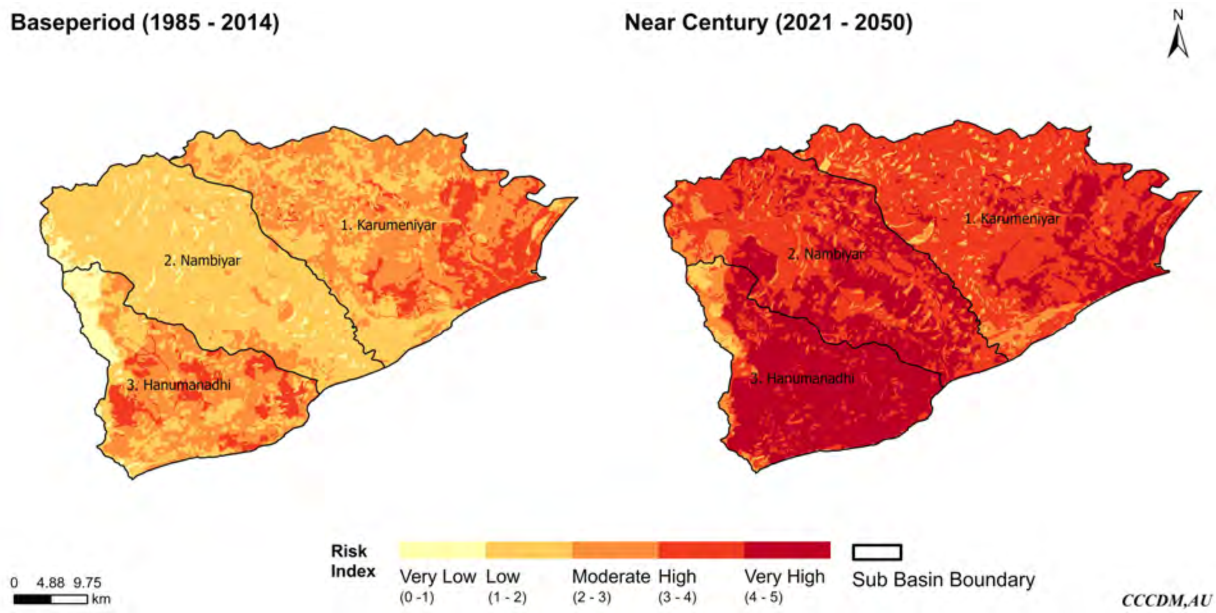


Fig. 59 Drought Risk Spatial Distribution of Nambiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

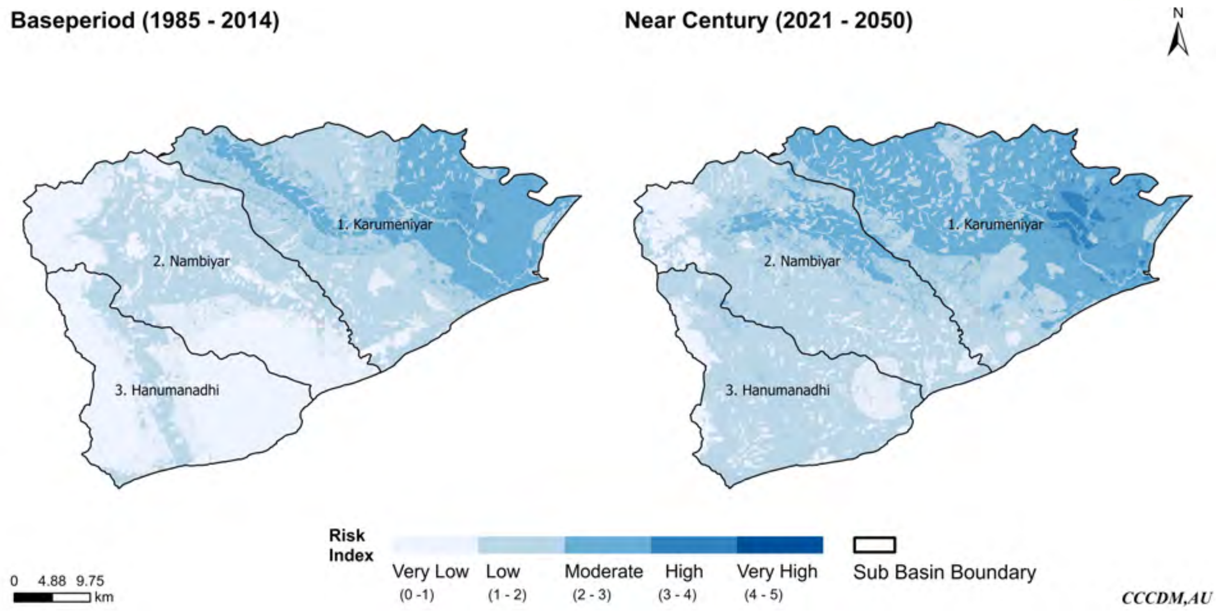


Fig. 60 Flood Risk Spatial Distribution of Nambiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In flood risk assessment, there is no critical sub-basin for Nambiyar River at the baseline, and it will remain the same. The Nambiyar basin is expected to experience a 79.6% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 133.8%. More specifically, within the Karumeniyar sub-basin, there is an anticipated increase of 86.6% in extreme rainfall events and a 112.4% increase in extreme rainfall days.

The subbasin ranking based on the drought and flood risk assessment is shown in Fig 61, and the most critical subbasin to be prioritised for future adaptation work is given in Table 18.

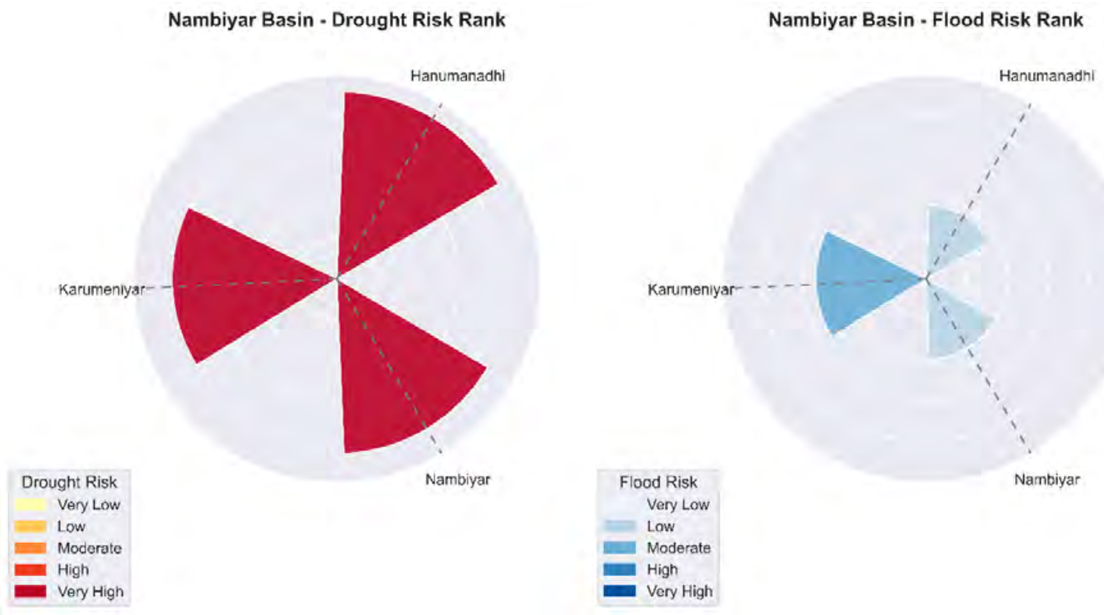


Fig. 61 Graphical Representation of Drought and Flood Risk for Nambiyar Sub-basins

Table 18. Drought Risk and Flood Risk Critical Sub-Basins of Nambiyar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Nambiyar (3)	2002	Hanumanadhi, Nambiyar, Karumeniyar	-

(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from very low (4.38%), low (48.47%), and medium (25.91%) class in baseline to high (39.16%), and very high (39.48%) class in future. The overall flood risk intensifies from the baseline to future periods. The very low (27.8%) class of flood risk in baseline has a shift to low (12.8%), medium (12.8%) and high (2.3%) in future periods. The areal extent of drought and flood risk for the baseline and future scenarios is given in Figs 62 and 63.

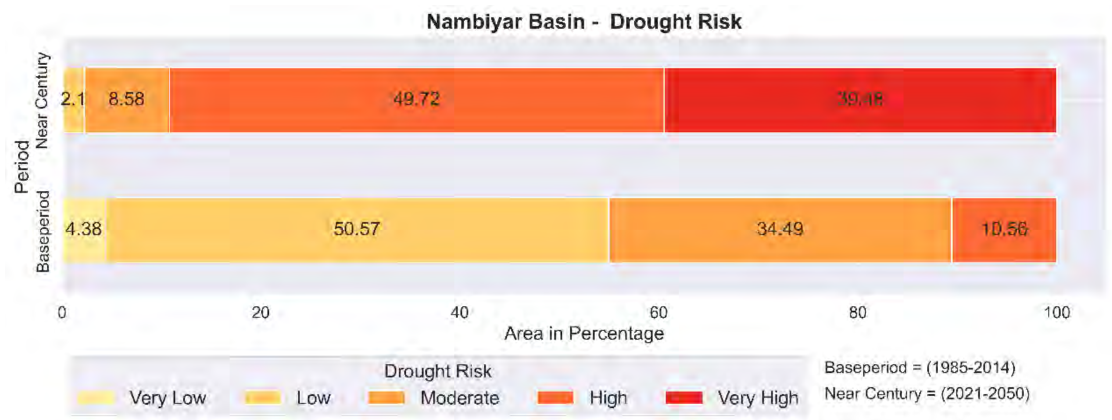


Fig. 62 Areal percentage of Drought Risk Assessment for Nambiyar River Basin

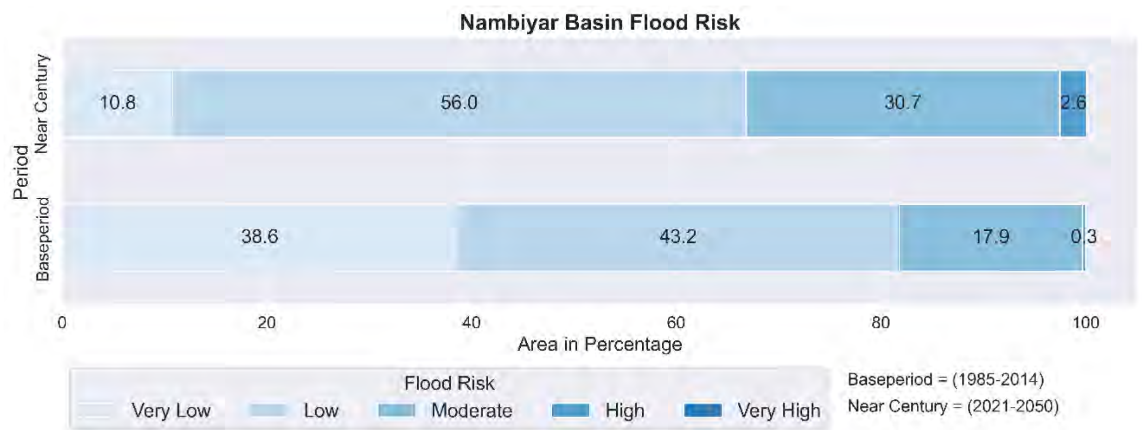


Fig. 63 Areal percentage of Flood Risk Assessment for Nambiyar River Basin

According to the climate risk assessment, the Nambiyar basin is not prone to flood but has severe drought intensity in future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) has almost completed the interlinking of rivers, namely Tamiraparani, Karumeniyar, and Nambiyar, in the Nambiyar basin. In addition, there is also a proposal for desilting works for the Nambiyar and Karumeniyar rivers. Upon executing this project, the Nambiyar basin can withstand future climate extremes of flood and drought. Additionally, there is a need for more water harvesting structures, such as artificial recharge systems, to meet the demand and conserve the watersheds of the Nambiyar basin.

4.8 Palar River Basin

Palar river basin is one of the significant north-east flowing rivers of Tamil Nadu, which has an amoeba-shaped watershed boundary and is represented in Fig 64. This basin is entirely bounded by Andhra Pradesh state at the northwest, Chennai basin at the northeast, Pennaiyar basin at the southwest and Varahanadhi basin at the southeast. In contrast, the river flows into the Bay of Bengal in the eastern direction. The basin boundary lies between the latitude of 12°15’00” and 13°37’00” and longitude of 77°53’00” to 80°10’00”. The basin is entirely divided into nine prominent rivers for its sub-basins are Upper Palar, Malattar, Agaramar, Kavundinyanadhi, Poiney, Vegavati, Cheyyar, Kiliyar, and Lower Palar has a total area of about 10309.44 km^2. The Administrative boundary that falls under this basin is some of the districts, namely, Vellore, Thiruvannamalai, and Kancheepuram in the majority, while the minimal parts of Tirupattur, Ranipet and Chengalpattu were in it.

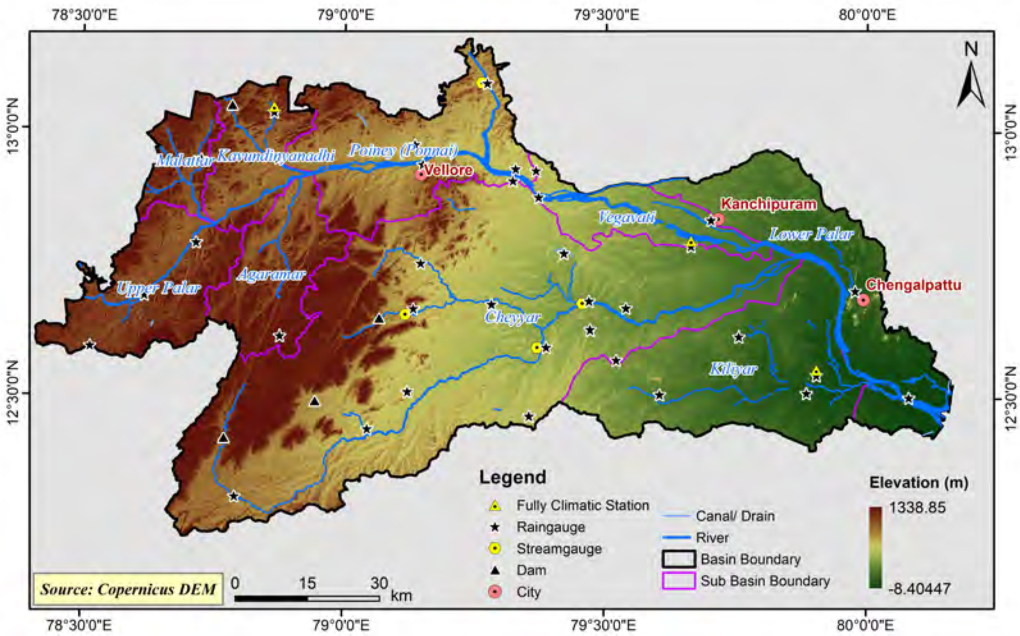


Fig. 64 Palar River Basin Index Map

Palar basin is the forested catchment on the foothills of Eastern Ghats. It has an elevation of 1338.85 m above MSL, and the slope ranges between 0 and 25. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 19 below.

Table 19. Hydro-Meteorological Observatories for Palar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Upper Palar	3	-	-
2	Malattar	1	-	-
3	Agaramar	1	-	-
4	Kavundinyanadhi	2	1	-
5	Poiney	6	-	1
6	Vegavati	3	1	-
7	Cheyyar	13	-	3
8	Kiliyar	4	1	-
9	Lower Palar	2	-	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (20.19%), clay (19.41%), sandy loam (14.73%), loam (11.7%), loamy sand (8.41%), clay loam (5.43%), sandy clay (5.42%), silty clay (3.05%), and sand (0.74%). This basin entirely falls under the agro-climatic zone of the northeastern region. Henceforth, the major land use of the Palar River basin is agricultural land (61.18%), forestland (18.51%), built-ups (6.59%), wasteland (3.24%), and wetland (0.01%). The waterbodies of this basin are covered by 10.47% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Palar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 65 and 66 illustrate the spatial distribution depicting the drought and flood risk within the Palar River basin.

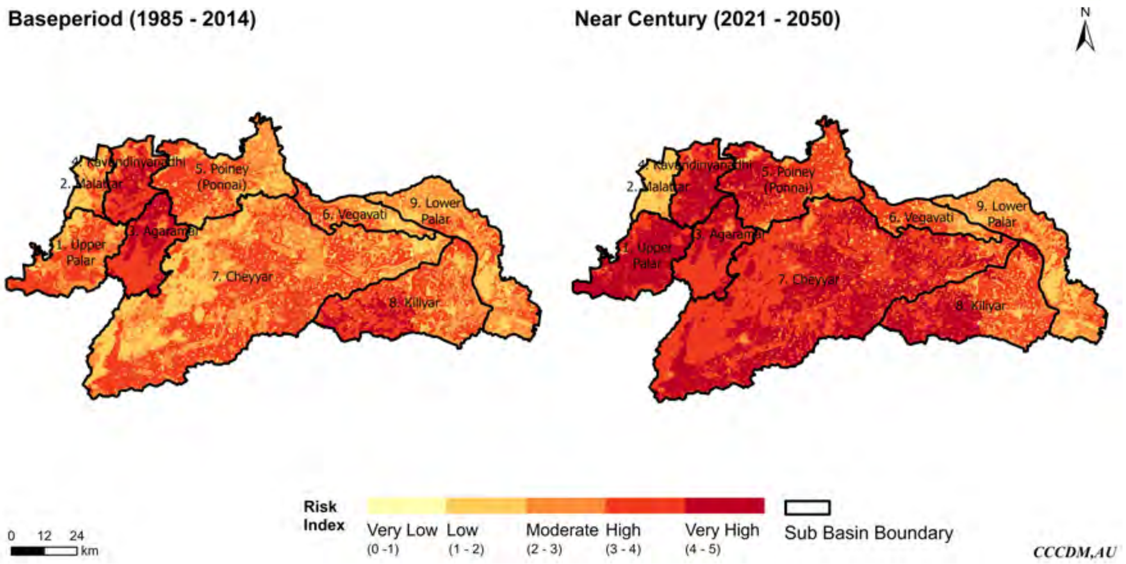


Fig. 65 Drought Risk Spatial Distribution of Palar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

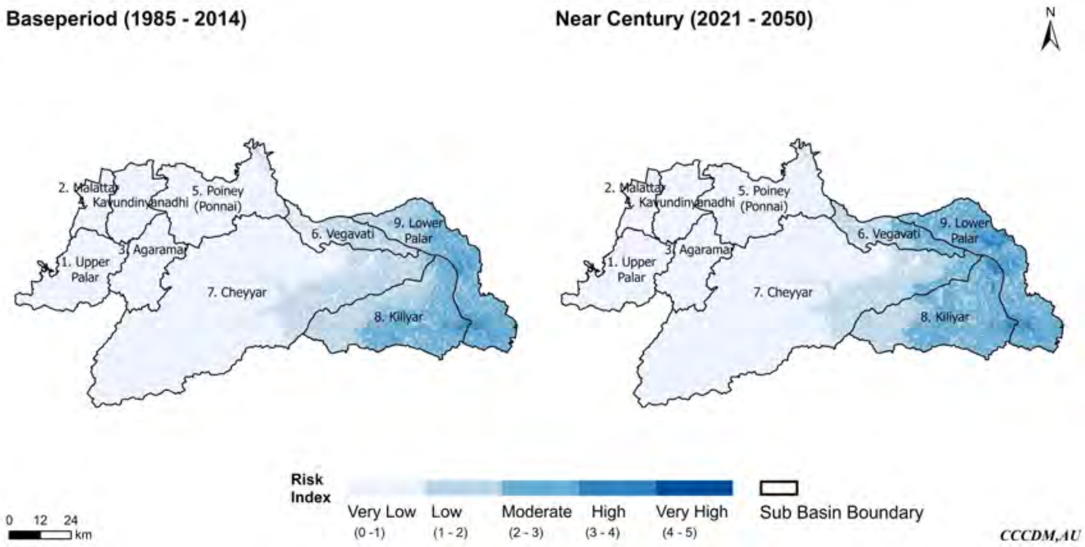


Fig. 66 Flood Risk Spatial Distribution of Palar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, the critical sub-basin for Palar River is Kavudinyanadhi and Agaramar in baseline and shifts to increase in density of drought to all the sub-basins such as Kavudinyanadhi, agaramar, cheyyar, upper Palar, kiliyar and poiney at future. The base period witnessed four drought years, while projections for the near century indicate an increase to 7 drought years. Additionally, the drought magnitude, which was 5.5 during the base period, is anticipated to rise to 9.6. Specifically, in the Palar, the Upper Palar sub-basin is expected to undergo eight drought years with a magnitude of 11 in the future scenario.

In flood risk assessment, there is no critical subbasin for Palar River at the baseline, and it will remain the same. The Palar basin is expected to experience a 30.9% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 110%. More specifically, within the Lower Palar sub-basin, there is an anticipated increase of 33.4% in extreme rainfall events and a 39.1% increase in extreme rainfall days.

Fig 67 displays the ranking of subbasins according to their assessment of drought and flood risks. Additionally, Table 20 presents the most crucial subbasin for prioritising future adaptation efforts.

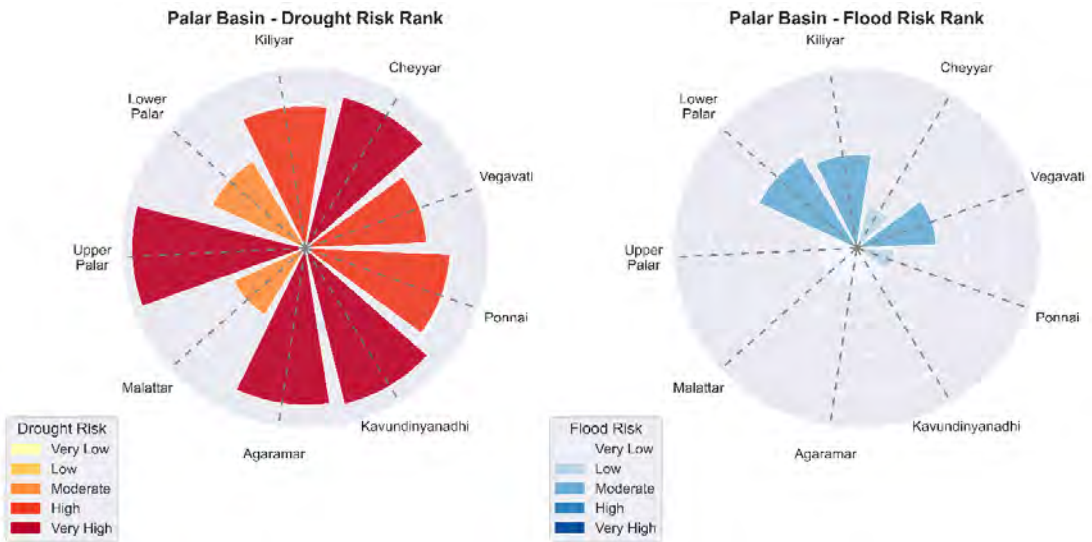


Fig. 67 Graphical Representation of Drought and Flood Risk for Palar Sub-basins

Table 20. Drought Risk and Flood Risk Critical Sub-Basins of Palar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km²)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Palar (9)	17634	Upper Palar, Agaramar, Kavundinyanadhi, Kiliyar, Poiney, Cheyyar	-

(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))

The overall drought risk is increasing from baseline to future, in which the drought classification has a shift from low (14.05%) and medium (19.14%) class in baseline to high (5.47%) and very high (27.87%) class in future. The overall flood risk will slightly intensify from the baseline to future periods. The very low (1.7%) and low (3.9%) class of flood risk in baseline has a shift to the medium (4.8%) class in the future period. Figs 68 and 69 provide information about the extent of drought and flood risk in terms of area for both the baseline and future scenarios.

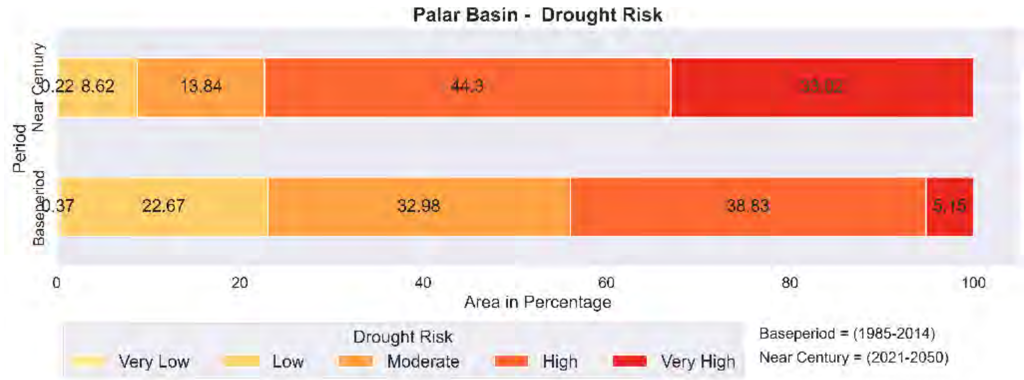


Fig. 68 Areal percentage of Drought Risk Assessment for Palar River Basin

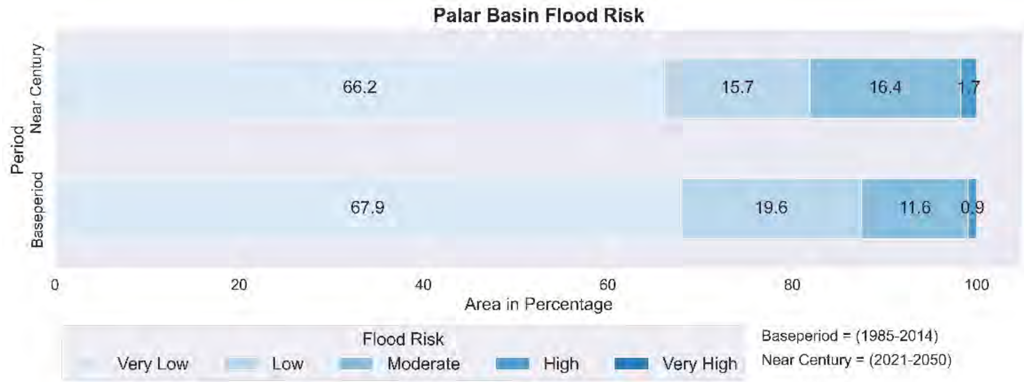


Fig. 69 Areal percentage of Flood Risk Assessment for Palar River Basin

According to the climate risk assessment, the Palar basin is not prone to flood but has severe drought intensity in future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) has a proposal for the interlinking of rivers, namely, the Palar, Lennar and Cauvery rivers; under this scheme, the Pennaiyar River (Sadhana Dam) was connected through the canal with the clear river of the Palar basin where the feasibility report was completed to execute the phase I. Upon executing this project, the Palar basin can withstand future climate extremes of flood and drought. Additionally, there is a need for more water harvesting structures, such as artificial recharge systems, to meet the demand on dry days by conserving the groundwater table that falls under the watersheds of the Palar basin.

4.9 Pambar Kottakaraiyar River Basin

Pambar Kottakaraiyar river basin is one of the major east-flowing rivers of Tamil Nadu, which has a shaped watershed boundary as represented by Fig 70. The Agniyar basin on the north entirely bounds this basin, the Cauvery basin in the western part and the Vaigai basin in the south, whereas the river flows into Palk Strait and Palk Bay in the eastern direction. The basin boundary lies in between the latitude from 9°30’00” to 10°25’00” and longitude from 78°10’00” to 79°00’00”. The basin is divided into three prominent rivers, and its sub-basins are Manimuttar, Pambar, and Kottakaraiyar. It has a total area of about 5926.95 km^2. The Administrative boundary under this basin is some of the districts, namely, Sivagangai, in the majority, while the minimal parts of Dindigul, Madurai, Ramanathapuram and Pudukottai are in it.

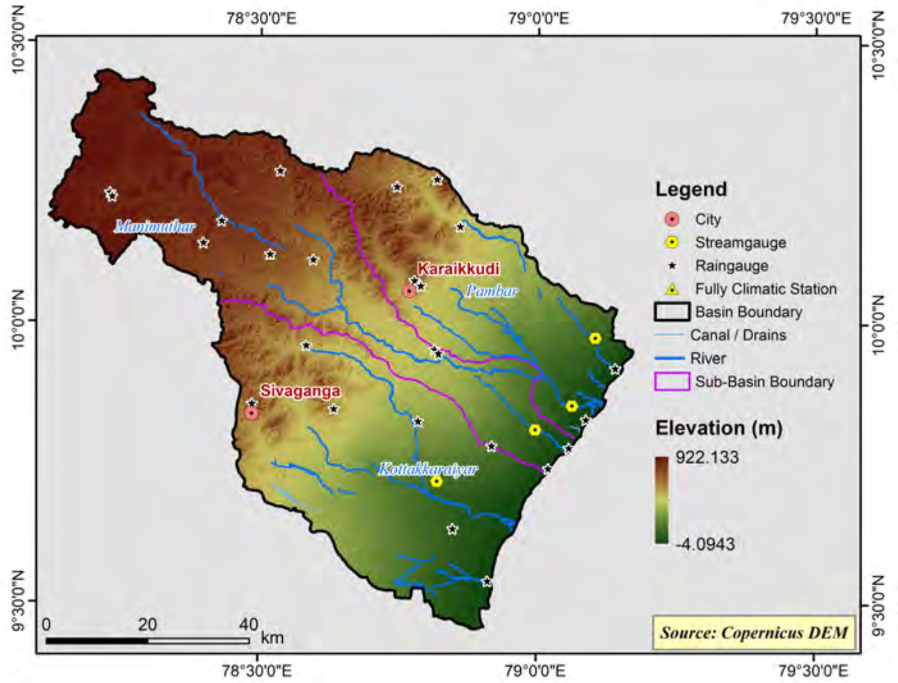


Fig. 70 Pambar Kottakaraiyar River Basin Index map

Pambar basin is a non-forested catchment with an elevation of 922.133 m above MSL and a slope range between 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 21 below.

Table 21. Hydro-Meteorological Observatories for Pambar Kottakaraiyar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Manimuttar	11	1	1
2	Pambar	7	1	2
3	Kottakaraiyar	7	-	1

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy loam (21.17%), clay (16.13%), sandy clay loam (14.45%), sandy clay (14.2%), loamy sand (6.6%), sand (5.7%), clay and loam (4.2%). This basin entirely falls under the agro-climatic zone of the Cauvery Delta, southern and western regions. Henceforth, the major land use of the Pambar Kottakaraiyar river basin is agricultural land (69.76%), forestland (5.88%), built-ups (4.6%), wasteland (2.29%), and wetland (0.59%). The waterbodies of this basin are covered by 16.87% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Pambar Kottakaraiyar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 71 and 72 depict the spatial distribution of the drought and flood risk in the Pambar Kottakaraiyar river basin.

In drought risk assessment, the critical sub-basin for Pambar Kottakaraiyar River is Manimuttar and Kottakaraiyar in baseline and shifts to increase in density of drought for the same in the future. The base period witnessed five drought years, while projections for the near century indicate an increase to 6 drought years. Additionally, the drought magnitude, which was 6.5 during the base period, is anticipated to rise to 8.7. Specifically, in the Pambar, Kottakaraiyar sub-basin is expected to undergo six drought years with a magnitude of 7 in the future scenario.

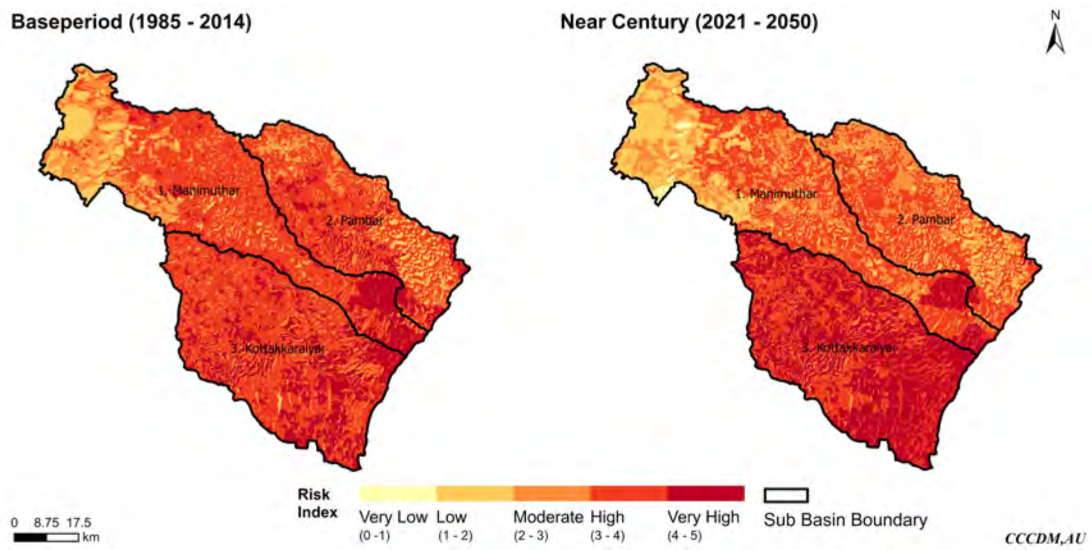


Fig. 71 Drought Risk Spatial Distribution of Pambar Kottakaraiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

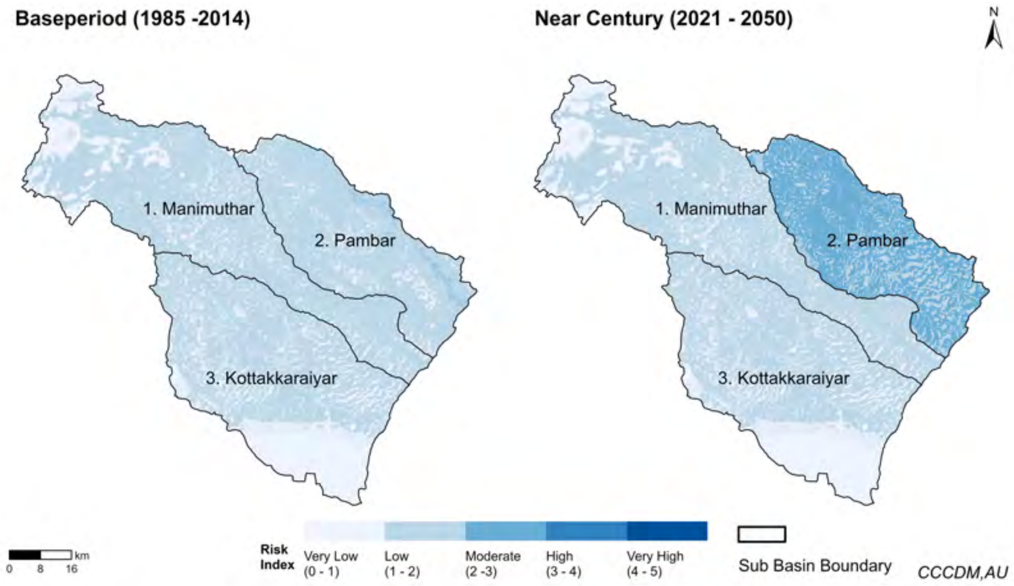


Fig. 72 Flood Risk Spatial Distribution of Pambar Kottakaraiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

There is no critical sub-basin for the Pambar Kottakaraiyar River baseline in flood risk assessment, and it will remain the same. The Pambar basin is expected to experience a 46.9% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 93.6%. More specifically, within the Pambar sub-basin, there is an anticipated increase of 44.1% in extreme rainfall events and an 84% increase in extreme rainfall days.

According to assessments of the Risks of drought and flooding, Fig 73 shows the subbasin rankings. Table 22 lists the subbasin most important for ranking future adaptation efforts.

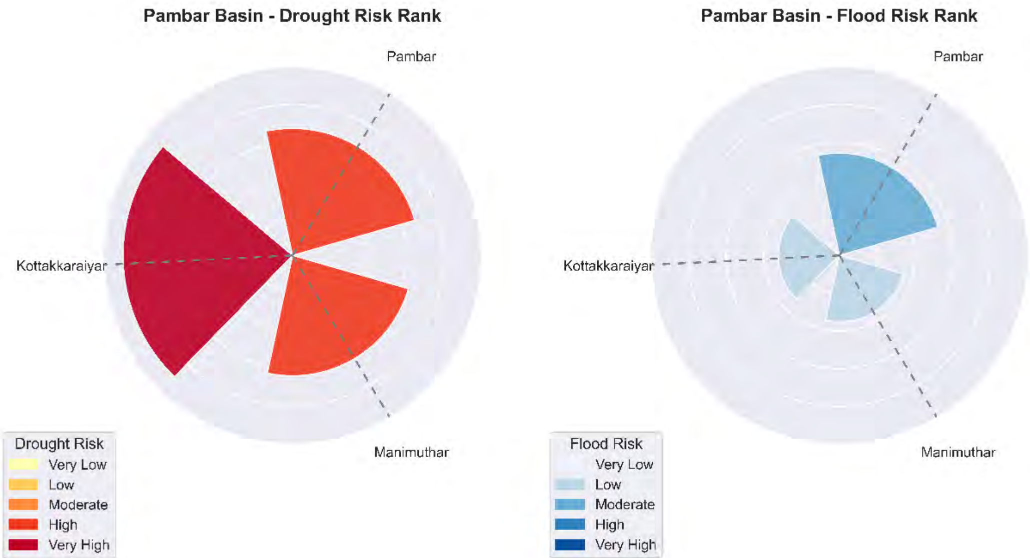


Fig. 73 Graphical Representation of Drought and Flood Risk for Pambar Sub-basins

Table 22. Drought Risk and Flood Risk Critical Sub-Basins of Pambar Kottakaraiyar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Pambar Kottakaraiyar (3)	5931	Kottakkaraiyar, Manimuthar	-

(**SSP2-4.5 Scenario durning Near Century (2021 - 2050)*)

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from high (15.17%) class in baseline to low (5.99%), medium (3.37%) and very high (5.23%) class in future. The overall flood risk will slightly intensify from the baseline to future periods. The very low (2.6%) and low (14.5%) class of flood risk in baseline has a shift to a medium (17%) class in a future period. Figs 74 and 75 indicate the risk area for both the baseline and the future scenarios' droughts and floods of the Pambar river basin.

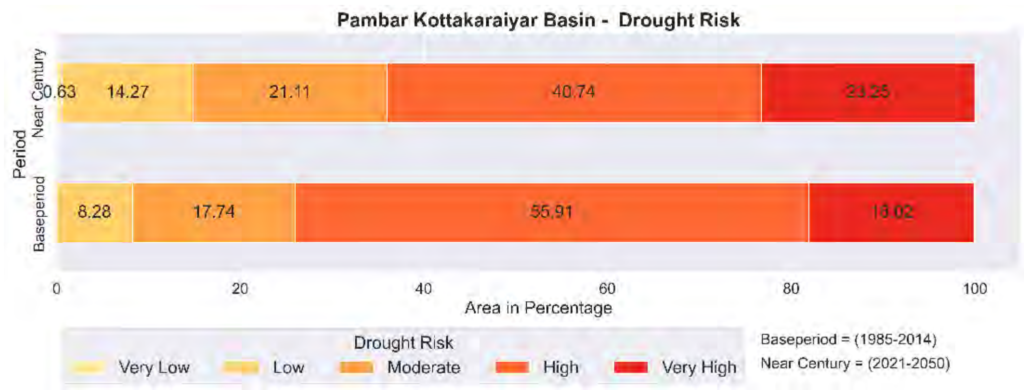


Fig. 74 Areal percentage of Drought Risk Assessment for Pambar Kottakaraiyar River Basin

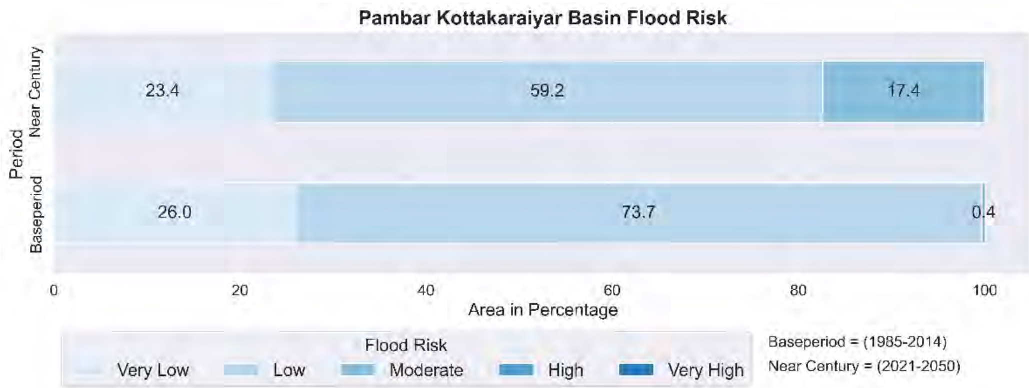


Fig. 75 Areal percentage of Flood Risk Assessment for Pambar Kottakaraiyar River Basin

According to the climate risk assessment, the Pambar basin is not prone to flood but has severe drought intensity in future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department

(WRD) has a proposal under the scheme of Cauvery - Agniyar - South Vellar – Manimuthar (Pambar Kottakaraiyar Basin) - Vaigai - Gundar Link Canal Scheme. Upon executing this project, the Pambar Kottakaraiyar basin will be capable of withstanding future climate extremes of flood and drought. Additionally, there is a need for better management of existing water harvesting structures, such as cascades of tanks, to meet the demand on wet and dry days by conserving the surface and groundwater under the watersheds of the Pambar Kottakaraiyar basin.

4.10 Parambikulam Aliyar (PAP) River Basin

Parambikulam Aliyar river basin is the only north-western flowing river of Tamil Nadu, which has a bird-shaped watershed boundary and is represented in Fig 76. The Cauvery basin entirely bounds this basin in the north-eastern and south-eastern parts, whereas the river flows in the western direction and enters the state of Kerala through the Western Ghats. The basin boundary lies in between the latitude from 10°10’00” to 10°57’20” and longitude from 76°43’00” to 77°12’30”. The basin is divided into four prominent rivers, and its sub-basins are Walayar, Palar, Aliyar, and Sholaiyar. It has a total area of about 2406.38 km². The Administrative boundary that falls under this basin is some of the districts, namely, Coimbatore, in the majority, while the minimal parts of Thiruppur were in it.

Fig. 76 Parambikulam Aliyar (PAP) River Basin Index map

Parambikulam Aliyar basin is the densely forested catchment on the foothills of Western Ghats and has an elevation of 2509.49 m above MSL, and the slope ranges between 0 and 35. The Public

Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 23 below.

Table 23. Hydro-Meteorological Observatories for Parambikulam Aliyar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Walayar	2	-	-
2	Palar	2	-	1
3	Aliyar	9	2	1
4	Sholaiyar	8	-	1

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (50.66%), clay loam (11.34%), sandy loam (11.13%), sandy clay (8.34%), clay (7.81%), and loamy sand (4.87%). This basin entirely falls under the agro-climatic zone of the western region. Henceforth, the major land use of the PAP river basin is agricultural land (59.28%), forestland (33.61%), built-ups (4.48%), and wasteland (1.27%). The waterbodies of this basin are covered by 1.36% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Parambikulam Aliyar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). The spatial distribution of drought and flood risk of the PAP river basin is shown in Figs 77 and 78.

In drought risk assessment, there is no critical sub-basin for Parambikulam Aliyar River in the baseline, and this remains the same in the future. The base period witnessed three drought years, while projections for the near century indicate an increase to 4 drought years. Additionally, the drought magnitude, four during the base period, is anticipated to rise to 5.8. Specifically, in the Parambikulam Aliyar (PAP), the Walayar sub-basin is expected to undergo four drought years with a magnitude of 6 in the future scenario.

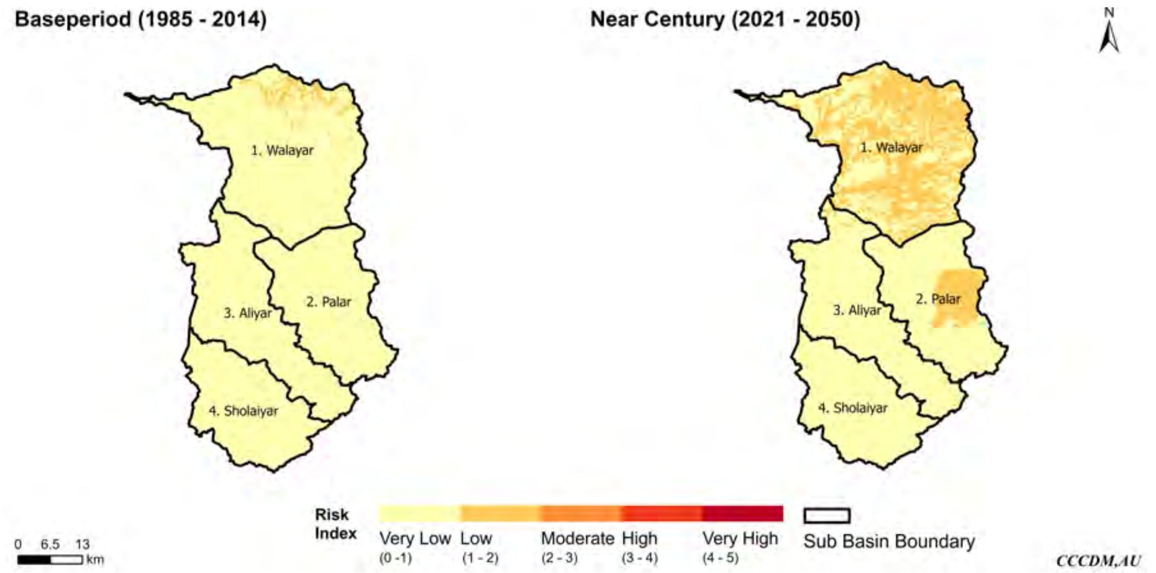


Fig. 77 Drought Risk Spatial Distribution of Parambikulam Aliyar Project (PAP) River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

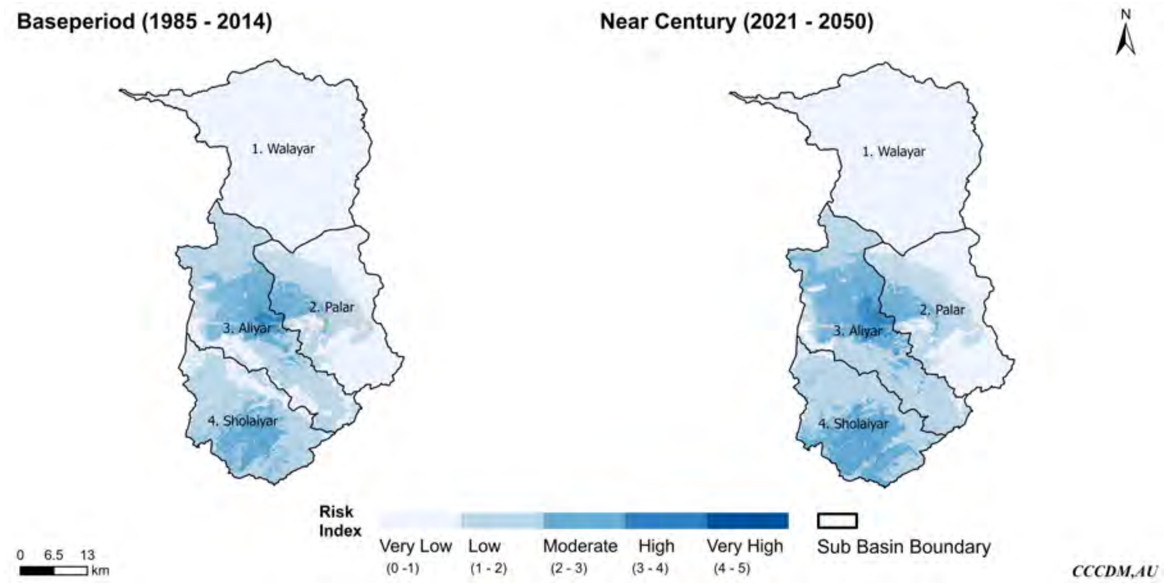
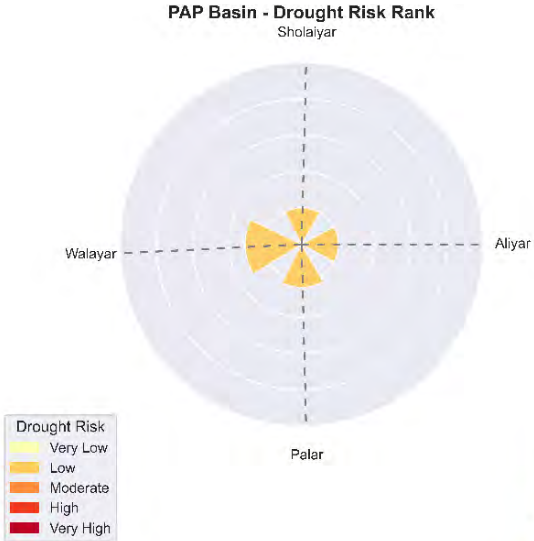


Fig. 78 Flood Risk Spatial Distribution of Parambikulam Aliyar Project (PAP) River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In flood risk assessment, there is no critical sub-basin for the Parambikulam Aliyar River baseline, which remains the same in the future. The Parambikulam Aliyar (PAP) basin is expected to experience a 62% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 120.2%. More specifically, within the Sholaiyar sub-basin, there is an anticipated increase of 50.2% in extreme rainfall events and a 91.4% increase in extreme rainfall days.

The subbasin ranking based on the drought and flood risk assessment is shown in Fig 79, and the most critical subbasin to be prioritised for future adaptation work is given in Table 24.



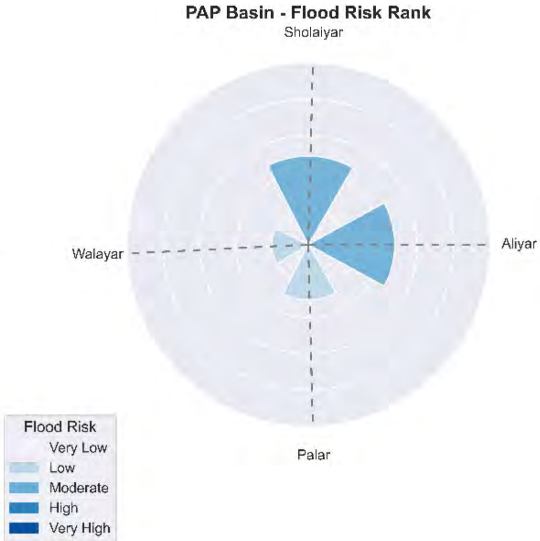


Fig. 79 Graphical Representation of Drought and Flood Risk for Parambikulam Aliyar (PAP) Sub-basins

Table 24. Drought Risk and Flood Risk Critical Sub-Basins of PAP River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
PAP (4)	2407	-	Aliyar

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to the future, in which the drought classification shifts from a very low (22.35%) class in baseline to a low (22.35%) class in future. The overall flood risk will slightly intensify from the baseline to future periods. The very low (4.7%) class of flood risk in baseline has a shift to medium (4.3%) and high (1.2%) class in a future period. The areal extent of drought and flood risk for the baseline and future scenarios is given in Figs 80 and 81.

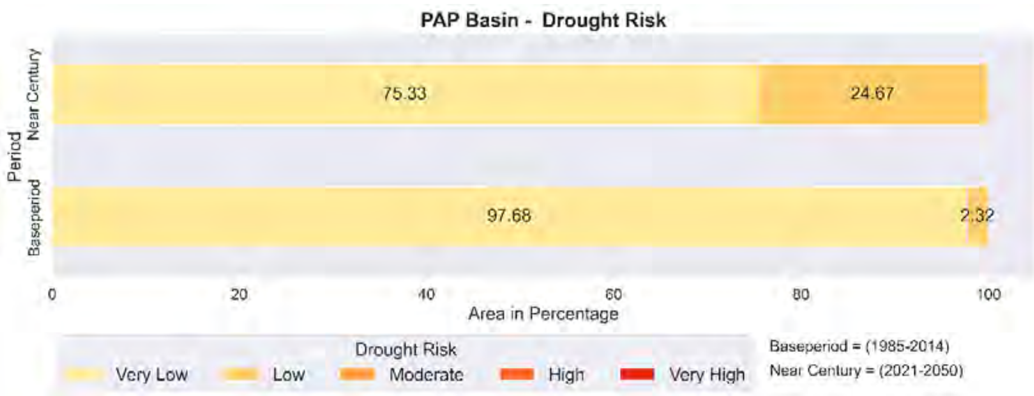


Fig. 80 Areal percentage of Drought Risk Assessment for Parambikulam Aliyar (PAP) River Basin

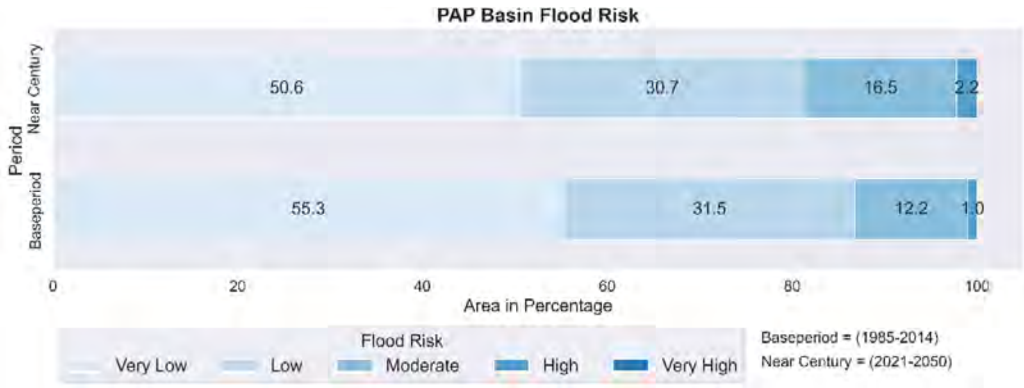


Fig. 81 Areal percentage of Flood Risk Assessment for Parambikulam Aliyar (PAP) River Basin

According to the climate risk assessment, the Parambikulam Aliyar basin is not prone to flooding and drought intensity in future projections. Still, there is a slight increase in both drought and flood risk, as per the analysis. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) has implemented most of the work, such as desilting hydraulic structures, especially canals, dams, and reservoirs. Additionally, an automated irrigation community is being executed to regularise and meet the demand for irrigation for the command area that falls under the watersheds of the Parambikulam Aliyar basin. The execution of this system can enhance water conservation, and excessive water can be diverted to the nearby subbasins.

4.11 Paravanar River Basin

Paravanar River Basin is one of the significant northeastern-flowing rivers of Tamil Nadu. It has a bowl-shaped watershed boundary, which is represented in Fig 82. This basin is entirely bounded by the Palar basin in the northern part and the Pennaiyar basin in the southern part, whereas the river flows into the Bay of Bengal in the eastern direction. The basin boundary lies between the latitude from 11⁰18‘‘ to 11⁰45‘‘ and longitude from 79°18” to 79°45”. The basin is divided into two prominent rivers for its sub-basins, caravanner and Uppanar, with a total area of about 872.34 km^2. The Administrative boundary under this basin is some of the districts, namely, Villupuram, in the majority, while the minimal parts of Tiruvannamalai and Chengalpattu were in it. Paravanar basin is a non-forested catchment with an elevation of 172.043 m above MSL. The slope ranges between 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 25 below.

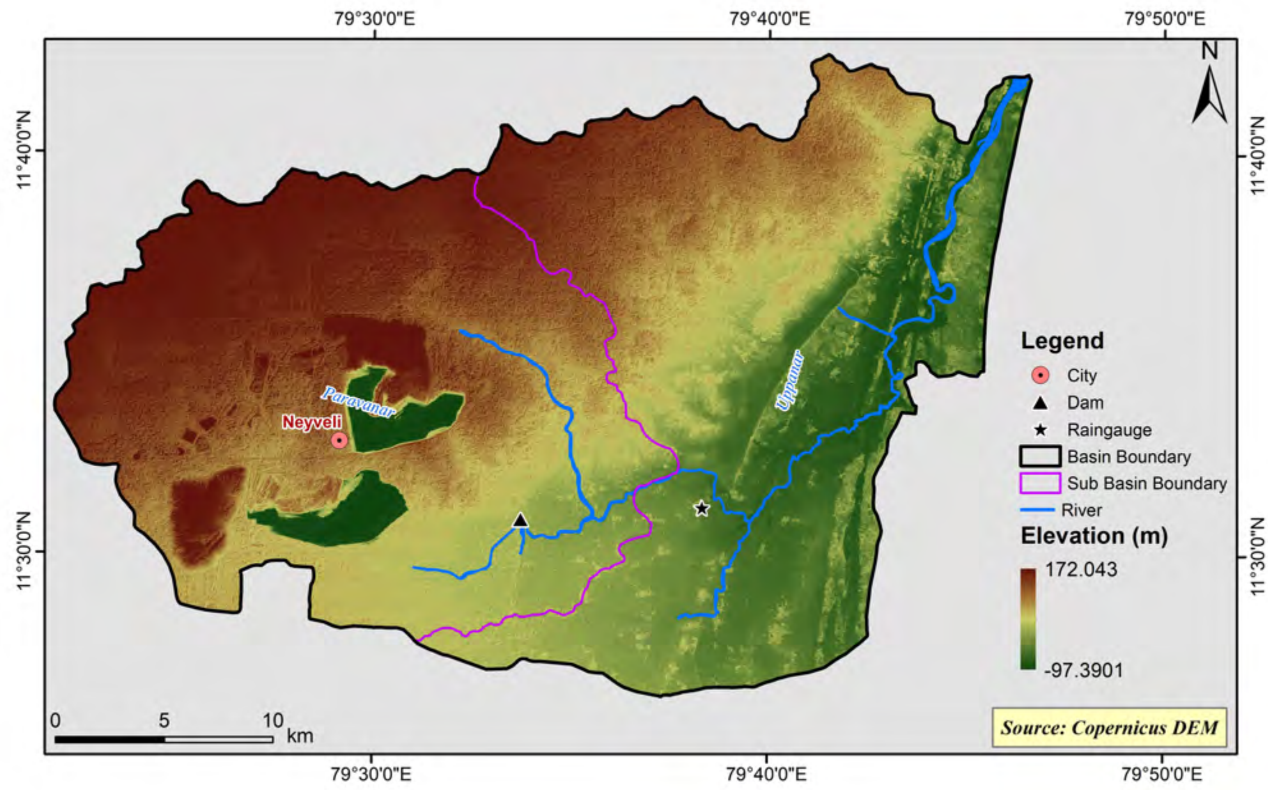


Fig. 82 Paravanar River Basin Index map

Table 25. Hydro-Meteorological Observatories for Paravanar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Paravanar	-	-	-
2	Uppanar	1	-	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy loam (30.78%), sandy clay (13.82%), clay loam (9.2%), clay (9.16%), sandy clay loam (8.79%), sand (6.96%) and silty clay (0.05%). This basin entirely falls under the agro-climatic zone of the northeastern region. Henceforth, the major land use of the Paravanar River basin is agricultural land (69.26%), built-ups (21.3%), forestland (2.19%), wasteland (1.69%) and wetland (1.42%). The waterbodies of this basin are covered by 4.13% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Paravanar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 83 and 84 illustrate the spatial distribution depicting the drought and flood risk within the Paravanar River basin.

In drought risk assessment, there is no critical subbasin for Paravanar River at the baseline, and it will remain the same. The base period witnessed four drought years, while projections for the near century indicate an increase to 6 drought years. Additionally, the drought magnitude, which was 4.8 during the base period, is anticipated to rise to 7.5. Specifically, in the Paravanar, the Uppanar sub-basin is expected to undergo six drought years with a magnitude of 8 in the future scenario.

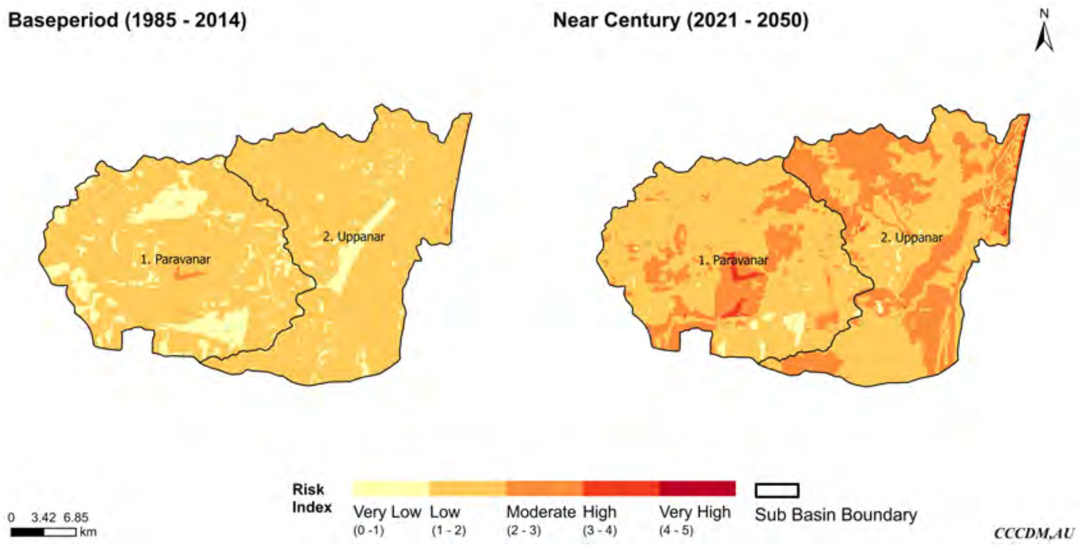


Fig. 83 Drought Risk Spatial Distribution of Parvanar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

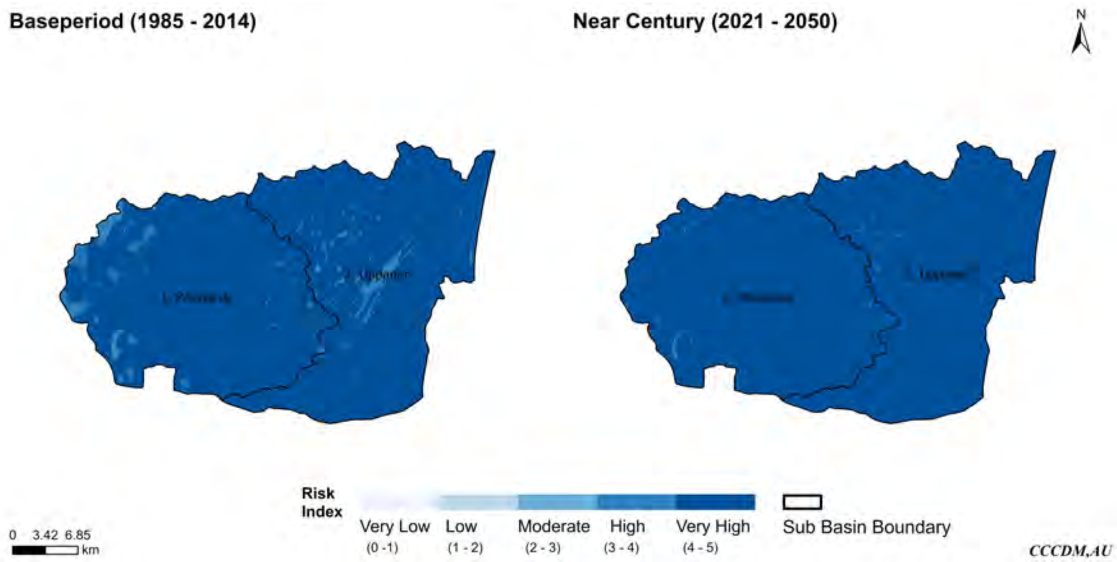


Fig. 84 Flood Risk Spatial Distribution of Paravanar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In flood risk assessment, the critical sub-basins for Paravanar River are Paravanar and Uppanar in baseline and will remain the same in the future. The Paravanar basin is expected to experience a 36.1% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 21%. More specifically, within the Paravanar sub-basin, there is an anticipated increase of 40% in extreme rainfall events and a 26.1% increase in extreme rainfall days.

Fig 85 displays the ranking of subbasins according to their assessment of drought and flood risks. Additionally, Table 26 presents the most crucial subbasin for prioritising future adaptation efforts.

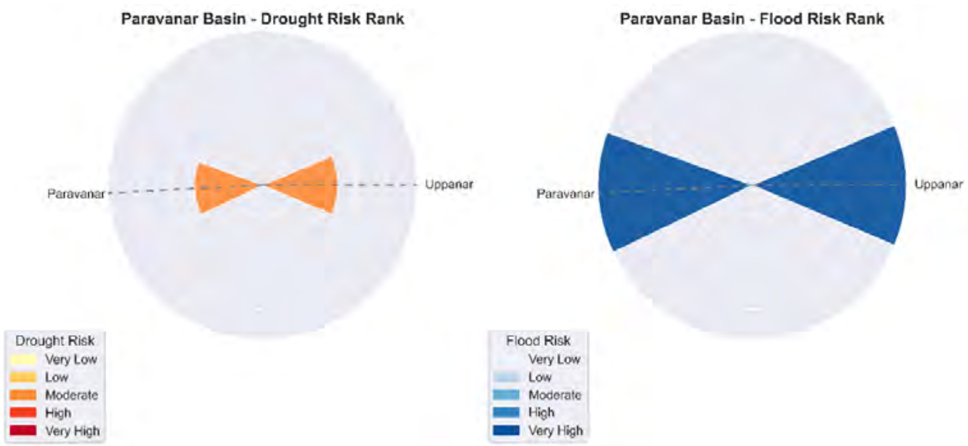


Fig. 85 Graphical Representation of Drought and Flood Risk for Paravanar Sub-basins

Table 26. Drought Risk and Flood Risk Critical Sub-Basins of Paravanar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km²)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Paravanar (2)	873	Paravanar	Paravanar, Uppanar

(**SSP2-4.5 Scenario durning Near Century (2021 - 2050)*)

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from very low (11.38%) and low (22.56%) class in baseline to medium (30.96%) and high (1%)class in future. The overall flood risk will slightly intensify from the baseline to future periods. The high (3.8%) class of flood risk in baseline has shifted to a very high (3.9%) class in the coming period. Figs 86 and 87 provide information about the extent of drought and flood risk in terms of area for both the baseline and future scenarios.

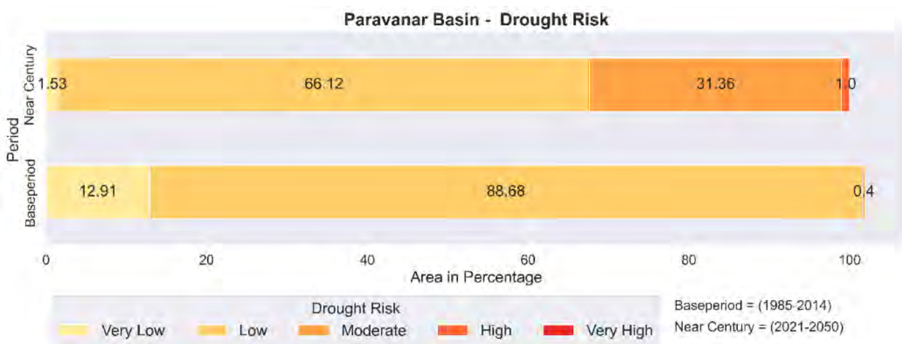


Fig. 86 Areal percentage of Drought Risk Assessment for Paravanar River Basin

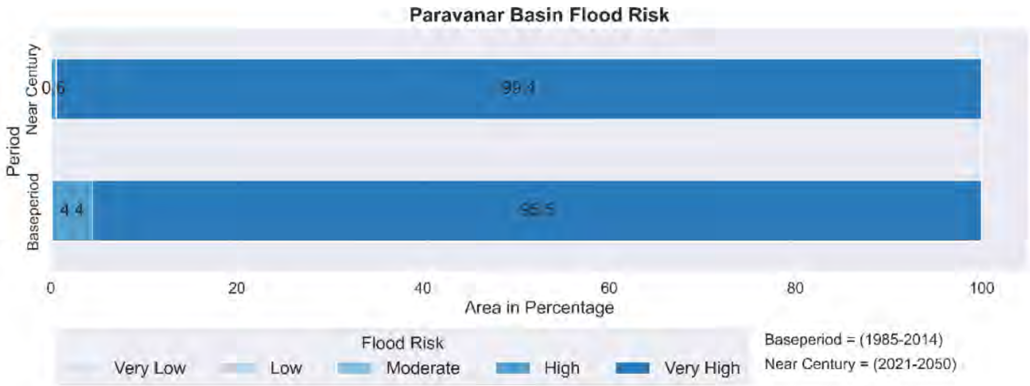


Fig. 87 Areal percentage of Flood Risk Assessment for Paravanar River Basin

According to the climate risk assessment, the Paravanar basin is not drought-prone but has severe flood intensity in both baseline and future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) had worked on desilting works in Uppanar drains. Additionally, there is a need for more water-harvesting structures. The execution of a specific water adaptation framework can enhance water conservation, and excessive water can be diverted to the nearby subbasins.

4.12 Pennaiyar River Basin

Pennaiyar river basin is one of the significant north-eastern flowing rivers of Tamil Nadu, which has a shaped watershed boundary and is represented in Fig 88. The Palar basin entirely bounds this basin in the north-western, the Varahanadhi basin in the north-eastern, the Cauvery basin in the south-eastern, the Velar basin in the southern and the Paravanar basin in the south-eastern part. Meanwhile, the river flows into the Bay of Bengal in the eastern direction. The basin boundary lies in between the latitude from 11°38’30” to 12°54’00” and longitude from 77°39’30” to 79°54”15”.

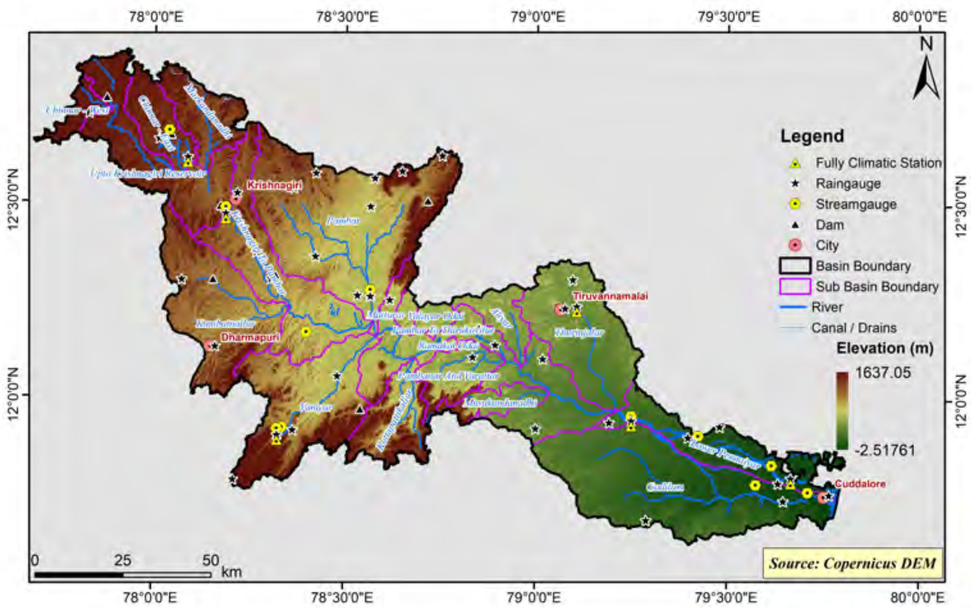


Fig. 88 Pennaiyar River Basin Index map

The basin is entirely divided into two prominent rivers for its sub-basins are; chinnar west, chinar east, markandanadhi, kambainallur, pambar, vaniyar, matturar, kottapattiKallar, valayar odai, ramakal odai, pambanar and varattar, aliyar, musukundanadhi, thurinjalar, gadilam, upto krishnagiri reservoir, krishnagiri to pambar, pambar to thirukovilur, and lower Pennaiyar that has a total area of about 11375.56 km^2. The Administrative boundary that falls under this basin is some of the districts, namely, Krishnagiri, Dharmapuri, Tirupattur, and Tiruvannamalai, in the majority, while the minimal parts of Kallakurichi, Cuddalore and Villupuram were in it.Pennaiyar basin is the second largest inter-state boundary river that falls under forested catchment at the foothills of Eastern Ghats and has an elevation of 1637.05 m above MSL. The slope ranges between 0 and 25. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 27 below.

Table 27. Hydro-Meteorological Observatories for Pennaiyar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Chinnar West	1	-	-
2	Chinar East	2	1	1
3	Markandanadhi	-	-	-
4	Kambainallur	2	-	-
5	Pambar	8	-	1
6	Vaniyar	4	1	2
7	Matturar	1	-	-
8	KottapattiKallar	-	-	-
9	Valayar Odai	-	-	-
10	Ramakal Odai	-	-	-
11	Pambanar and Varattar	1	-	-
12	Aliyar	-	-	-
13	Musukundanadhi	-	-	-
14	Thurinjalar	3	1	-
15	Gadilam	4	2	2
16	Upto Krishnagiri Reservoir	1	-	1
17	Krishnagiri To Pambar	2	1	2
18	Pambar To Thirukovilur	4	-	-
19	Lower Pennaiyar	5	-	3

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (23.16%), sandy loam (22.23%), clay (15.88%), loamy sand (13.93%), clay loam (4.91%), sandy clay (4.1%), loam (3.28%), sand (2.9%), and silty clay (0.96%). This basin falls under the agro-climatic zone of the north-western and north-eastern regions. Henceforth, the major land use of the Pennaiyar River basin is agricultural land (68.85%), forestland (15.72%), wasteland (5.64%), built-ups (4.58%) and wetland (0.02%). The waterbodies of this basin are covered by 5.19% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought for the Pennaiyar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 89 and 90 depict the spatial distribution of the drought and flood risk in the Pennaiyar River basin.

In drought risk assessment, the critical sub-basin for Pennaiyar River is Chinnar – West, Chinnar – East, Markandanadhi, Upto Krishnagiri Reservoir, Kambainallur, Vaniyar, KottapattiKallar, Pambar to Thirukovilur, Matturar, Valayar in baseline and remains the same in addition to Pambar and Krishnagiri to Pambar by an areal extent that gets intensified at future. The base period witnessed five drought years, while projections for the near century indicate an increase to 6 drought years. Additionally, the drought magnitude, which was 5.7 during the base period, is anticipated to rise to 7.5. Specifically, in the Pennaiyar, Chinnar-east sub-basin is expected to undergo six drought years with a magnitude of 8 in the future scenario.

In flood risk assessment, the critical sub-basins for Pennaiyar River are Gadilam and lower Pennaiyar sub-basins in baseline and remain the same in the future. The Pennaiyar basin is expected to experience a 46.5% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 128.5%. More specifically, within the Lower Pennaiyar sub-basin, there is an anticipated increase of 46.6% in extreme rainfall events and a 33.5% increase in extreme rainfall days.

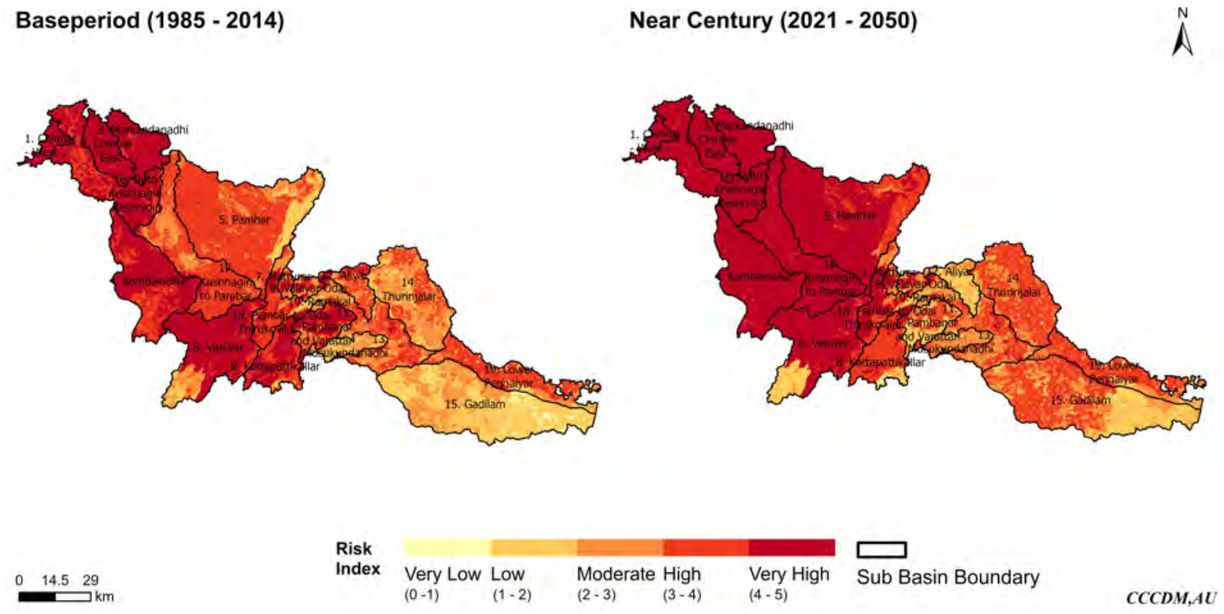


Fig. 89 Drought Risk Spatial Distribution of Pennaiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

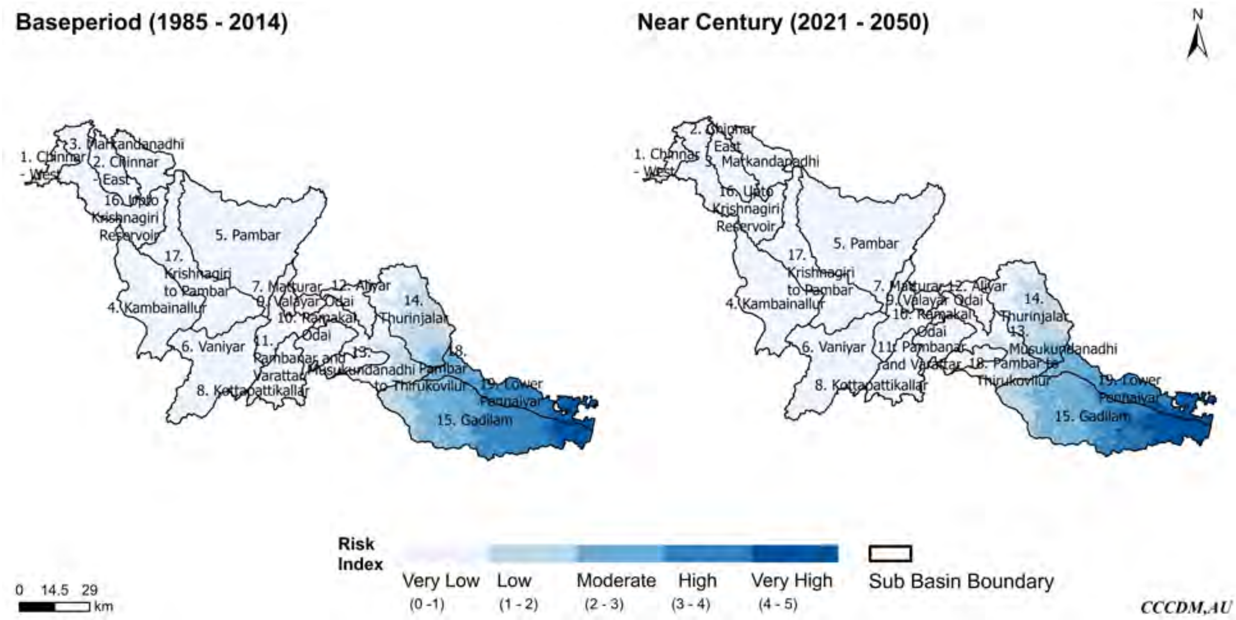


Fig. 90 Flood Risk Spatial Distribution of Pennaiyar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

According to assessments of the hazards of drought and flooding, Fig 91 shows the subbasin's rankings. Table 28 also lists the most critical subbasin for ranking future adaptation efforts.

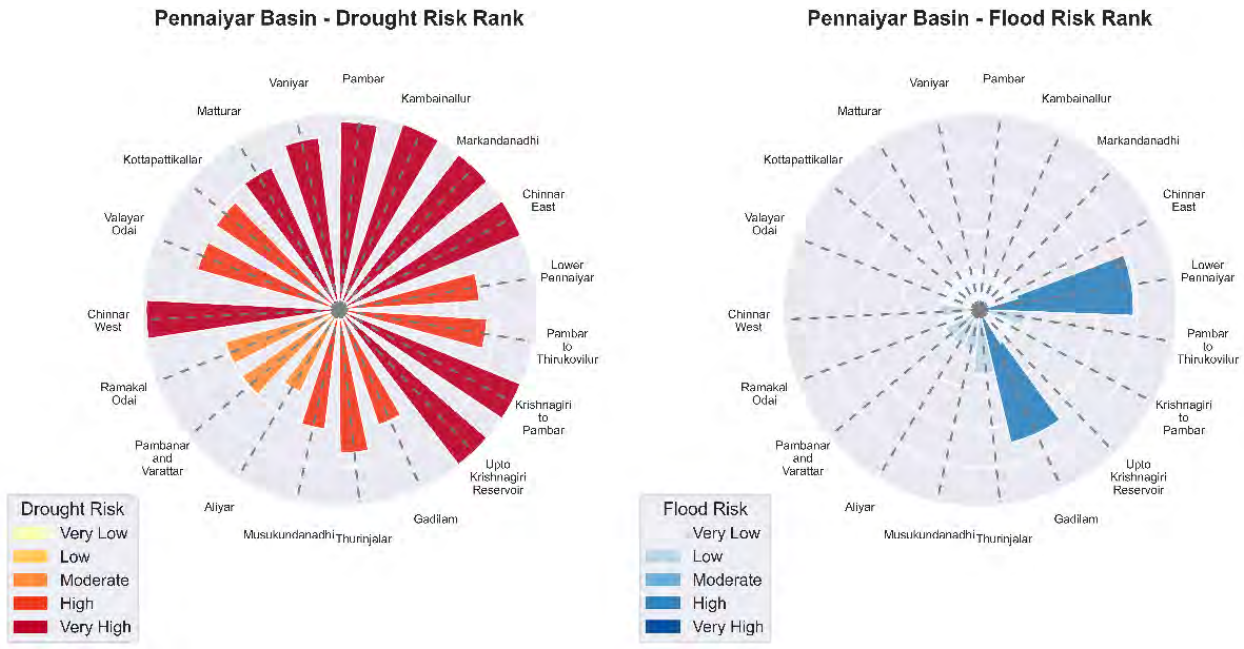


Fig. 91 Graphical Representation of Drought and Flood Risk for Pennaiyar Sub-basins

Table 28. Drought Risk and Flood Risk Critical Sub-Basins of Pennaiyar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km²)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Pennaiyar (19)	11384	Chinnar – West, Chinnar – East, Markandanadhi, Upto Krishnagiri Reservoir, Pambar, Kambainallur, Krishnagiri to Pambar, Vaniyar, Pambar to Thirukovilur, Matturar, Valayar	Gadilam, Lower Pennaiyar

(**SSP2-4.5 Scenario durning Near Century (2021 - 2050)*)

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from low (4.76%), medium (6.65%), and high (8.84%) class in baseline to very high (21.1%) class in future. The overall flood risk will slightly intensify from the baseline to future periods. The high (1.9%) class of flood risk in baseline has shifted to a very high (1.9%) class in the future. Figs 92 and 93 indicate the risk area for both the baseline and the future scenarios' droughts and floods of the Pennaiyar River basin.

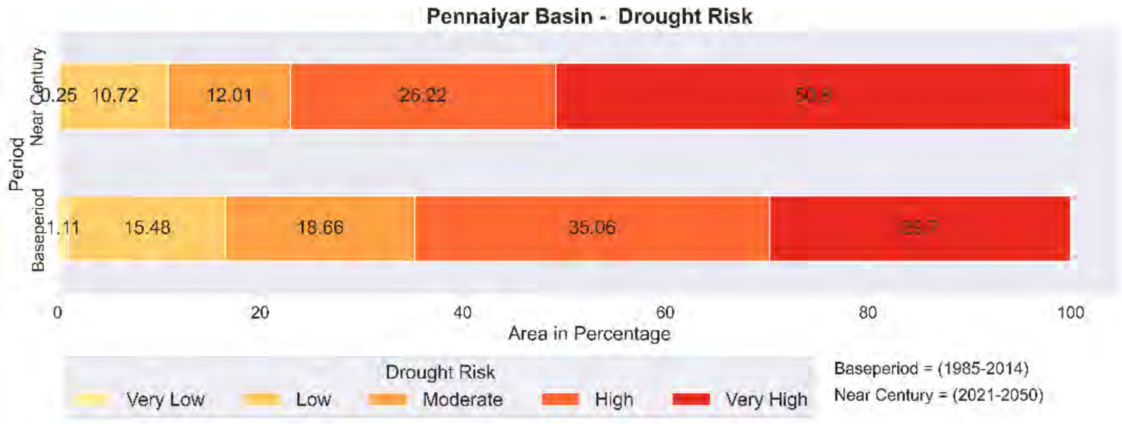


Fig. 92 Areal percentage of Drought Risk Assessment for Pennaiyar River Basin

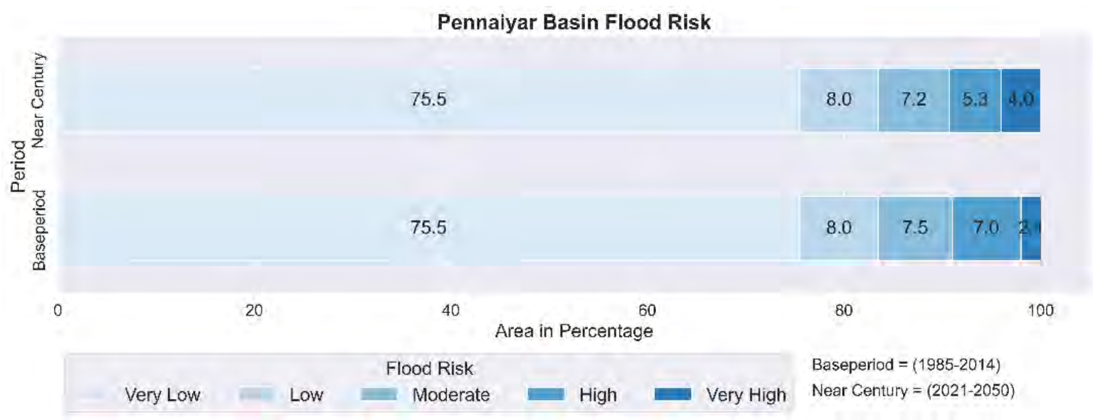


Fig. 93 Areal percentage of Flood Risk Assessment for Pennaiyar River Basin

According to the climate risk assessment, the Pennaiyar basin is severely prone to drought intensity and more prone to flood intensity in both baseline and future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) has proposed a new reservoir in the Chinar sub-basin to meet dry cropland as an irrigation demand, recharging the groundwater by excess flood water from Pennaiyar to Malattar subbasins and pumping the excess flood water from the lower to upper tanks within the sub-basins of Pennaiyar river. Additionally, there is a need for more flood carrier canals to meet the demand for dry subbasins in the Pennaiyar River. The execution of site-specific water harvesting structures can be helpful for better water management of the Pennaiyar River basin.

4.13 Tamiraparani River Basin

Tamiraparani river basin is one of the significant south-eastern flowing rivers of Tamil Nadu, which has a fan/leaf-shaped watershed boundary and is represented in Fig 94. This basin is entirely bounded by the Western Ghats, Vaippar and Kallar basin at the north, and the Kodaiyar and Nambiyar basin at the south; meanwhile, the river flows into the Gulf of Mannar at the Bay of Bengal in the eastern direction. The basin boundary lies between the latitude from 8º26’45” to 9º12’00” and longitude from 77º09’00” to 78º08’30”. The basin is entirely divided into seven prominent rivers for its sub-basins are Upper Tamiraparani, manimuttar, gadananadhi, pachaiyar, chittar, uppodai and Lower Tamiraparani that has a total area of about 5717.21 km^2. The administrative boundary under this basin is some districts, namely Tenkasi, Tirunelveli, and Thoothukudi, which are in the majority, while the minimal parts of Kanyakumari are in it.

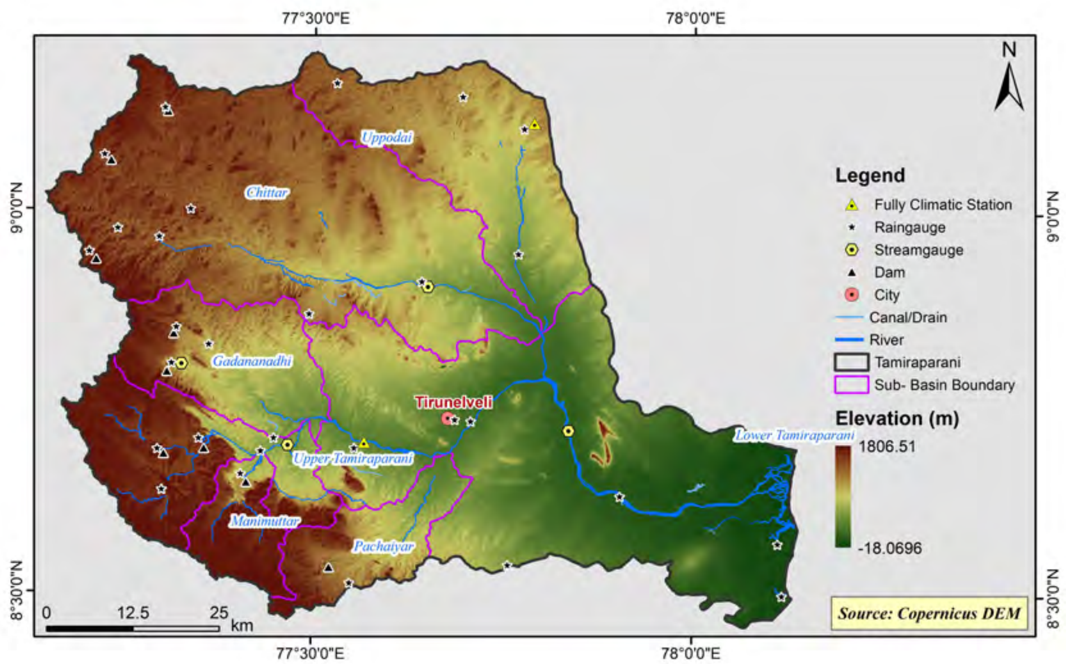


Fig. 94 Tamiraparani River Basin Index map

Tamiraparani basin is the densely forested catchment at the foothills of the Western Ghats and perennial stream type that has an elevation of 1806.51 m above MSL, and the slope ranges between 0 and 35. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 29 below.

Table 29. Hydro-Meteorological Observatories for Tamiraparani River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Upper Tamiraparani	5	-	1
2	Manimuttar	1	-	-
3	Gadananadhi	3	-	1
4	Pachaiyar	1	-	-
5	Chittar	8	-	1
6	Uppodai	4	1	-
7	Lower Tamiraparani	7	1	1

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (24.07%), sandy loam (21.42%), sandy clay (21.07%), clay (12.42%), clay loam (6.95%), loamy sand (3.66%) and sand (0.84%). This basin entirely falls under the agro-climatic zone of the southern region. Henceforth, the major land use of the Tamiraparani River basin is agricultural land (62.7%), forestland (15.95%), built-ups (7.5%), wasteland (5.6%) and wetland (0.5%). The waterbodies of this basin are covered by 7.75% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Tamiraparani basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). The spatial distribution of drought and flood risk of the Tamiraparani River basin is shown in Figs 95 and 96.

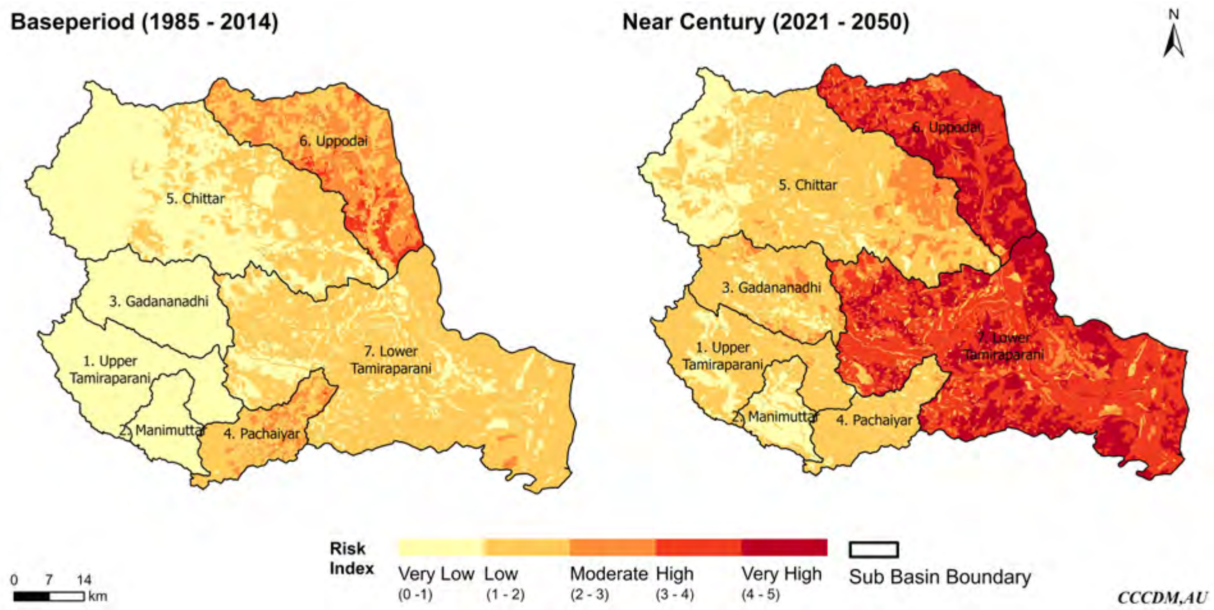


Fig. 95 Drought Risk Spatial Distribution of Tamiraparani River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, the critical sub-basin for Tamiraparani River is uppodai in baseline and extended from uppodai to lower Tamiraparani, which intensifies in the future. The base period witnessed four drought years. In comparison, projections for the near century indicate an increase to 6 drought years. Additionally, the drought magnitude, which was 4.4 during the base period, is anticipated to rise to 8.3. Specifically, in the Tamiraparani, Lower Tamiraparani sub-basin is expected to undergo eight drought years with a magnitude of 11 in the future scenario.

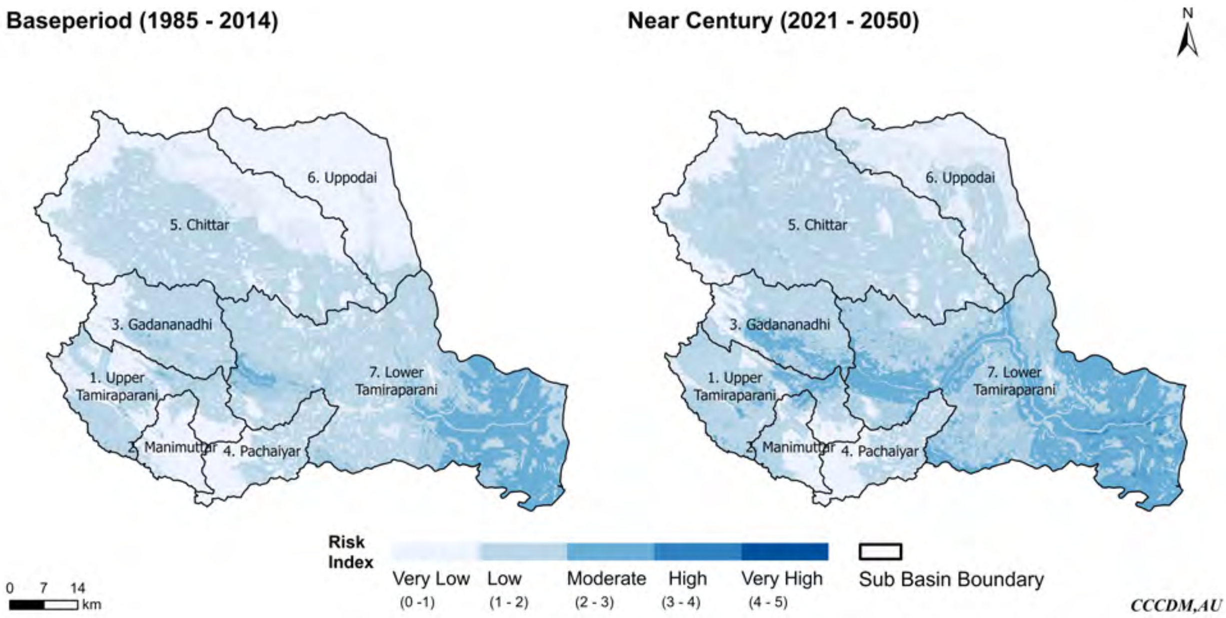


Fig. 96 Flood Risk Spatial Distribution of Tamiraparani River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In flood risk assessment, there is no critical sub-basin for the Tamiraparani River baseline, and it remains the same in the future. The Tamiraparani basin is expected to experience a 72.5% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 107.3%. More specifically, within the Lower Tamiraparani sub-basin, there is an anticipated increase of 87.8% in extreme rainfall events and a 105.3% increase in extreme rainfall days.

The subbasin ranking based on the drought and flood risk assessment is shown in Fig 97, and the most critical subbasin to be prioritised for future adaptation work is given in Table 30.

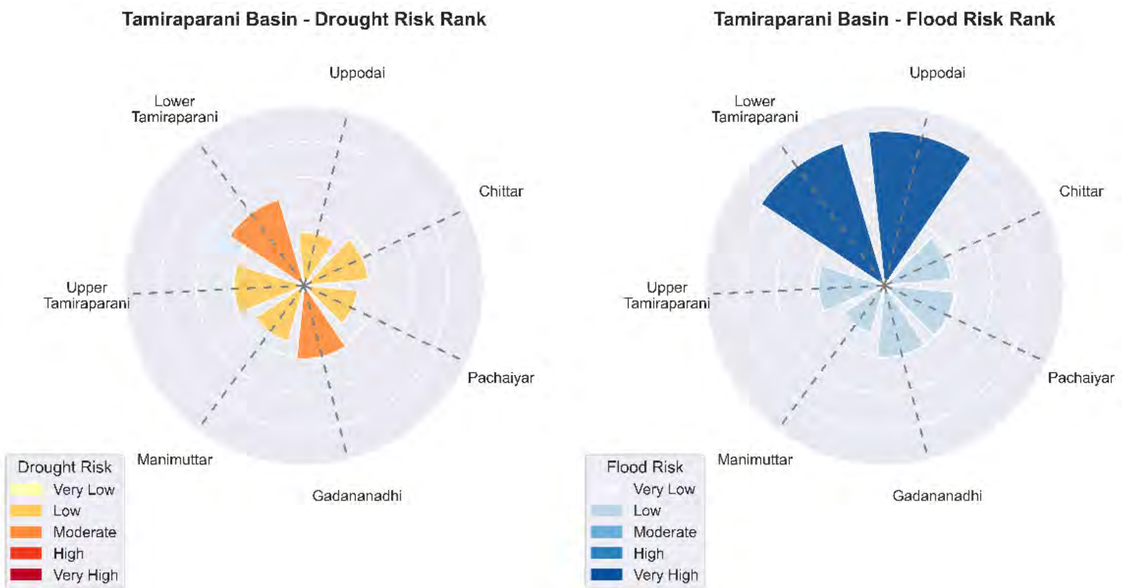


Fig. 97 Graphical Representation of Drought and Flood Risk for Tamiraparani Sub-basins

Table 30. Drought Risk and Flood Risk Critical Sub-Basins of Tamiraparani River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km^2)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Tamiraparani (7)	5721	Uppodai, Lower Tamiraparani	Lower Tamiraparani

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from very low (33.95%) and low (5.86%) class in baseline to high (12.06%) and very high (13.98%) class in future. The overall flood risk will slightly intensify from the baseline to future periods. The very low (17.1%) class of flood risk in baseline has a shift to the low (7%) and medium (9.7%) class in the future period. The areal extent of drought and flood risk for the baseline and future scenarios is given in Figs 98 and 99.

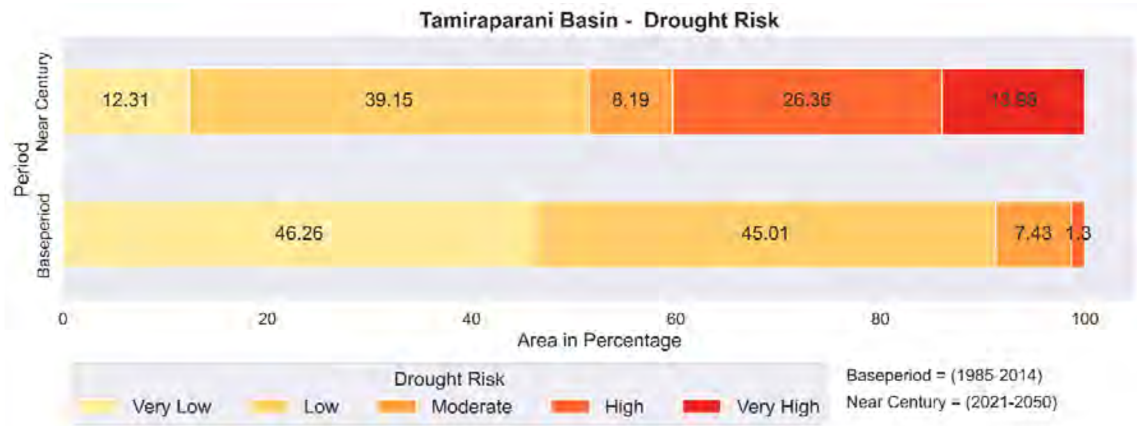


Fig. 98 Areal percentage of Drought Risk Assessment for Tamiraparani River Basin

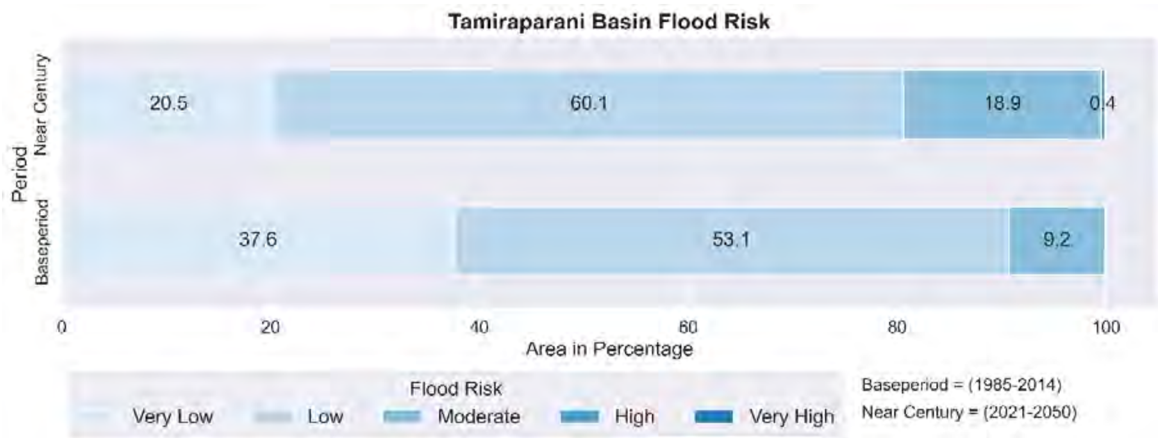


Fig. 99 Areal percentage of Flood Risk Assessment for Tamiraparani River Basin

According to the climate risk assessment, the Tamiraparani basin is severely prone to drought intensity but not to flood in both baseline and future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) completed and progressive works are: 1) Topographic survey and development of Decision Support System are being carried out for Tamiraparani Basin 2) The ongoing scheme of Construction of Tail End Check dams at confluence points of Tamiraparani River with sea 3) Detailed Progress Report for ne reservoir formation at korai yar river 4) Proposal of new flood carrier canal from lower to upper reach of chittar subbasin. Upon executing this project, the Tamiraparani basin will be capable of withstanding future climate extremes of flood and drought. Adding more water harvesting structures like groundwater recharge systems at dry croplands will conserve the watersheds of the Tamiraparani basin.

4.14 Vaigai River Basin

Vaigai river basin is one of the significant south-eastern flowing rivers of Tamil Nadu, which has a half-leaf shaped watershed boundary and is represented in Fig 100. This basin is entirely bounded by the Western Ghats, the Cauvery basin at the north-west, Pambar Kottakaraiyar at the north-east, the Vaippar basin at the south-west, and Gundar basin at the south-east Meanwhile, the river flows into the Palk strait and Gulf of Mannar at the Bay of Bengal in eastern direction. The basin boundary lies in between the latitude from 9°15’00” to 10°20’00” and longitude from 77°10’00” to 79°15’00”.

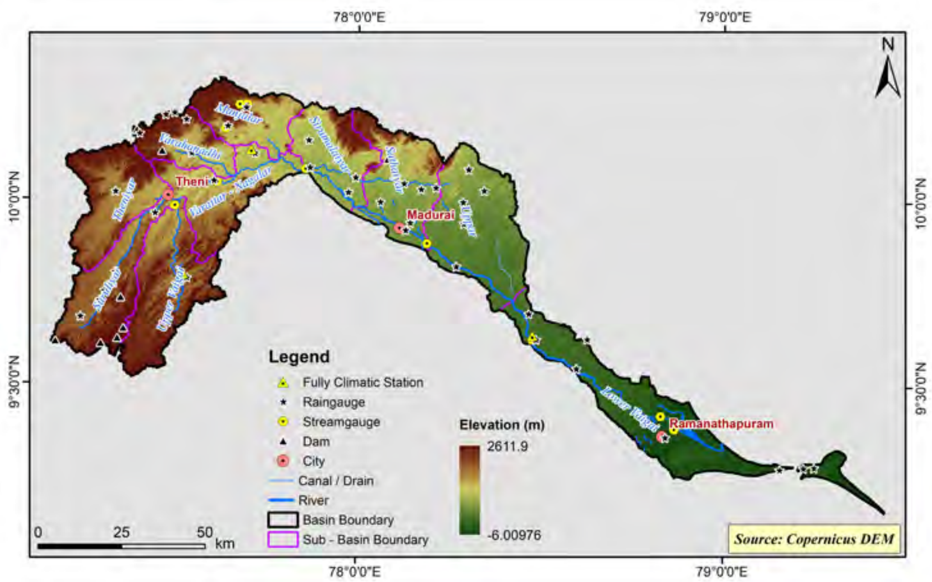


Fig. 100 Vaigai River Basin Index map

The basin is entirely divided into ten prominent rivers for its sub-basins: upper Vaigai, suruliyar, theniyar, Varattar Nagalar, Varahanadhi, manjalar, sirumalaiyar, sathaiyar, uppar, and Lower Vaigai that has a total area of about 6792.68 km^2. The Administrative boundary under this basin is some of the districts, namely, Theni and Madurai, in the majority, while the minimal parts of Dindigul, Sivagangai and Ramanathapuram were in it.

Vaigai basin is the densely forested catchment at the foothills of Western Ghats and has an elevation of 2611.90 m above MSL, and the slope ranges between 0 and 35. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 31 below.

Table 31. Hydro-Meteorological Observatories for Vaigai River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Upper Vaigai	1	1	-
2	Suruliyar	5	-	1
3	Theniyar	1	-	-
4	Varattar Nagalar	2	1	2
5	Varahanadhi	5	-	-
6	Manjalar	2	-	3
7	Sirumalaiyar	4	-	-
8	Sathaiyar	6	-	1
9	Uppar	5	-	-
10	Lower Vaigai	8	1	3

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

The soil texture of the basin consists of sandy clay loam (25.48%), sandy loam (18.04%), clay (16.9%), loamy sand (11.03%), sandy clay (10.17%), clay loam (5.14%), sand (3.07%), and loam (0.79%). This basin entirely falls under the agro-climatic zone of the western and southern regions. Henceforth, the major land use of the Vaigai River basin is agricultural land (63.51%), forestland (14.25%), wasteland (9.94%), built-ups (5.62%) and wetland (0.56%). The waterbodies of this basin are covered by nearly about 6.12% as a whole.

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Vaigai basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 101 and 102 illustrate the spatial distribution depicting the drought and flood risk within the Vaigai River basin.

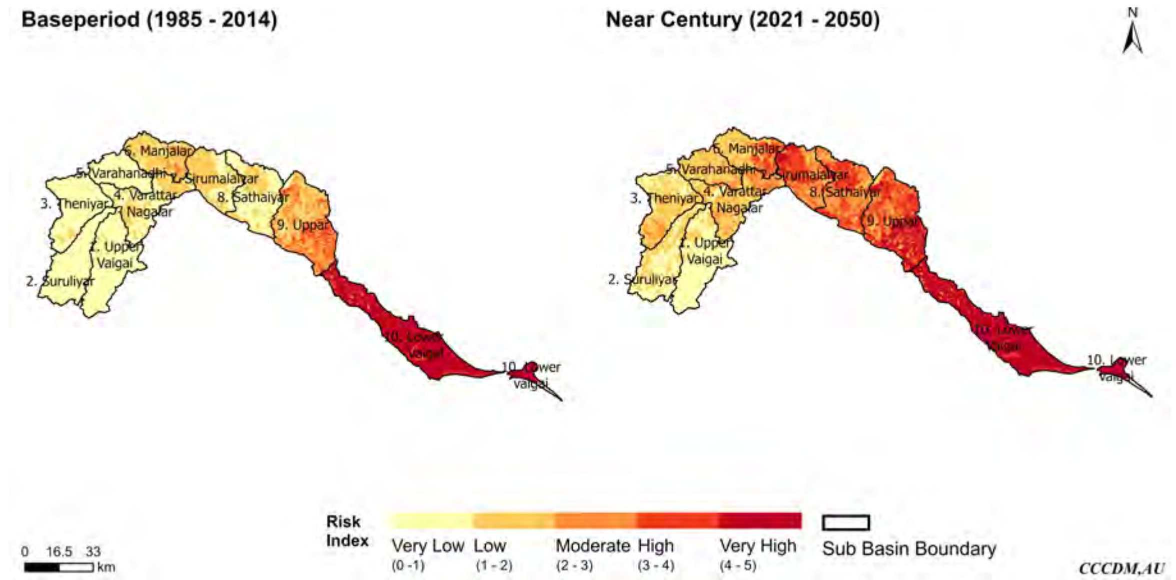


Fig. 101 Drought Risk Spatial Distribution of Vaigai River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

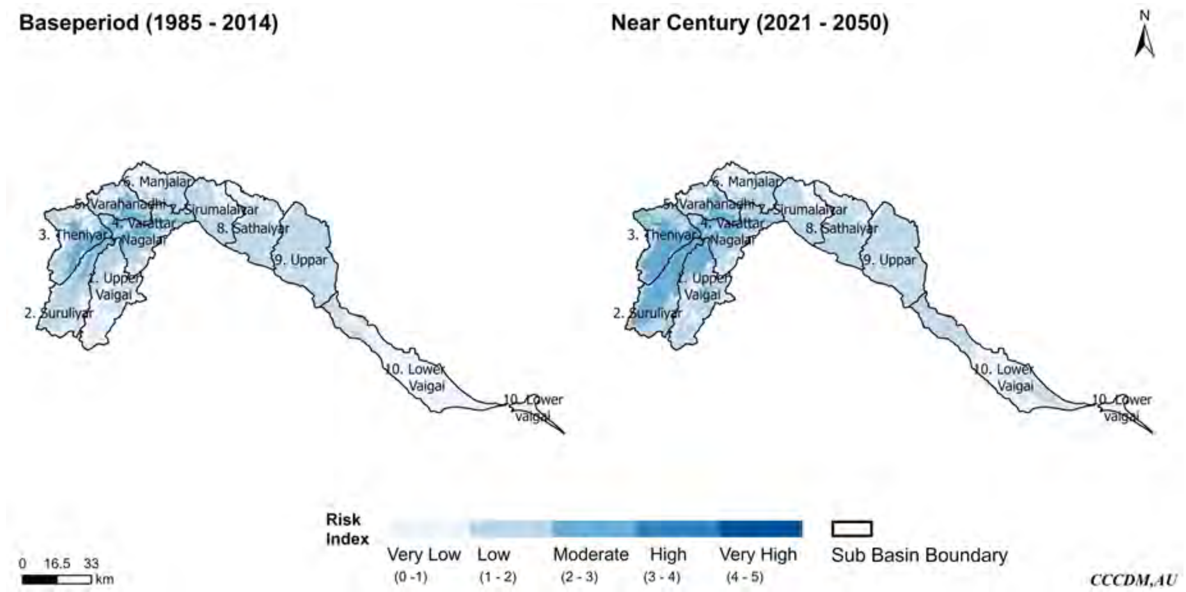


Fig. 102 Flood Risk Spatial Distribution of Vaigai River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, the critical sub-basin for Vaigai River is lower Vaigai in baseline and extended from lower Vaigai to upper in an upward direction that gets intensified in the future. The base period witnessed four drought years. In comparison, projections for the near century indicate an increase to 6 drought years. Additionally, the drought magnitude, which was 5.1 during the base period, is anticipated to rise to 8.2. Specifically, in the Vaigai, the Lower Vaigai sub-basin is expected to undergo eight drought years with a magnitude of 11 in the future scenario.

In flood risk assessment, there is no critical subbasin for the Vaigai River at the baseline, and it will remain the same. The Vaigai basin is expected to experience a 65.4% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 93.2%. More specifically, within the Theniyar sub-basin, there is an anticipated increase of 70.3% in extreme rainfall events and an 83.9% increase in extreme rainfall days.

Fig 103 displays the ranking of subbasins according to their assessment of drought and flood risks. Additionally, Table 32 presents the most crucial subbasin for prioritising future adaptation efforts.

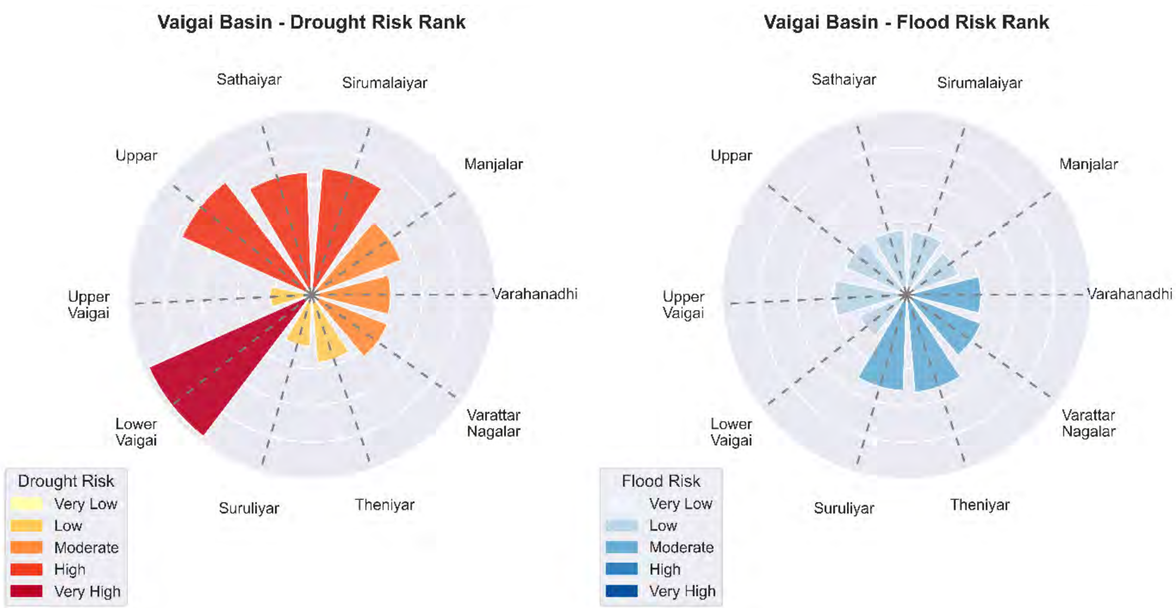


Fig. 103 Graphical Representation of Drought and Flood Risk for Vaigai Sub-basins

Table 32. Drought Risk and Flood Risk Critical Sub-Basins of Vaigai River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	**Area (km^2)**	**Drought Risk Critical Sub-Basin***	**Flood Risk Critical Sub-Basin ***
Vaigai (10)	6797	Sirumalaiyar, Sathaiyar, Uppar, Lower Vaigai	-

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from very low (33.69%) class in baseline to low (6.88%), medium (9.69%), high (12.94%) and very high (4.18%) class in future. The overall flood risk will slightly intensify from the baseline to future periods. The very low (13.6%) class of flood risk in baseline has a shift to low (4%) and medium (9%) classes in future periods. Figs 104 and 105 provide information about the extent of drought and flood risk in terms of area for both the baseline and future scenarios.

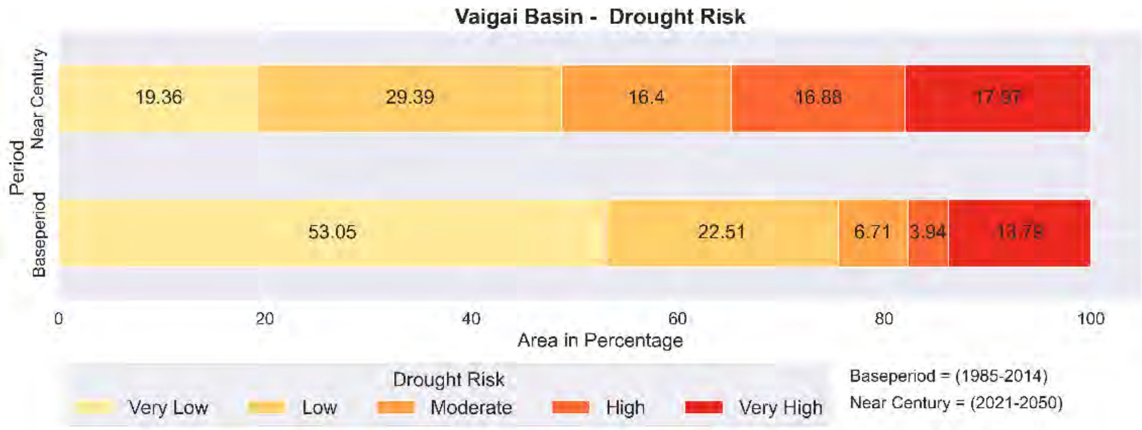


Fig. 104 Areal percentage of Drought Risk Assessment for Vaigai River Basin

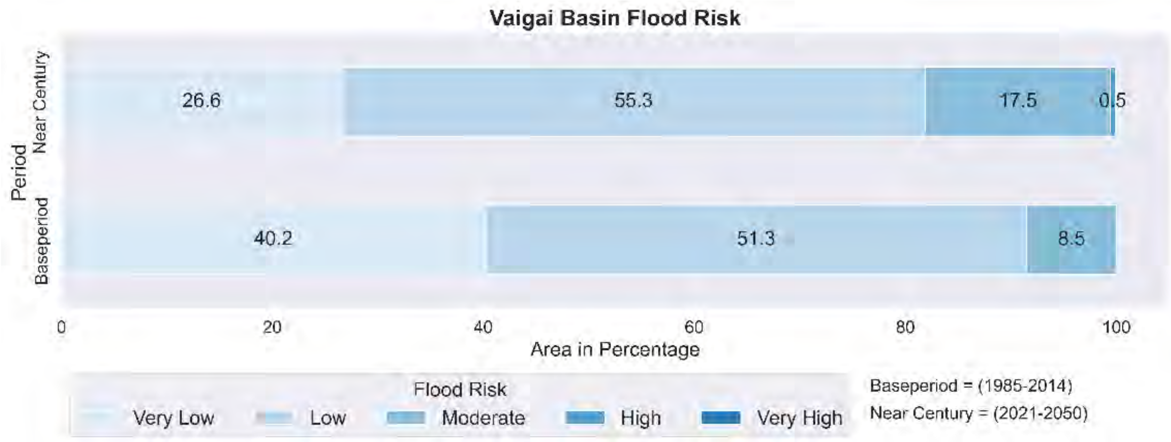


Fig. 105 Areal percentage of Flood Risk Assessment for Vaigai River Basin

According to the climate risk assessment, the Vaigai basin is severely prone to drought intensity but not to flood in both baseline and future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) completed and progressive works are: 1) Topographic survey and development of Decision Support System are being carried out for Vaigai Basin 2) Proposal on Cauvery - Agniyar - South Vellar - Manimuthar - Vaigai - Gundar Link Canal Scheme. Upon executing this project, the Vaigai basin can withstand future climate extremes of flood and drought. Adding more water harvesting structures like dams and reservoirs will conserve the watersheds of the Vaigai basin upstream.

4.15 Vaippar River Basin

Vaippar river basin is one of the significant south-eastern flowing rivers of Tamil Nadu, which has a fan/leaf-shaped watershed boundary and is represented in Fig 106. This basin is entirely bounded by the Western Ghats, Vaigai basin at the north-west, Gundar basin at the north-east, Tamiraparani at the south-west, and Kallar basin at the south-east Meanwhile, the river flows into the Palk Strait and Gulf of Mannar at the Bay of Bengal in eastern direction. The basin boundary lies between the latitude from 8^{o}59'00" to 9^{o}49'00" and longitude from 77^{o}15'00" to 78^{o}23'00". The basin is entirely divided into thirteen prominent rivers for its sub-basins are nichabanadhi, kalingalar, deviyar, nagariyar, sevalaperiyar, kayalkudiyar, Vallampatti Odai, arjunanadhi, kousiganadhi, sindapalli uppodai, uppathurar, sinkottaiyar, and Vaippar that has a total area of about 5320.17 km^2. The Administrative boundary under this basin is some of the districts, namely, Virudhunagar, in the majority, while the minimal parts of Tenkasi, Thoothukudi, and Madurai are in it.

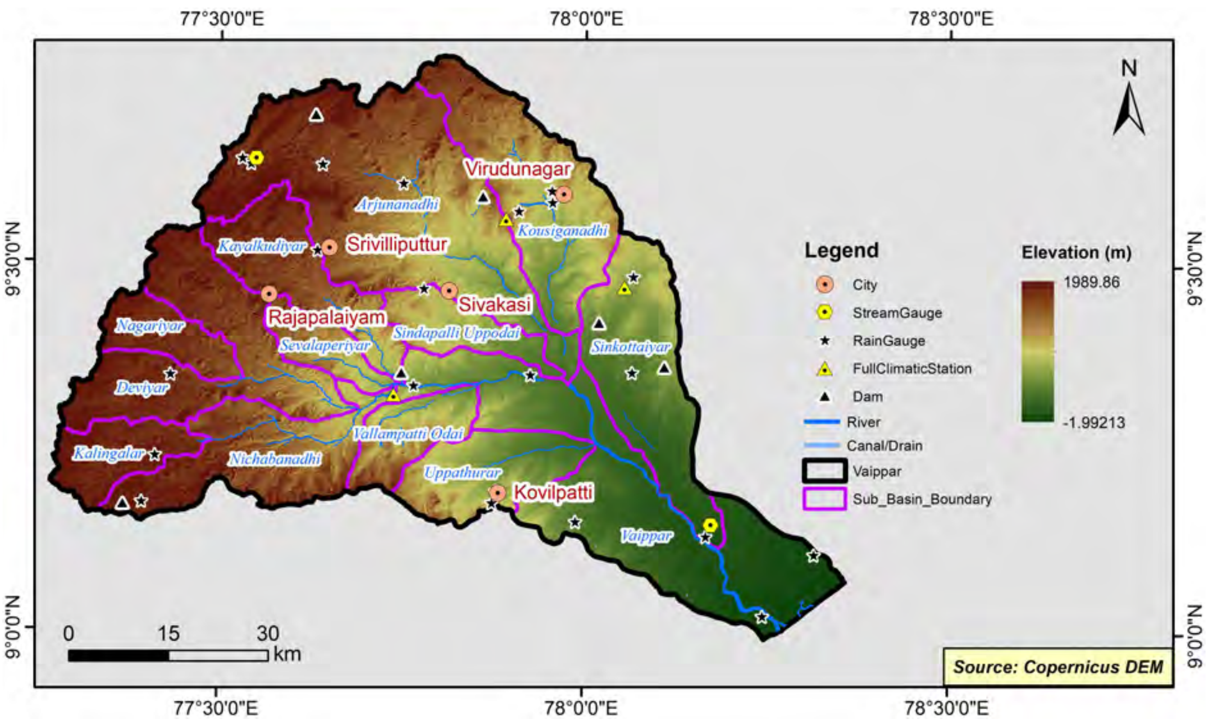


Fig. 106 Vaippar River Basin index map

Vaippar basin is the densely forested catchment at the foothills of Western Ghats and has an elevation of 1989.86 m above MSL, and the slope ranges between 0 and 35. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 33 below. The soil texture of the basin consists of sandy clay loam (23.88%), sandy clay (22.05%), clay (16.3%), clay loam (14.02%), sandy loam (13.04%), loamy sand (2.4%), and sand (0.54%). This basin entirely falls under the agro-climatic zone of the southern region. Henceforth, the major land use of the

Vaippar River basin is agricultural land (75.93%), forestland (8.64%), built-ups (4.61%), wasteland (3.81%) and wetland (0.4%). The waterbodies of this basin are covered by 6.6% as a whole.

Table 33. Hydro-Meteorological Observatories for Vaippar River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Nichabanadhi	1	1	-
2	Kalingalar	1	-	-
3	Deviyar	1	-	-
4	Nagariyar	-	-	-
5	Sevalaperiyar	-	-	-
6	Kayalkudiyar	1	-	-
7	Vallampatti Odai	-	-	-
8	Arjunanadhi	4	-	1
9	Kousiganadhi	3	1	-
10	Sindapalli Uppodai	1	-	-
11	Uppathurar	2	-	-
12	Sinkottaiyar	3	1	1
13	Vaippar	6	-	1

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Vaippar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 107 and 108 depict the spatial distribution of the drought and flood risk in the Vaippar River basin.

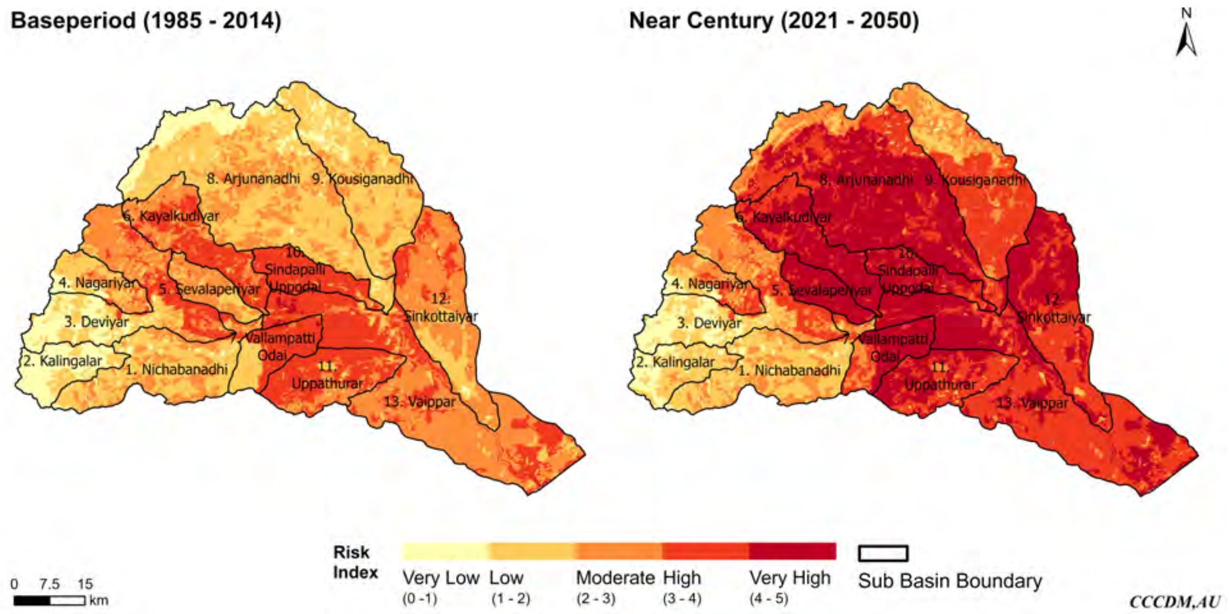


Fig. 107 Drought Risk Spatial Distribution of Vaippar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

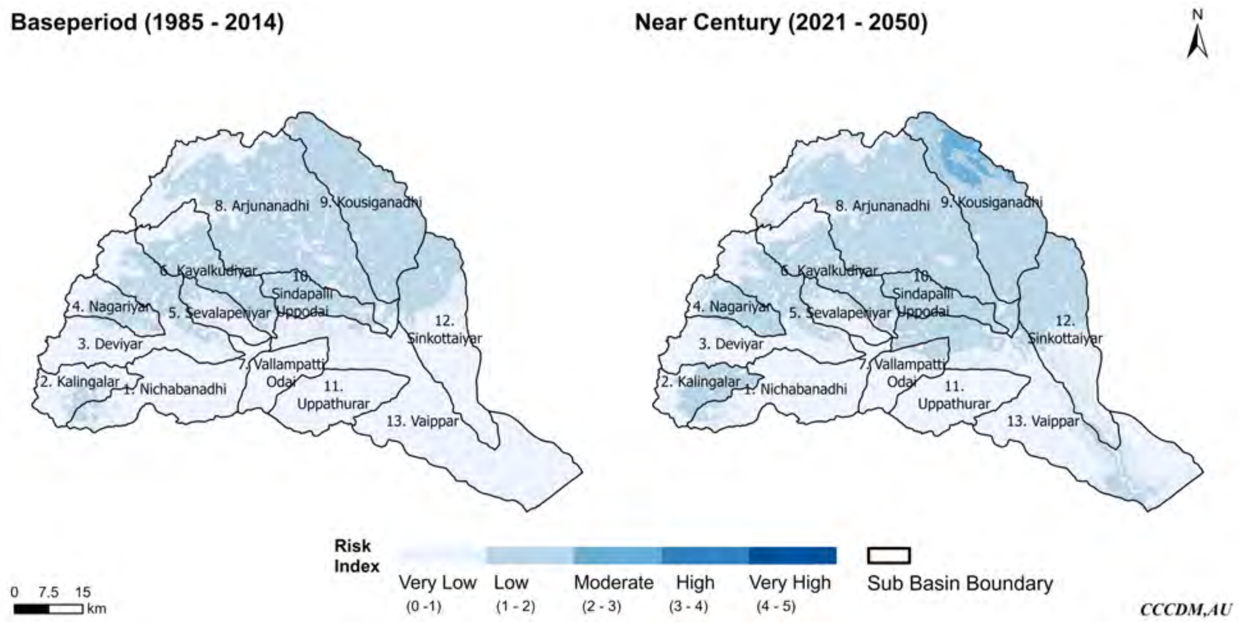


Fig. 108 Flood Risk Spatial Distribution of Vaippar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, the critical sub-basins for Vaippar River are kayalkudiyar, sevalaperiyar, deviyar, sindapalli uppodai, vallampatti odai, uppathurar, Vaippar and sinkottaiyar in baseline and remains the same in addition to arjunanadhi and kousiganadhi that gets intensified at future and the base period witnessed four drought years. In comparison, projections for the near century indicate an increase to 7 drought years. Additionally, the drought magnitude, which was 5.1 during the base period, is anticipated to rise to 9.6. Specifically, in the Vaippar, the Sevalaperiyar sub-basin is expected to undergo eight drought years with a magnitude of 11 in the future scenario.

In flood risk assessment, there is no critical subbasin for Vaippar River at the baseline, and it will remain the same. The Vaippar basin is expected to experience a 67% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 131.5%. More specifically, within the Koushiganadhi sub-basin, there is an anticipated increase of 63% in extreme rainfall events and a 104.1% increase in extreme rainfall days.

Fig 109 displays the ranking of subbasins according to their assessment of drought and flood risks. Additionally, Table 34 presents the most crucial subbasin for prioritising future adaptation efforts.

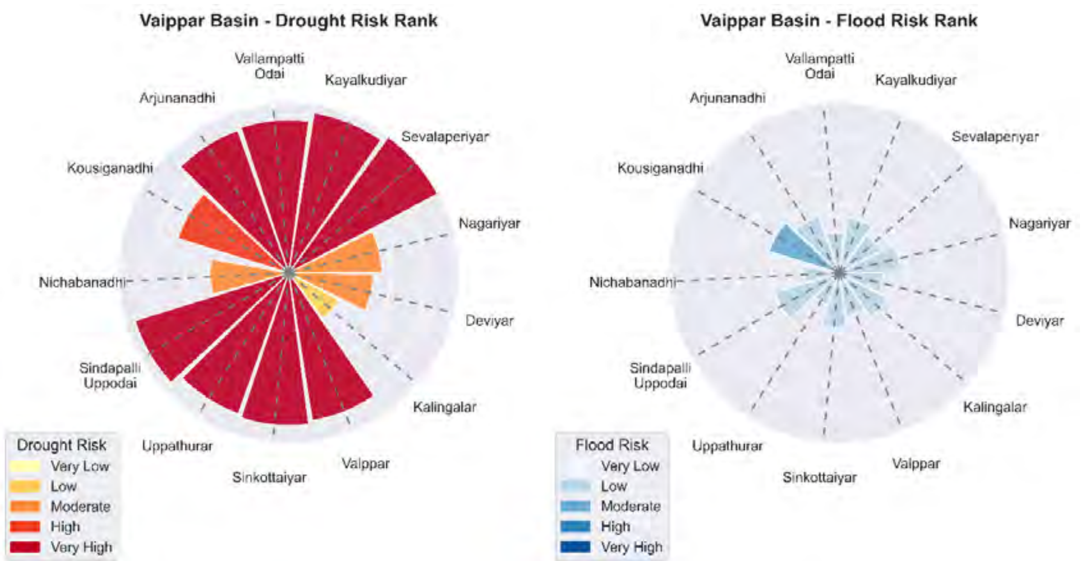


Fig. 109 Graphical Representation of Drought and Flood Risk for Vaippar Sub-basins

Table 34. Drought Risk and Flood Risk Critical Sub-Basins of Vaippar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km²)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Vaippar (13)	5323	Sevalaperiyar, Kayalkudiyar, Vallampatti Odai, Arjunanadhi, Sindapalli Uppodai, Uppathurar, Sinkottaiyar, Vaippar	-

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from very low (5.17%), low (22.18%) and medium (20.57%) class in baseline to high (10.62%) and very high (37.3%) class in futureThe overall flood risk gets slightly intensified from baseline to future period. The very low (12.1%) class of flood risk in baseline has a shift to the low (10.2%) and medium

(1.9%) class in the future period. Figs 110 and 111 indicate the risk area for the baseline and the future scenarios of droughts and floods in the Vaippar River basin.

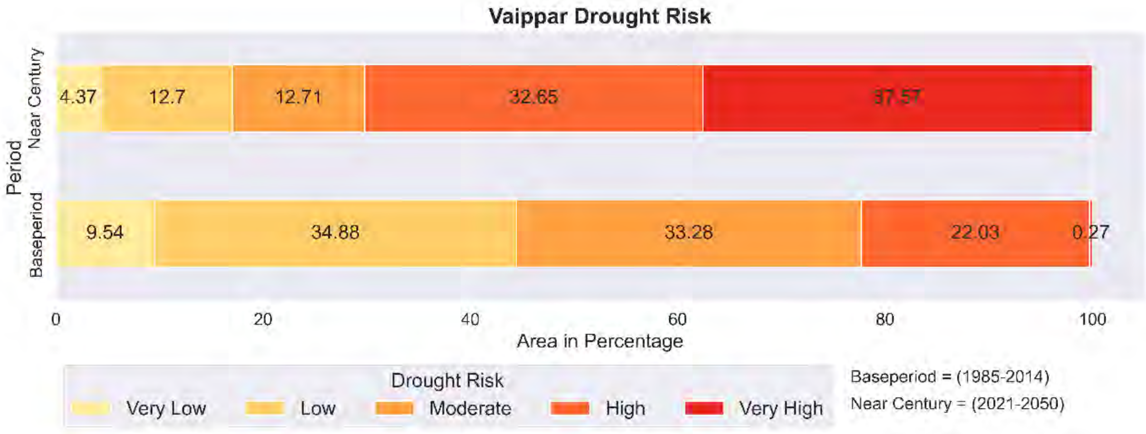


Fig. 110 Areal percentage of Drought Risk Assessment for Vaippar River Basin

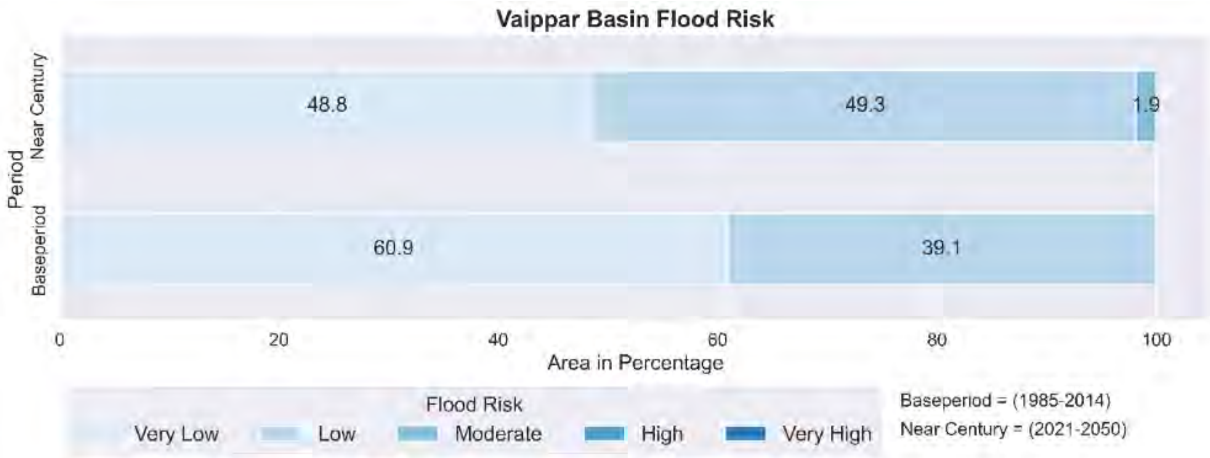


Fig. 111 Areal percentage of Flood Risk Assessment for Vaippar River Basin

According to the climate risk assessment, the Vaippar basin is severely prone to drought intensity but not to flood in both baseline and future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) completed and progressive works are 1) Feasibility Report on the Pamba-Achankoil-Vaippar Link Project to irrigate Virudhunagar and Tenkasi districts Tamil Nadu 2) Proposal on Tamiraparani - Uppar Odai - Malattar - Vaippar Link. Upon executing this project, the Vaippar basin can withstand future climate extremes of flood and drought. Adding more water harvesting structures like groundwater recharge shafts and check dams will conserve the watersheds of the Vaippar basin.

4.16 Varahanadhi River Basin

Varahanadhi river basin is one of the significant north-eastern flowing rivers of Tamil Nadu, which has a trapezoidal watershed boundary and is represented in Fig 112. This basin is entirely bounded by the Palar basin in the north and the Pennaiyar basin in the south; meanwhile, the river flows into the Bay of Bengal in the eastern direction. The basin boundary lies in between the latitude from 11°50’00” to 12°28’00” and longitude from 79°08’00” to 80°10’00”. The basin is divided into three prominent rivers, and its sub-basins are Ongur, Varahanadhi, and Nallavur. It has a total area of about 4529.91 km^2. The administrative boundary under this basin is the districts, namely, Villupuram, which is the majority, while the minimal parts of Chengalpattu and Tiruvannamalai were in it.

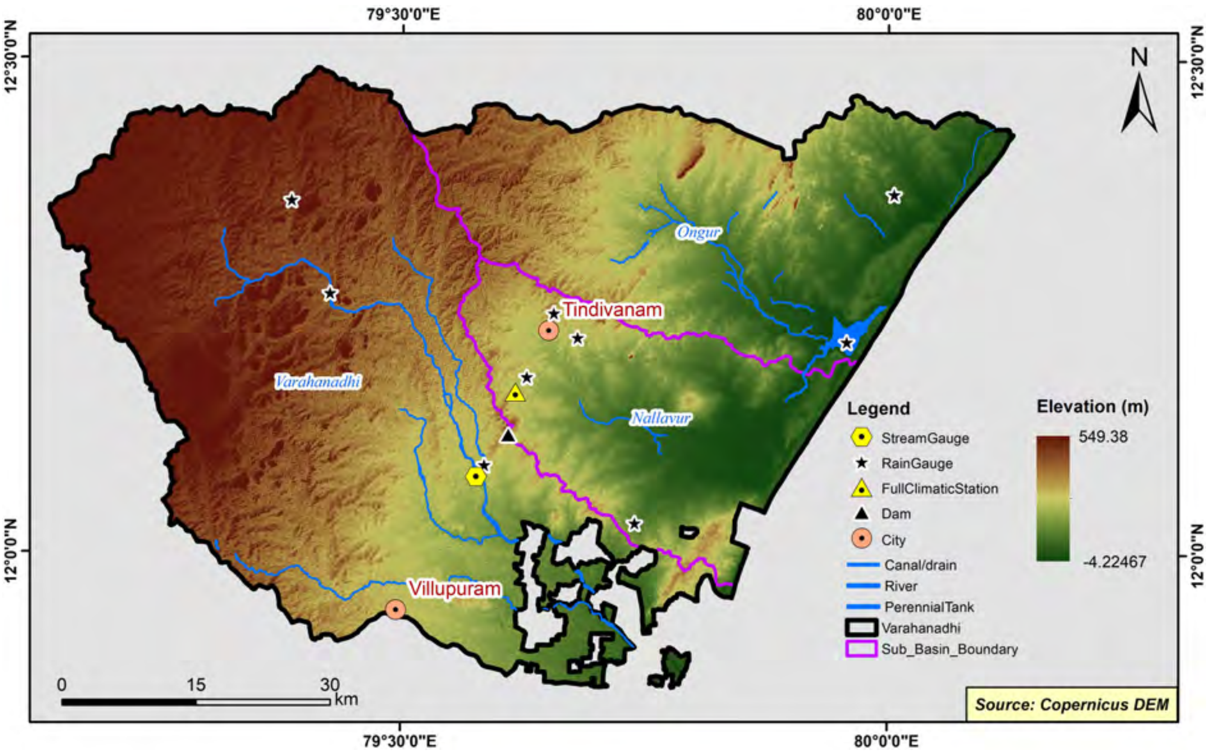


Fig. 112 Varahanadhi River Basin Index map

Varahanadhi basin is a non-forested catchment with an elevation of 549.38 m above MSL and a slope range between 0 and 10. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 35 below. The soil texture of the basin consists of sandy clay loam (27.69%), sandy loam (22.74%), clay (19.5%), loamy sand (8.2%), sand (2.4%), silty clay (1.97%), clay loam (1.76%), sandy clay (1.61%), and silty clay loam (0.12%). This basin entirely falls under the agro-climatic zone of the northeastern region. Henceforth, the major land use of the Varahanadhi river basin is agricultural land (76.66%), built-ups (4.7%), wasteland (3.81%), forestland (2.8%) and wetland (0.76%). The waterbodies of this basin are covered by nearly 11.27% as a whole.

Table 35. Hydro-Meteorological Observatories for Varahanadhi River Basin

S. No	Name of the Sub basins	Number of Observatories		
		RG	FCS	SG
1	Ongur	2	-	1
2	Varahanadhi	3	-	-
3	Nallavur	4	1	-

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Varahanadhi basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). The spatial distribution of drought and flood risk of the Varahanadhi river basin is shown in Figs 113 and 114.

There is no critical sub-basin for the Varahanadhi River baseline in drought risk assessment, and it will remain the same. During the base period, there were four drought years, and projections for the near century suggest continuing this pattern. Moreover, the expected drought magnitude was 4.7 in the base period, which is projected to increase to 5.5 in the future. Specifically, within the Varahanadhi Basin, the Nallavur sub-basin is anticipated to experience four drought years with a magnitude of 6 in the future scenario.

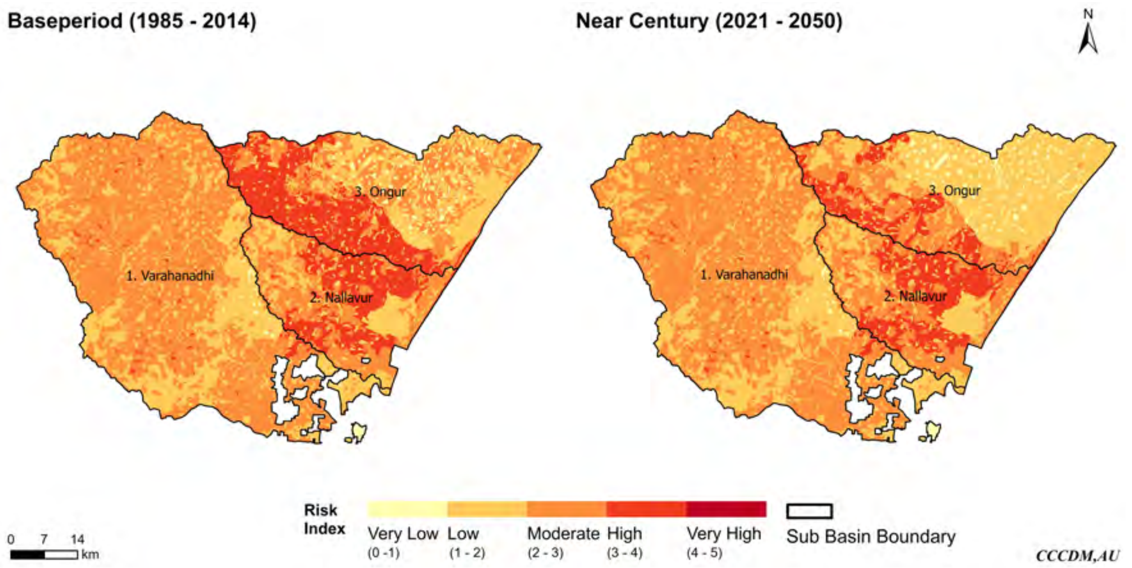


Fig. 113 Drought Risk Spatial Distribution of Varahanadhi River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

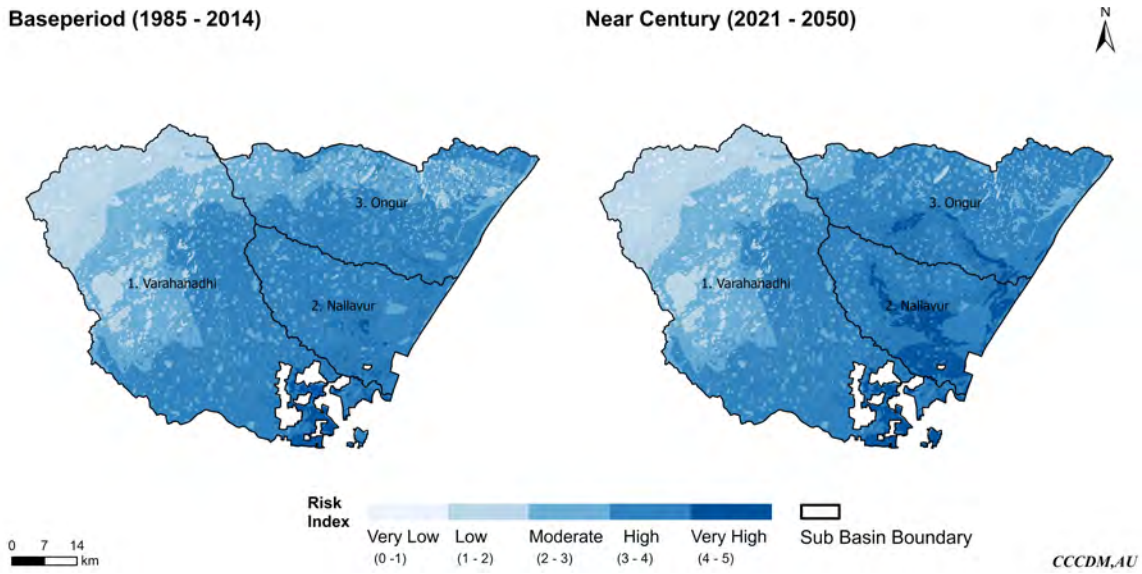


Fig. 114 Flood Risk Spatial Distribution of Varahanadhi River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In flood risk assessment, the critical sub-basin for Varahanadhi River is Nallavur and Ongur in baseline and remains the same in the future. One-day extreme rainfall occurrences (RX1) are projected to rise by 42.9% in the Varahanadhi basin, while the number of extreme rainfall days (R25) is projected to increase by 40.7%. More precisely, it is anticipated that there will be a 37.6% rise in the frequency of extreme rainfall days and a 30.3% increase in extreme rainfall events within the Nallavur sub-basin.

The Subbasins Ranking based on the drought and flood risk assessment is shown in Fig 115, and the most critical subbasins to be prioritised for future adaptation work are given in Table 36.

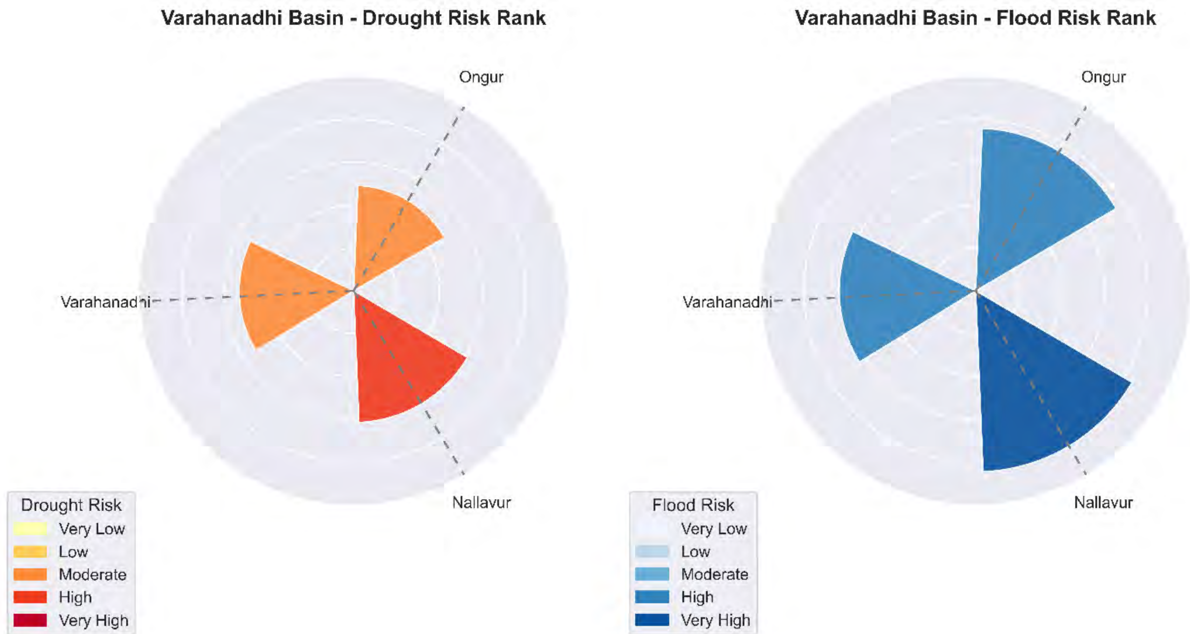


Fig. 115 Graphical Representation of Drought and Flood Risk for Varahanadhi Sub-basins

Table 36. Drought Risk and Flood Risk Critical Sub-Basins of Varahanadhi River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	Area (km²)	Drought Risk Critical Sub-Basin*	Flood Risk Critical Sub-Basin *
Varahanadhi (3)	4531	Nallavur, Ongur	Nallavur, Ongur

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall drought risk is increasing from baseline to future in which the drought classification has a shift from medium (2.26%) and high (4.98%) class in baseline to very low (0.47%) and low (6.79%) class in future. The overall flood risk will slightly intensify from the baseline to future periods. The low (1.2%) and medium (5.4%) class of flood risk in baseline has a shift to the high (1.4%) and very high (5.3%) classes in future periods. The areal extent of drought and flood risk for the baseline and future scenarios is given in Figs 116 and 117.

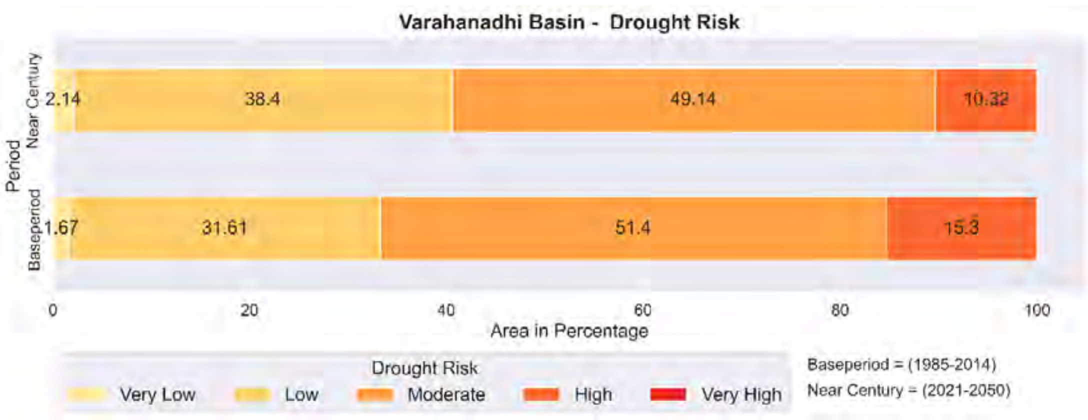


Fig. 116 Areal percentage of Drought Risk Assessment for Varahanadhi River Basin

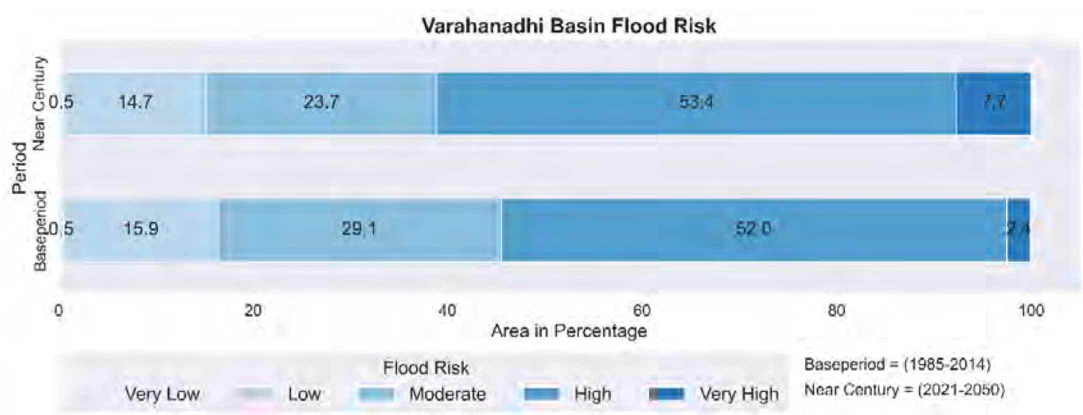


Fig. 117 Areal percentage of Flood Risk Assessment for Varahanadhi River Basin

According to the climate risk assessment, the Varahanadhi basin is severely prone to flood intensity but not to drought in both baseline and future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) has completed progressive work on a Topographic survey and is developing a Decision Support System for the Varahanadhi Basin. Upon executing this project, the Varahanadhi basin can withstand future climate extremes of flood and drought. Adding more water harvesting structures like groundwater recharge shafts and check dams will conserve the watersheds of the Varahanadhi basin.

4.17 Vellar River Basin

The Vellar River basin is one of the significant northeastern flowing rivers of Tamil Nadu, which has a fan/leaf-shaped watershed boundary and is represented in Fig 118. The Pennaiyar Basin entirely bounds this basin in the northwest, the Paravanar Basin in the northeast, and the Cauvery Basin in the south. Meanwhile, the river flows into the Bay of Bengal in the eastern direction. The basin boundary lies in between the latitude from 11°27’45” to 11°45’6” and longitude from 78°29’29” to 78°54’25”. The basin is entirely divided into seven prominent rivers for its sub-basins: Upper Velar, swethanadhi, chinar, Annaivari Odai, gomukhi, manimukdhanadhi, and Lower Vellar. It has a total area of about 7466.94 km^2. The administrative boundary under this basin is the districts Kallakurichi, Salem and Cuddalore, which comprise the majority, while the minimal parts of Nammakal, Perambalur and Ariyalur are in it.

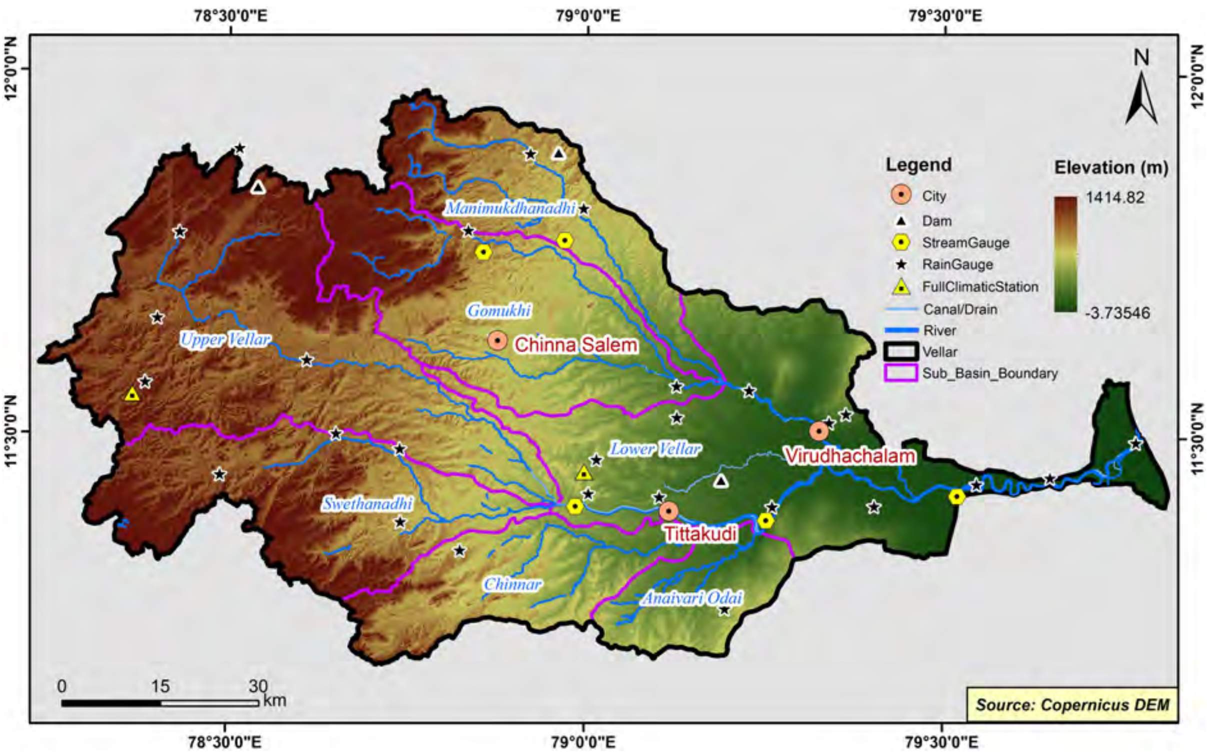


Fig. 118 Vellar River Basin Index map

Vellar basin is the densely forested catchment at the foothills of Eastern Ghats and has an elevation of 1414.82 m above MSL, and the slope ranges between 0 and 25. The Public Works Department (PWD) maintains hydro-meteorological observatories for this basin, as shown in Table 37 below.

The soil texture of the basin consists of sandy clay (29.16%), sandy clay loam (23.14%), sandy loam (18.87%), clay (12.94%), clay loam (3.74%), loamy sand (2.26%), and sand (1.9%). This basin entirely falls under the agro-climatic zone of the northeastern region. Henceforth, the major land use of the Vellar River basin is agricultural land (69.58%), forestland (19.17%), built-ups (3.63%), wasteland (2.65%) and wetland (0.07%). The waterbodies of this basin are covered by nearly 4.84% as a whole.

Table 37. Hydro-Meteorological Observatories for Vellar River Basin

S. No	**Name of the Sub basins**	**Number of Observatories**		
		RG	**FCS**	**SG**
1	Upper Vellar	5	1	-
2	Swethanadhi	4	-	-
3	Chinnar	1	-	-
4	Annaivari Odai	1	-	-
5	Gomukhi	3	-	1
6	Manimukdhanadhi	2	-	1
7	Lower Vellar	12	1	3

RG – Rain Gauges; FCS – Full Climatic Stations; SG – Stream Gauges

Drought and Flood Risk Assessment

Based on the IPCC Assessment Report AR6 risk assessment methodology, the climate extremes such as flood and drought in the Vellar basin were assessed for the baseline (1985 – 2014) and future period (2021 – 2050). Figs 119 and 120 illustrate the spatial distribution depicting the drought and flood risk within the Vellar River basin.

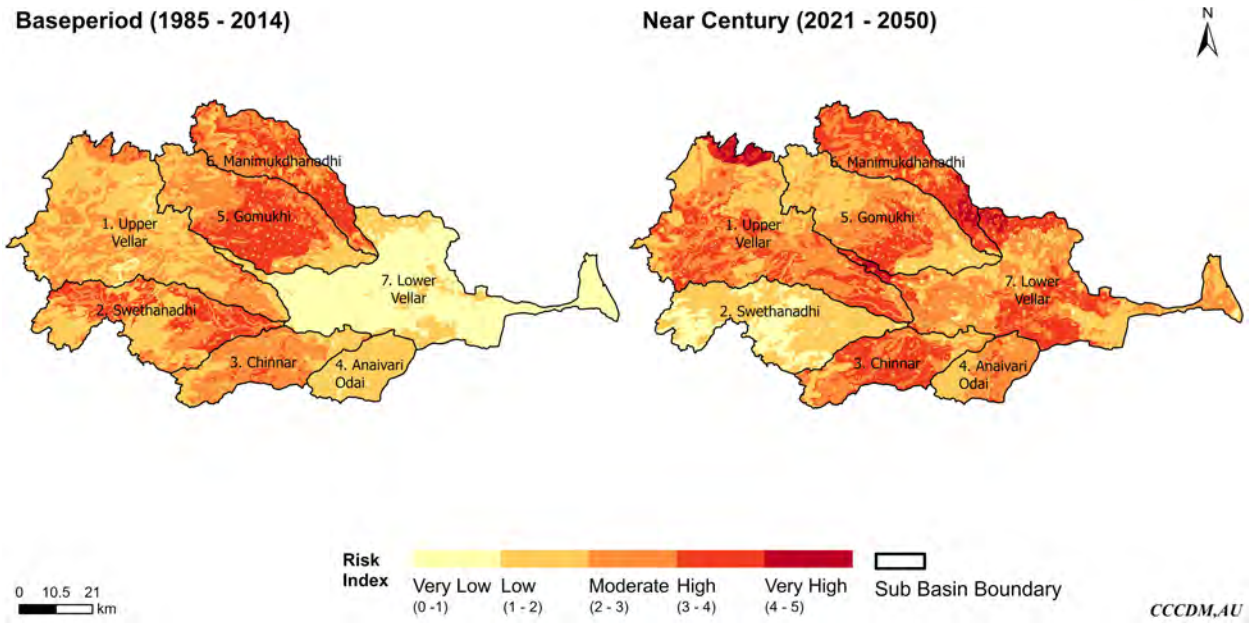


Fig. 119 Drought Risk Spatial Distribution of Vellar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

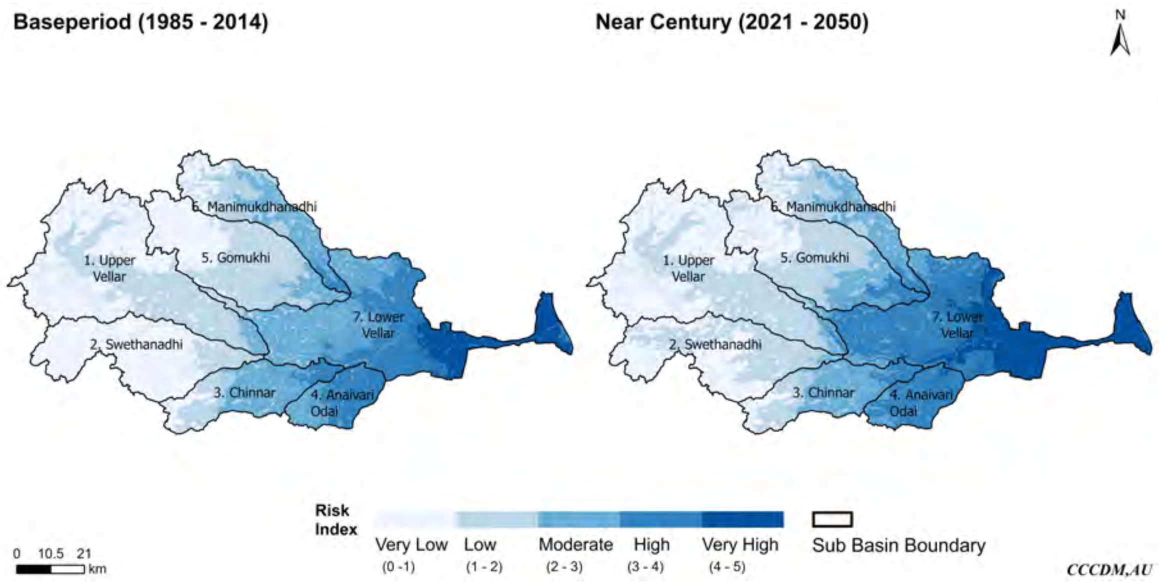


Fig. 120 Flood Risk Spatial Distribution of Vellar River Basin during the base period (1985-2014) and near-century (2021-2050) under SSP2-4.5 scenario

In drought risk assessment, the critical sub-basin for Vellar River is Swethanadhi, gomukhi and Manimukdhanadhi in baseline and remains the same in addition to Chinnar, upper and lower Vellar in the future. The base period witnessed four drought years, while projections for the near century indicate an increase to 5 drought years. Additionally, the drought magnitude of 4.7 during the base period, is anticipated to rise to 6.8. Specifically, in the Vellar, the Manimukdhanadhi sub-basin is expected to undergo six drought years with a magnitude of 8 in the future scenario.

In flood risk assessment, the critical sub-basin for Vellar River is anaivari odai and lower velar in baseline, which will remain the same. The Vellar basin is expected to experience a 29.5% increase in one-day extreme rainfall events (RX1), and the number of extreme rainfall days (R25) is projected to rise by 100.5%. More specifically, within the Lower Vellar sub-basin, there is an anticipated increase of 31.5% in extreme rainfall events and a 45.4% increase in extreme rainfall days.

Fig 121 displays the ranking of subbasins according to their assessment of drought and flood risks. Additionally, Table 38 presents the most crucial subbasin for prioritising future adaptation efforts.

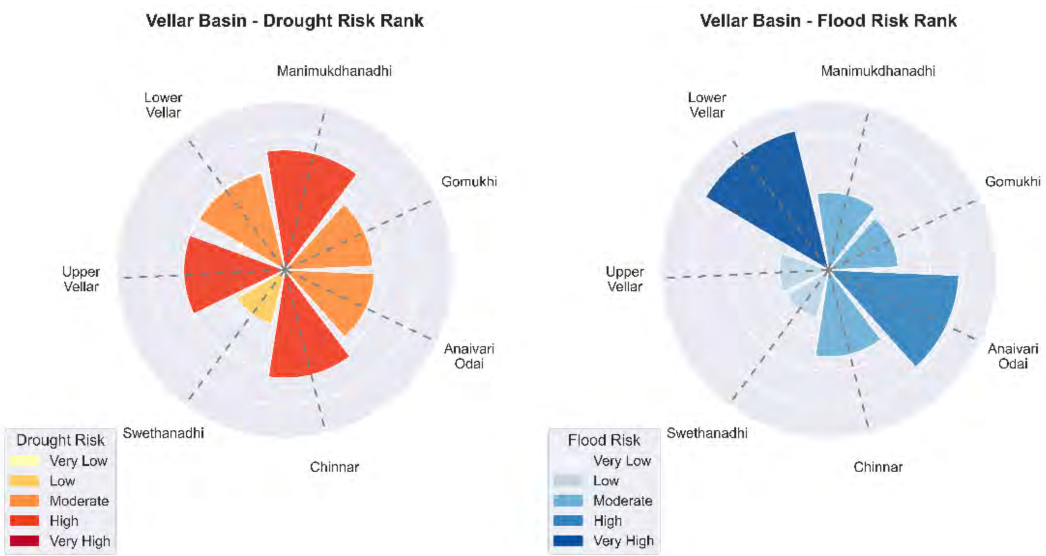


Fig. 121 Graphical Representation of Drought and Flood Risk for Vellar Sub-basins

Table 38. Drought Risk and Flood Risk Critical Sub-Basins of Vellar River Basin under SSP2-4.5 during Near Century (2021-2050)

River Basin (No .of Sub-Basin)	**Area (km^2)**	**Drought Risk Critical Sub-Basin***	**Flood Risk Critical Sub-Basin ***
Vellar (7)	7472	Upper Vellar, Manimukdhanadhi, Lower Vellar	Lower Vellar

*(*SSP2-4.5 Scenario durning Near Century (2021 - 2050))*

The overall flood risk will slightly intensify from the baseline to future periods. The overall drought risk is increasing from baseline to future in which the drought classification has a shift from very low (14.29%) and low (1.72%) class in baseline to medium (5.51%), high (8.83%) and very high (1.68%) class in future. The very low (6.5%) and medium (7%) class of flood risk in baseline has a shift to low (2.9%), high (6.1%) and very high (4.5%) class in a future period. Figs 122 and 123 provide information about the extent of drought and flood risk in terms of area for both the baseline and future scenarios.

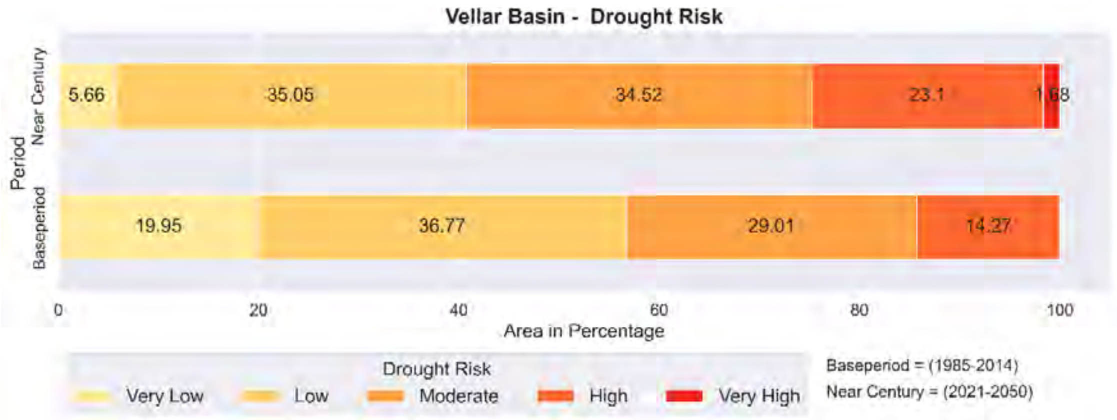


Fig. 122 Areal percentage of Drought Risk Assessment for Vellar River Basin

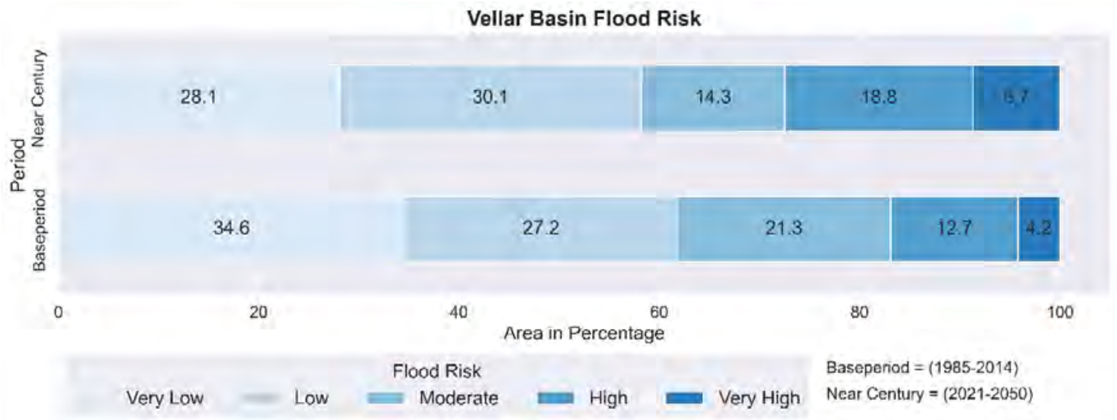


Fig. 123 Areal percentage of Flood Risk Assessment for Vellar River Basin

According to the climate risk assessment, the Vellar basin is severely prone to flood intensity and more prone to drought in both baseline and future projections. It continues to have the same characteristics in terms of climate extremes. As part of climate-adaptive measures, this basin has to be rehabilitated, renovated, and maintained by its existing water harvesting structures. The TN-PWD Water Resources Department (WRD) completed and progressive work is 1) Conducting and Preparing a Water Audit Study Report for the "Gomukhi Nadhi Reservoir Project" to evaluate the System Performance and 2) Proposal for the construction of a new reservoir at Chinnar River to meet irrigation demand on its ayacut. Upon executing this project, the Vellar basin will be capable of withstanding future climate extremes of flood and drought. Adding more water harvesting structures like farm ponds, groundwater recharge shafts, and check dams will conserve the watersheds of the Vellar subbasins.

4.18 Flood and Drought Risks of Tamil Nadu

Extensive analysis was conducted to assess the risk of drought and flood in 17 river basins in Tamil Nadu using the IPCC risk assessment framework. The EC-EARTH3 model was employed to project key climatic variables like precipitation and minimum and maximum temperatures. These projected variables were then integrated with a process-based hydrological model to simulate hydrological variables. This simulation aimed to quantify the potential hazards of flood and drought events.

Utilising the risk assessment results, the 17 basins were ranked to identify the most critical basin in terms of flood and drought risk for the near century period (2021 – 2050) under the SSP2-4.5 scenario, as illustrated in Fig 124. The objective was to identify the critical basins where climate-resilient actions could be implemented to effectively counter the imminent climatic risks.

Among the 17 river basins examined, Nambiyar, Pennaiyar, Palar, Gundar, and Vaippar require special attention due to their vulnerability to drought. Conversely, river basins like Paravanar, Varahanadhi, Chennai, Kodaiyar, and Vellar should strategically plan for potential flood occurrences. Focusing on these specific river basins will aid stakeholders in managing and mitigating the risks posed by floods and droughts.

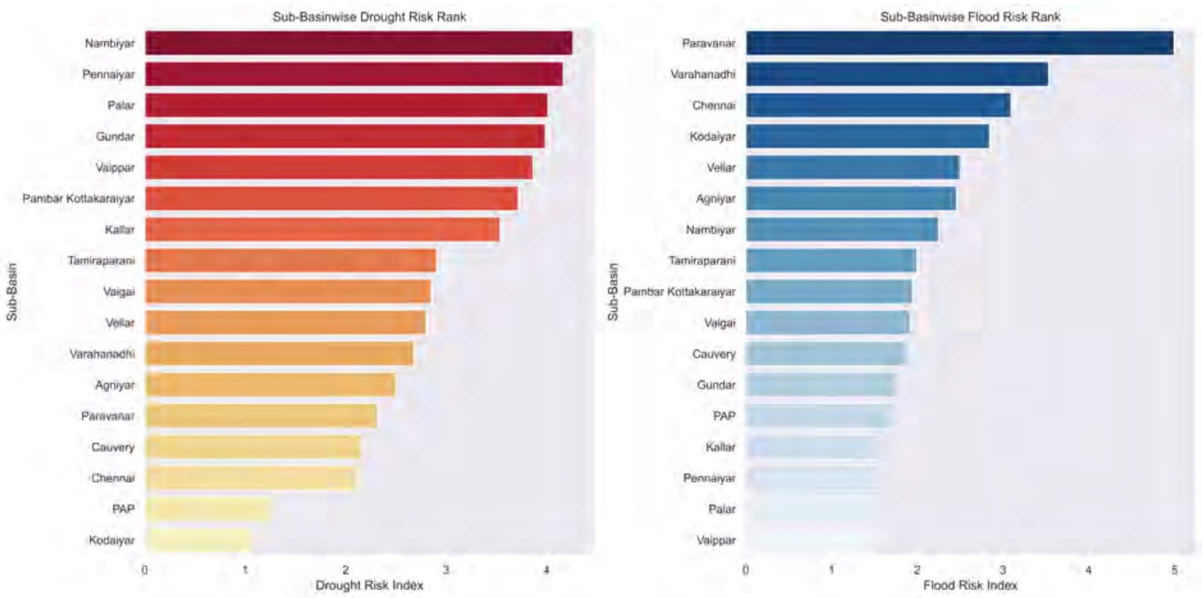


Fig 124 Graphical representation of Flood and Drought Risk for 17 River Basins of Tamil Nadu

5 CLIMATE ADAPTATION STRATEGIES FOR RIVER BASINS

Increasing adaptation is observed in natural and human systems, yet most climate risk management and adaptation currently being planned and implemented are incremental. There are gaps between current adaptation and the adaptation needed to avoid the increase of climate impacts that can be observed across sectors and regions, especially under medium and high warming levels. Droughts and Floods are the most common hazards for which adaptation is being implemented, and many of these have physical, affordability and social limits.

5.1 Climate Adaptation from Global to Local Level Approach

IPCC AR6 WGII preferred major adaptation options such as climate-smart agriculture, ecosystem-based disaster risk reduction and investing in urban blue-green infrastructure to meet adaptation, mitigation and sustainable development goals simultaneously, presenting opportunities for climate-resilient development pathways in Asia (high confidence). Climate risks, vulnerability, and adaptation measures must be factored into decision-making across all levels of governance (high confidence).

As per WRD policy note 2023-2024, the existing and ongoing projects to meet the water demand are, most commonly, Water harvesting structures (Check dams, farm ponds, canals, tanks, shafts & dykes) and the Interlinking of rivers. In the operation and maintenance of existing water adaptation measures, periodical rehabilitation, renovation, and restoration were done. Even though the adaptive measures that WRD framed are based on historical extreme events faced in specific areas, such as the extent of the basin or sub-basins, in the future, the frequency of events will be more likely to increase due to climate change. Based on these criteria, no such basin has taken action except for the Cauvery Delta under the assistance of the Asian Development Bank (ADB). Once the projects are completed, the challenges of extreme events can be faced to some extent in the future.

The gaps and barriers in framed adaptive measures by WRD significant are: Inter-linking of rivers has to be done from north to south Tamil Nadu to meet the demand of each of the 17 river basins, encroachments have to be addressed to regulate the rehabilitation, renovation and restoration of existing water bodies and requesting for more research studies concerning climate change and its projections on river basin scale using geospatial techniques. The water adaptation measures, whatever exists, are the significant activities recommended by IPCC reports as climate adaptive measures. Still, it is recommended that climate change be considered while planning for the water adaptation policies by the PWD - WRD, Government of Tamil Nadu.

From all the measures mentioned above, the need for water adaptive measures through the lens of climate will recommend site-specific investigations to be done at the cadastral level to face sudden drop downs like flash floods. Also, it is firmly intended to choose nature-based solutions like afforestation on riparian boundaries to adapt to climate change in future. The IPCC-recommended climate and water adaptation strategies are the master lists for policymakers in framing adaptation measures so that vulnerable factors can be less exposed to climate risks like floods and droughts. For instance, agro-forestry practices can reduce the flood risk by reducing soil erosion and drought by replenishing the groundwater table. Also, the recommendation for farm ponds in groundwater-exploited zones remains unusable. Therefore, a thorough understanding by site-specific analysis of river basins must be done to draw the most accurate water adaptation measures for future climate projections.

The adaptation action planning delineates the distribution of activities across the river basin in the Tamil Nadu region, explicitly addressing the challenges posed by flood and drought risks. By strategies recommended by the Intergovernmental Panel on Climate Change (IPCC), the predominant measures are aligned with Nature-Based Solutions (NBS), followed by grey infrastructure and technological interventions. The practical implementation of these strategies holds the potential to enhance the state's climate resilience by incorporating site-specific measures. The identified actions are broadly categorised into Rainwater Harvesting, River/ Canal Restoration, Stormwater Management, and Watershed Management/ Catchment Conservation.

Based on the alluvial plot (Fig 125) and Table 39, it is apparent that Watershed Management /Catchment conservation takes a prominent position among the various categories. This observation underscores the significant role of Watershed Management in the proposed strategies. The strategic emphasis on this category implies that actions related to managing watershed areas are exceptionally vital for mitigating the impacts of climate-related risks in the region.

Watershed Management encompasses a range of initiatives designed to optimise the basin's utilisation and conservation of water resources. These initiatives may include land-use planning, afforestation, and soil conservation for sustainable water management. The prioritisation of Watershed Management in the adaptation action planning underscores the recognition of its effectiveness in addressing climate-related challenges specific to the Tamil Nadu region.

Rainwater Harvesting aims to capture the local precipitation to mitigate water scarcity during periods of drought. This involves capturing and storing rainwater for various uses, promoting self-sufficiency in water resources. River/Canal Restoration efforts aim to rehabilitate and preserve natural river systems, fostering ecological balance and reducing the susceptibility to flood risks. Stormwater Management focuses on controlling and directing excess rainwater to prevent urban flooding, emphasising the importance of resilient infrastructure in mitigating climate-related hazards. These measures enhance climate resilience and contribute to sustainable urban development.

The identified measures are further associated with the primary climate risk data of Tamil Nadu's river basins. Nambiyar, Pennaiyar, and Palar are crucial basins facing drought risks, and it is essential to prioritise adaptation measures like watershed management and rainwater harvesting in these areas to mitigate potential future drought risks. Similarly, for flood-prone basins like Paravanar, Varahanadhi, and the Chennai river basin, emphasis should be placed on activities such as River/Canal Restoration and Stormwater management to avert flood risks. In the case of basins like Cauvery and Tamiraparani, which are susceptible to floods and droughts in the near future, planners should channel their maximum efforts into watershed management and river/ Canal restoration activities to enhance the climate resilience of these basins.

In summary, the adaptation action planning for the Tamil Nadu region prioritises Nature-Based Solutions, grey infrastructure, and technology to address flood and drought risks. The categorisation of actions into Rainwater Harvesting, River/ Canal Restoration, Stormwater Management, and Watershed Management reveals a strategic focus on Watershed Management, reflecting its pivotal role in climate resilience efforts. The comprehensive approach outlined in the plan underscores the importance of site-specific measures to effectively combat climate-related challenges in the region.

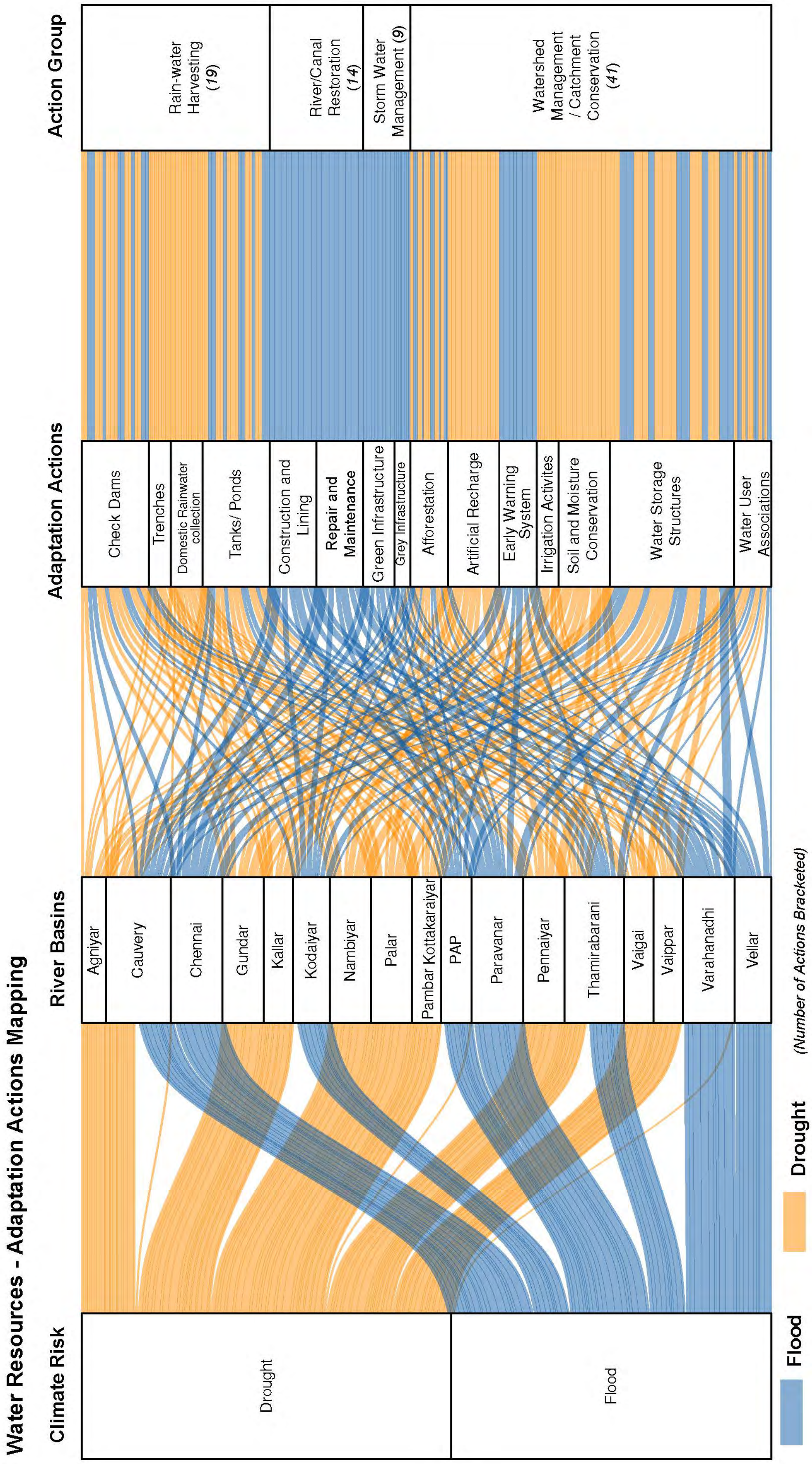


Fig. 125 Water Resources Adaptation Actions Mapping

Table 39. List out of Climate and Water Adaptation Actions

Sl. No	List of Water Adaptation Strategies
1	**Rainwater Harvesting Structures**
1.1	**Check Dams**: Brushwood Check Dam, Earthen Check Dam, Boulder Check Dam, Masonry Check Dam, Gabion Check Dam
1.2	**Trenches**: Staggered Trench, Continuous Contour Trench, Water Absorption Trench
1.3	**Tanks/ Ponds**: Storage Tanks, Surface Storage Ponds, Check Ponds, Mini Percolation Tank, Community Water Harvesting Ponds
1.4	**Domestic Rainwater Collection**: Rooftop Rainwater Harvesting System, Rain Barrels, Rain Gardens, Bore well Recharge, Open well Recharge, Recharge Pits
2	**River/Canal Restoration**
2.1	**Construction And Lining**: Construction of Feeder Canal/ Distributary Canal/ Minor Canal/ Sub-Minor Canal, Lining of Feeder Canal/ Distributary Canal/Minor Canal/Sub-Minor Canal/Water Courses Canal, Earthen lining, Concrete lining, Geo-membrane lining, Floodplain reconnection and wetland features, Restoring meanders to straightened rivers, River diversion
2.2	**Repair And Maintenance**: Renovation of Feeder Canal/ Distributary Canal/ Minor Canal/Sub-Minor Canal, Repair and Maintenance of Feeder Canal/ Distributary Canal/ Minor Canal/Sub-Minor Canal/Water Course Canal, Vegetation management, Debris Removal, Rewetting and Bank Stabilization, Sediment management
3	**Stormwater Management**
3.1	**Grey Infrastructure**: Gutters, Stormwater Drainage, Culverts
3.2	**Green Infrastructure**: Permeable Pavement, Rain Gardens, Bio retention Cells, Swale, Green Roofs, Wetlands
4	**Watershed Management/ Catchment Conservation**
4.1	**Afforestation**: Urban Afforestation, Agroforestry, Natural Afforestation
4.2	**Soil And Moisture Conservation**: Contour Ploughing, Terracing, Mulching, Crop Rotation, Contour Bunding, Grassland Management, Infiltration Basins
4.3	**Water User Associations**: Community-Based Water User Associations, Urban Water User Associations, Groundwater User Associations
4.4	**Artificial Recharge of Groundwater**: Percolation Tanks, Recharge Wells, Injection Wells, Managed Aquifer Recharge, Porous Pavement Systems, Treated Wastewater Recharge, Groundwater Banking
4.5	**Irrigation Activities**: Sprinkler Irrigation, Drip Irrigation, Surface Irrigation
4.6	**Early Warning System**: Radar Systems, Forecast Models, Hydrological Monitoring Stations, Meteorological Monitoring Stations, Mobile Applications, Early Warning Centres, Reservoir Operation Plans
4.7	**Water Storage Structures**: Earthen Gully Plugs, Stone Boulder Gully Plugs, Bio- Drainage Trees, Percolation Tank, Farm Ponds, Fisheries Ponds, Stone Spur, Earthen Spur, Irrigation Open Well, Reservoir, Barrage

6 Knowledge Dissemination

As a part of the project on flood and drought risk assessment of Tamil Nadu, knowledge dissemination was done through the capacity building programme to create awareness of climate change impacts on water resources for the policymakers.

The Water Resources Engineers (WRD) from the Tamil Nadu Public Works Department (PWD) participated in a training programme. Three two-day capacity-building sessions were organised for WRD engineers. Approximately 50 engineers representing all 38 districts of Tamil Nadu received training on climate risk information at the sub-basin level through this programme.

The training programme addresses the goals of river basin hydrology to respond to climate change through adaptation measures, with a specific focus on understanding the water balance components in the water sector. The programme's main aim is to impart knowledge and provide the scientific methodology to assess the behavioural changes of river basins under climate risks.

The capacity building programme "Training Manual" on the topic "Climate Risk Assessment and Adaptation Plan of Tamil Nadu" has been released by Tmt. Supriya Sahu IAS, Additional Chief Secretary to Government of Tamil Nadu, Dept. of Environment, Climate Change and Forest. Prof.Dr.R.Velraj, Vice Chancellor, Anna University; Dr.Nayanika Singh, UK PACT India Programme Adviser, British High Commission, New Delhi; Thiru. Deepak Bilgi IFS, Director of Environment and Climate Change, Government of Tamil Nadu; Dr. A. Ramachandran, Founder Director and Emeritus Professor, CCCDM; and Dr.Kurian Joseph, Professor and Director, CCCDM, were present. This training manual equips Water Resources Engineers (WRD) from the Tamil Nadu Public Works Department (PWD) with the skills to assess climate change impacts on river basins in Tamil Nadu. Through comprehensive instruction, engineers learn to utilise hydrological models for accurate evaluations and conduct flood and drought risk assessments. By participating in this training programme, WRD engineers gain vital expertise for effectively managing water resources amidst evolving climatic conditions, ensuring resilience and sustainability in Tamil Nadu's hydrological systems.

Fig. 126 Release of the "Training Manual" on "Climate Risk Assessment and Adaptation Plan of Tamil Nadu"

In that regard, The officials from the WRD department have suggested future adaptation actions at the sub-basin level based on the existing problems through a capacity-building programme. Some of the proposed actions are listed below.

- Restore tanks, interlink rivers, and construct check dams to enhance water storage and distribution efficiency
- Implement climate change adaptation training for farmers and engineers
- Promote mixed crop patterns, capacity building, and regulate water usage to mitigate drought
- Strengthen river banks, desilt channels, and rehabilitate existing water structures
- Enhance data acquisition for climatic data and prioritise groundwater recharge projects
- Regulate bore well digging and limit domestic and commercial bore well usage
- Divert floodwater from surplus basins to deficient ones and manage water flow to prevent overexploitation
- Conduct a comprehensive survey of water resources to prevent water flow to other states
- Encourage tree plantation, remove invasive species, and conduct awareness programs for groundwater recharge
- Establish water usage associations and enforce strict measures against encroachment
- Introduce more rain gauges and measuring gauging stations for accurate monitoring
- Rehabilitate and improve existing water structures, increasing their capacity

- Integrate interdisciplinary departmental activities for basin improvement
- Avoid single-crop cultivation in drought-prone areas and encourage crop alteration
- Provide financial support and encourage farmers' cooperation in effective water utilisation
- Create awareness among the public about future climate scenarios and adaptation measures
- Monitor rainfall and weather patterns through frequent installations and external agencies
- Link rivers strategically to ensure efficient distribution of floodwaters
- Initiate large-scale irrigation infrastructure revamping and propose new dam constructions
- Incorporate climate change considerations into future project formulations
- Design sub-basin structures considering climate change impacts on discharge
- Ensure structural adequacy of water infrastructure based on future flood forecasts
- Map recharge structures in drought-prone areas for effective water management
- Encourage community involvement in water resource management through open-access initiatives
- Strengthen regulatory measures for micro-level hydrological structures
- Foster cooperation among stakeholders for sustainable water management practices.

The glimpses of the Three Capacity Building programme are portrayed in the Figs 126 and 127.

Fig. 127 Glimpses of the Three Capacity Building programme for Water Resources Department Engineers

7 WAY FORWARD

The climate studio has completed the multi-sectoral climate risk assessment, and districts that are very high and high-risk prone have been delineated. Further, the State Government has initiated the climate change mission activities at the district level. The District Climate Change Mission shall work with all Departments at the District level in line with the State Action Plan. The Government of Tamil Nadu has appointed Green Fellows in each district to support the mission activities. It is imperative to understand and map the level of actions implemented at the cadastral level to reduce the risk and enhance the resilience of the district. In line with this need, the next phase of a climate-resilient district-level climate change action plan has to be formulated. District Climate Change Action Plan (DCCAP) for 38 districts of Tamil Nadu.

It is identified that Ramanathapuram, Dharmapuri, Krishnagiri, Tiruvannamalai, Thoothukudi, and Virudhunagar districts are projected to face very high drought risk in the future period (2021 – 2050) and Mayiladuthurai Tiruvarur, Nagapattinam, Cuddalore, and Chennai districts are projected to experience very high flood risk. It is inferred that the inland and southern districts face severe drought, whereas the coastal districts are subjected to severe flooding.

A climate risk assessment using a hydrological model was conducted to analyse the flood and drought risk for 17 river basins in Tamil Nadu. The critical basins and sub-basins in the flood and drought risks were identified for the near century under SSP2-4.5 scenarios. Adaptation action mapping has been carried out for the identified critical basins based on the IPCC framework.

The IPCC framed climate adaptation strategies that were sorted out and fitted into the river basins of Tamil Nadu as existing and recommended actions that have to be considered as a priority. The limitations of this study are likely to be addressed in the district-level climate action plan as the next phase, in which micro-watershed level climate risk assessment will be done using an integrated hydrological model where both surface and groundwater assessment will be addressed in detail. Also, this study addresses only pluvial floods, a limitation that will be addressed by including fluvial and coastal flooding and stormwater modelling. Finally, the site-specific climate adaptation actions from a hydrological perspective will be framed to meet the future climate risks of the river basins of Tamil Nadu.

However, in light of the changing climate, all the basins will be covered at a closer level to determine future risks. This could be carried out only when there are adequate basin observatories for deriving site-specific adaptation frameworks. The Water Management Authority should come forward to monitor the hydrological behaviour of different basins. Using the observed and the global data, deep learning and synthesised artificial intelligence will be empowered in the next phase to evolve the hydrological parameters such as runoff, soil erosion and flood for every 25 km^2 grid will be studied.

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