GOVERNMENT OF KERALA

Abstract

Water Resources Department- Resilient Kerala Program- Integrated River Basin Management Plan for Greater Pamba Basin- Approved-Orders issued.

WATER RESOURCES (ISWC) DEPARTMENT

G.O.(Rt)No.504/2025/WRD Dated,Thiruvananthapuram, 22-05-2025

Read 1 Letter No. MD/WRD/16/2025-AE1 dated 07/04/2025 from the Mission Director, Mission Directorate (PMU-RKI), Water Resources Department

ORDER

Government of Kerala, under the Rebuild Kerala Development Program (RKDP), has entered into agreements with international donor agencies including World Bank, Asian Infrastructure Investment Bank (AIIB), and Agence Française de Développement (AFD) for implementation of the Resilient Kerala Program (RKP) - Program for Results (PforR). The financing instrument for this program follows the Disbursement Linked Indicators (DLIs) approach. DLI 7 is defined as the development and implementation of an Integrated River Basin Management Plan for the Pamba River Basin. This plan aims to enhance the resilience of the Pamba River Basin and improve its capacity to mitigate and respond effectively to floods. The specific objectives of DLI 7 include:

i. Strengthening the Water Resources Department (WRD) with tools for flood management

ii. Implementing critical water resources management investments as defined in the Integrated River Basin Management plan

iii. Implementing investments in selected locations within the Pamba Basin to minimize flood damages in future

Irrigation Department is the implementing agency for DLI 7 and is responsible for supporting the development and implementation of measures to mitigate flood damages in the Pamba Basin.

2. As per letter read above, the Mission Director, Mission Directorate (PMU-RKI), Water Resources Department has furnished the finalized Integrated River Basin Management (IRBM) Plan for the Greater Pamba

Basin for approval so as to facilitate its implementation and to meet the disbursement-linked targets.

3. Government have examined the matter in detail and are pleased to approve the Integrated River Basin Management (IRBM) Plan for the Greater Pamba Basin, annexed to this Government Order.

(By order of the Governor)
BISHWANATH SINHA
ADDITIONAL CHIEF SECRETARY

To:

1. The Mission Director, Mission Directorate (PMU-RKI), Water Resources Department
2. All Chief Engineers, Water Resources Department
3. The Director, I&PRD (Web & New Media)
4. Water Resources(IR) Department
5. Stock File / Office Copy

Forwarded /By order
Signed by
Resmi B
Date: 23-05-2025 16:24:03
Section Officer

Prepared by
IRRIGATION DEPARTMENT
Government of Kerala

Rebuild Kerala

THE WORLD BANK

INTEGRATED RIVER BASIN MANAGEMENT PLAN FOR THE GREATER PAMBA BASIN
(PAMBA, ACHENKOVIL AND MANIMALA)

INTEGRATED RIVER BASIN MANAGEMENT PLAN FOR THE GREATER PAMBA BASIN

(PAMBA, ACHENKOVIL AND MANIMALA)

FINAL REPORT

Prepared by
IRRIGATION DEPARTMENT
Government of Kerala

Rebuild Kerala

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CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Expansion
AAP	Annual Action Plan
AC	Apex Committee
ACS	Additional Chief Secretary
Carto DEM	Cartosat-1 Digital Elevation Model
CCM	Constant of channel maintenance
CE	Chief Engineer
CGWB	Central Ground Water Board
CMIP	Coupled Model Intercomparison Project
CN	Curve Number
COD	Chemical Oxygen Demand
CS	Chief Secretary
CSR	Corporate Social Responsibility
CWC	Central Water Commission
CWRDM	Centre for Water Resources Development and Management
DEM	Digital Elevation Model
DEWATS	Decentralized Wastewater Treatment System
DGPS	Differential Global Positioning System
DLI	Disbursement Linked Indicator
DWLR	Digital Water Level Recorder
EIA	Environmental Impact Assessment
ENSO	El Niño-Southern Oscillation
ET	Evapotranspiration
FabDEM	Forest and Buildings removed Copernicus DEM
FAO	Food and Agriculture Organization
FDC	Flow Duration Curves
FRL	Full Reservoir Level
GEV	Generalized Extreme Value

GIAM	Global Irrigated Area Map
GIS	Geographical Information System
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Center's River Analysis System (
HED	Harbour Engineering Department
HoD	Head of Department
HoFF	Head of Forest Forces
HRU	Hydrological Response Units
HWSD	Harmonized World Soil Database
ICCS	Institute For Climate Change Studies
IDRB	Irrigation Design and Research Board
IMD	India Meteorological Department
IOD	Indian Ocean Dipole
IRBM	Integrated River Basin Management
IRBMP	Integrated River Basin Management Plan
IWRM	Integrated Water Resources Management
KSCSTE	Kerala State Council For Science, Technology, And Environment
KSDMA	Kerala State Disaster Management Authority
KSEB	Kerala State Electricity Board
KSPB	Kerala State Planning Board
KSPCB	Kerala State Pollution Control Board
KWA	Kerala Water Authority
LSGD	Local Self Government Department
LULC	Land Use And Land Cover
MCM	Million Cubic Meters
MD	Managing Director
MDG	Millennium Development Goals
MLD	Megaliters per Day
MoEFCC	Ministry of Environment, Forests & Climate Change
MSL	Mean Sea Level

MSL	Mean Sea Level
MSSRF	MS Swaminathan Research
MUSLE	Modified Universal Soil Loss Equation
MW	megawatt
NAQUIM	National Aquifer Mapping and Management Programme
NAWMP	National Ambient Water Quality Programme
NDMA	National Disaster Management Authority
NDSA	National Dam Safety Authority
NGO	Non-Governmental Organization
NHGs	Neighbourhood Groups
NSE	Nash-Sutcliffe Efficiency
NWMP	National Water Quality Monitoring Programme
OC	Organic Carbon
PBIAS	Percent Bias
PDF	Probability Density Function
PDNA	Post-Disaster Needs Assessment
PforR	Program-For-Results
PIP	Pamba Irrigation Project
PPP	Public Private Partnership
PPU	Percent Prediction Uncertainty
PWD	Public Works Department
RBCM	River Basin Conservation and Management
RBCMA	River Basin Conservation And Management Authority
RBLC	River Basin Level Committee
RBM	River Basin Management
RCP	Representative Concentration Pathways
RCPs	Representative Concentration Pathways
RET	Rare, Endangered, Or Threatened
RKI	Rebuild Kerala Initiative
RMU	Renovation, Modernization, And Upgradation

RTDAS	Real Time Data Acquisition Stations
RWSS	Rural Water Supply Scheme
SBR	Sequencing Batch Reactor
SC	Steering Committee
SDGs	Sustainable Development Goals
SDMA	State Disaster Management Authority
SEWA	Self-Employed Women's Association
SGHEP	Sabarigiri Hydroelectric Project
SHEPs	Small Hydroelectric Projects
SIA	Social Impact Assessments
SOLAWC	Soil Available Water Capacity
SRI	Standardized Runoff Index
SRI	Standardized Runoff Index
SRTM DEM	Shuttle Radar Topography Mission Digital Elevation Model
SSPs	Shared Socioeconomic Pathways
STP	Sewage Treatment Plant
STP	Sewage Treatment Plant.
SUFI-2	Sequential Uncertainty Fitting, Version 2
SWAT	Soil & Water Assessment Tool
SWIC	State Water Informatics Centre
SWMP	State Water Quality Monitoring Programme
TC	Technical Committee
TMB	Thanneermukkom Barrage
TSW	Thottappally Spillway
UASB	Upflow Anaerobic Sludge Blanket
UTM	Urchin Tracking Module
UWSS	Urban Water Supply Schemes
VCB	Vented Cross-Bars
WGS-84	World Geodetic System 1984
WRD	Water Resource Department

WSS	Water Supply Scheme

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EXECUTIVE SUMMARY

The Integrated River Basin Management (IRBM) Plan for the Greater Pamba Basin is a comprehensive framework designed to address Kerala's pressing challenges of flooding, water insecurity, and ecological degradation. Anchored in scientific analysis and participatory governance, the plan responds to the catastrophic 2018 Kerala floods, which caused unprecedented devastation, including loss of lives, destruction of crops, and critical damage to water infrastructure. The floods underscored systemic vulnerabilities, such as silt-clogged irrigation canals, collapsed hydraulic structures (sluice gates, check dams), and overwhelmed urban drainage systems. Coastal protection breaches also led to saltwater intrusion in the ecologically sensitive Vembanad Lake. These impacts catalysed the state's commitment to rebuilding sustainably through Integrated Water Resources Management (IWRM), guided by the "Navakeralam" vision of equitable development.

The Water Resources Department (WRD) of Kerala has demonstrated strong political will to adopt IWRM principles, embedding them into the Kerala State Water Policy to align water management with global best practices. This aligns with broader national efforts, such as India's National Water Policy and River Action Plans by the Ministry of Environment, Forests & Climate Change (MoEFCC), which emphasize integrated approaches to water quality and resource management. However, despite progressive policies, institutional gaps persist in translating IWRM from theory to practice, particularly in resolving inter-sectoral conflicts and enforcing regulations.

The Greater Pamba Basin, spanning the Pamba, Achankovil, and Manimala rivers, was profiled through geomorphological and topographical assessments. Structural interventions such as dams, canals, were mapped to evaluate their role in flood control and water supply. Morphometric analyses (stream order, drainage density) and hydrological modelling using the Soil and Water Assessment Tool (SWAT) were employed to understand basin behaviour. Future climate scenarios (CMIP/SSP projections) were integrated to simulate shifts in water availability, while stakeholder consultations identified risks like floods, droughts, and pollution. Flood management was prioritized, leading to hydrodynamic studies in Kuttanad, where numerical simulations assessed flood impacts across return periods and proposed structural solutions (regulators, embankments) to reduce severity.

The plan advocates establishing a statutory River Basin Conservation and Management Framework to coordinate basin activities, resolve conflicts, and institutionalize IWRM through inclusive committees. While aligning with Kerala's policy framework and national initiatives like the Jal Shakti Mission, implementation faces hurdles such as funding gaps for critical projects (e.g., flood regulators, Managed Aquifer Recharge), overlapping agency mandates, and climate uncertainties like salinity intrusion. A phased execution (2025–2030) will prioritize flood mitigation, with resources mobilized through external aid and public-private partnerships.

Establishing the River Basin Conservation and Management Framework as the empowered body ensures that it has the authority to coordinate stakeholders, and implement basin-wide strategies. In alignment with the Rebuild Kerala Initiative (RKI)'s vision to develop a green and resilient Nava Keralam, the IRBM Plan for the Greater Pamba Basin is a key component of the Resilient Kerala Program-for-Results (PforR) under Disbursement Linked Indicator (DLI) 7. This initiative strengthens flood management systems, implements critical water resource management (WRM) investments, and enhances the resilience of the Pamba River Basin through sustainable, participatory, and environment-friendly interventions. The IRBM Plan contributes directly to RKI's mission of building long-term resilience against natural disasters, climate change, and water-related vulnerabilities.

While climate uncertainties and funding gaps remain, the plan positions Kerala as a leader in sustainable river basin management, advancing the "Navakeralam" vision of a climate-resilient future. This initiative not only addresses local vulnerabilities but also offers replicable insights for tropical regions grappling with climate-induced water stress.

1. Introduction

1.1. Background

Kerala, a southwestern coastal state of India, is bordered by the Arabian Sea on the west and the Western Ghats on the east. The state extends north to south along a 590 km coastline, with a varying width of 35 to 120 km. Geographically, Kerala is divided into three distinct regions: hills and valleys, midlands and plains, and the coastal region. The eastern edge, near the Western Ghats, consists of steep mountains and deep valleys covered with dense forests. Due to its steep terrain, heavy rainfall, and narrow width, Kerala is home to numerous rivers. The state has 44 rivers, of which 41 originate from the Western Ghats and flow westward into the Arabian Sea. The remaining three rivers are tributaries of the Cauvery River, flowing eastward into the neighbouring states. During the 2018 floods, the districts of Pathanamthitta, Kottayam, Alappuzha, and Idukki were severely affected, suffering extensive damage. The three major rivers in these districts, Pamba, Manimala, and Achankovil, witnessed significant flooding, causing widespread destruction across various sectors in their basins. In response, the government initiated modern approaches to address flood-related challenges in the most affected areas. A holistic strategy was adopted, focusing on integrated water management within the Pamba, Manimala, and Achankovil river basins together coined as the Greater Pamba Basin

1.2. Relevance of Integrated River Basin Management in Greater Pamba Basin

Integrated River Basin Management (IRBM) is a holistic approach that considers the entire watershed system, ensuring that water resources are managed efficiently and sustainably. Unlike traditional water management methods that often focus on localized interventions, IRBM integrates hydrology, socio-economics, ecology, and climate resilience to address the growing pressures on water systems. In the case of the Greater Pamba River Basin, effective sectoral management is important to mitigate recurrent floods, pollution, and environmental degradation. Without a coordinated, science-driven approach, these pressures will compromise long-term water availability and resilience.

Drawing from global best practices, such as the Ganga River Basin Plan and the European Water Framework Directive, the IRBM Plan for the Greater Pamba Basin aims to create a holistic, data-driven, and participatory water governance framework. This ensures resolving various problems affected by the stakeholders.

1.3. Integrated Water Basin Development Goals for the Pamba River Basin

The challenges such as frequent floods, water scarcity, pollution, and ecosystem degradation demand an integrated approach to its management. The primary goals include flood risk management through early warning systems, resilient infrastructure, and natural flood management methods like wetland restoration. Sustainable water resource management is essential, promoting efficient water use, rainwater harvesting, groundwater recharge, and maintaining ecological flows. Ensuring water quality by implementing monitoring networks and pollution control measures will enhance the basin's water resources management in addition to the routine monitoring.

Policy integration across sectors, including agriculture, urban planning, and disaster management, will ensure cohesive decision-making. A data driven approach, with real-time hydrological and meteorological data systems, will support transparent, evidence-based management. By pursuing these integrated goals, the Greater Pamba River Basin can build resilience against climate change, ensure water security, and promote sustainable socio-economic growth for the region's communities.

1.4. Objectives of the Integrated River Basin Management Plan

The Integrated Management Plan for the Greater Pamba River Basin aims to address critical issues such as seasonal flooding, water scarcity, and ecological degradation through a focused and context-specific approach. Key objectives include,

1. To create a comprehensive database on the current state of the basin across various sectors, including detailed information on existing water-related structures and hydrometeorological data. Additionally, the database will encompass an in-depth study of the basin's morphometry to support effective analysis and decision-making.
2. To assess the current water availability in the basin using hydrological modelling, and estimate future water availability based on CMIP and SSP climate model projections. This analysis will support improved water resource management and planning in the basin.
3. To engage stakeholders through meetings to identify key issues in the basin and prioritize them using matrix analysis. Solutions suggested by stakeholders will be considered. Additionally, a detailed study of existing legislations will be conducted to address the identified issues. Proposals will be made to strengthen governance mechanisms, enhance coordination among stakeholders, and empower local communities in decision-making.
4. To conduct a detailed hydrodynamic study to model the complex river networks in the flood-affected basin. The study will assess the impact of floods across different return periods and analyse the effectiveness of various structural interventions. The results will provide insights into flood mitigation strategies and their potential impact on the region.

1.5. Scope of the Proposed River Basin Plan

The study is structured to provide an estimation of water resources for sustainable water management, flood resilience, and stakeholder engagement in the Greater Pamba Basin which includes, Pamba, Manimala and Achankovil basins which drain into the Kuttanad region. The Pamba, Manimala, and Achankovil river basins are considered for detailed assessment.

Although the Manimala and Muvattupuzha rivers drain into the Vembanad Lake System, only three rivers are included in this phase for a more simplified and effective management approach.

1.5.1. River Basin Profiling

The study primarily focuses on water-related data, including mapping structural interventions, analysing river systems and drainage patterns, and calculating morphometric parameters, providing a view of the current scenario. While socio-economic and environmental conditions are discussed, the analysis remains water-centric.

1.5.2. Water Resources Assessment

The Soil and Water Assessment Tool (SWAT) has been used for water resources assessment in the Pamba River Basin. The analysis utilized IMD gridded rainfall data along with rain gauge data from the Kerala Water Resources Department (WRD). Based on this, the current water availability in the basin has been calculated. Additionally, historical water availability has been estimated for comparison. Future water availability projections were made using climate models under the Shared Socioeconomic Pathways (SSP) and Coupled Model Intercomparison Project (CMIP) scenarios.

1.5.3. Stakeholder Engagement and Risk Prioritization

Multi-level stakeholder engagements have been conducted to identify and address key issues in the Pamba River Basin. Through detailed deliberations, high-risk problems such as floods, pollution, water security, and landslides were identified, most of which require a multi-sectoral approach. In this phase, flood management has been prioritized for resolution, with other issues planned for subsequent phases. Existing water management laws and policies will be reviewed and compared against the proposed basin management plan. The study also recommends an institutional framework to facilitate collaborative governance, ensuring effective implementation of the plan.

1.5.4. Flood Assessment and Mitigation measures

A one-dimensional hydrodynamic study was conducted in the flood-prone Kuttanad region to evaluate the impacts of floods across different return periods using simulations. Major structural intervention proposals were modelled to assess their effects, while minor interventions were excluded from modelling due to their evident benefit-cost ratio. A semi-automatic flood forecasting system was developed, with provisions for future advancements. The study will recommend targeted flood mitigation strategies to enhance resilience in the Pamba River Basin.

This integrated approach will contribute to the sustainable management of the Pamba River Basin, ensuring resilience against climate change, minimizing flood risks, and promoting equitable water use for communities across the region.

1.6. Methodology

1.6.1. River Basin Profiling

The existing scenario of the Greater Pamba River Basin has been assessed, covering its geomorphology and topography. The basin's physical characteristics, including elevation variations, slope patterns, and landforms, have been described to understand the natural setting. Structural interventions such as dams, reservoirs, canals, and other water management infrastructure have been mapped, and their significance in flood control, irrigation, and water supply has been analysed.

A detailed study of the river system within the basin has been conducted, examining its tributaries, drainage patterns, and connectivity. Morphometric parameters, including stream order, drainage density, and bifurcation ratio, have been calculated to assess the basin's hydrological behaviour. Index properties, representing the basin's shape and flow characteristics, have also been determined. The various irrigation systems operational in the basin have been analyzed, highlighting their role in supporting agriculture. The existing hydrometeorological network, comprising rainfall gauges, stream gauges, and weather stations, has been mapped to evaluate data availability for effective water management. The socio-economic status in the basin, and environmental status has been studied. Thus, a comprehensive idea about the resources in the basin has been obtained. A detailed assessment of the water availability in the basin is carried out for the better water management in the basin

1.6.2. Water Resources Assessment

A hydrological assessment has been conducted for the Pamba River Basin using the Soil and Water Assessment Tool (SWAT). The model was calibrated and validated using historical streamflow data to ensure accuracy and reliability. Future climate projections, based on the Coupled Model Intercomparison Project (CMIP) and Shared Socioeconomic Pathways (SSP), were integrated into the model to estimate changes in temperature and rainfall. Using these projections, the hydrological model simulated future scenarios, allowing for an assessment of potential shifts in water availability. From the calibrated model, the current water availability in the basin was estimated. Future water availability was then projected under various climate scenarios, offering valuable insights for water resource management, flood control, and adaptation planning in the region. The current availability of the ground water is also estimated. To understand various problems that is affecting the basin in the water sector, different level of stakeholder meetings has been conducted.

1.6.3. Stakeholder engagement and legislations

Multi-level stakeholder engagements have been conducted in the Pamba River Basin to identify and assess the key challenges faced by the stakeholders. Through these consultations, an understanding of the basin's issues was developed, leading to the creation of a risk matrix. The matrix facilitated the prioritization of risks, highlighting floods, droughts, pollution, landslides, and water security as the most significant concerns. Among these, flood management was selected for further detailed analysis due to its frequent occurrence and severe impacts.

Stakeholders proposed various solutions, which were categorized into structural and non-structural interventions. The existing legislations related to water management were reviewed and compared against the proposed basin plan. An institutional mechanism has also been discussed, suggesting a collaborative governance framework that involves local bodies, state authorities, and community organizations. A detailed hydro dynamic study in the basin is conducted for the effect of flood in the basin and solutions were proposed.

1.6.4. Flood Assessment Study

A detailed hydrodynamic study has been conducted in the most flood-prone areas of the Pamba River Basin, focusing on the Kuttanad region. Numerical simulations were carried out to assess the impact of floods across different return periods, providing valuable insights into the basin's flood behaviour. These simulations helped in understanding how flood levels vary under different scenarios. Based on the study, various structural interventions were proposed to mitigate flood impacts. The effectiveness of these interventions was further analyzed through additional simulations that incorporated the suggested measures. The results demonstrated that implementing a combination of structural solutions, including regulators, alternate channels, and embankment protection works, could significantly reduce the extent and severity of flooding for multiple return periods. It was concluded that the implementation of these interventions would enhance flood resilience in the Kuttanad region and contribute to effective flood management across the Pamba River Basin. A flood forecasting system has been developed as a non-structural measure for the flood.

1.7. Summary

The Integrated River Basin Management Plan for the Greater Pamba Basin is a comprehensive approach to addressing critical water resource challenges, including flooding, water scarcity, and environmental degradation. By leveraging scientific assessments, stakeholder engagement, and global best practices, this study aims to establish a sustainable and resilient water management framework. The combination of hydrological modelling, flood assessment, and policy integration will ensure that the basin's water resources are managed effectively for long-term ecological and socio-economic benefits. The insights gained from this study will serve as a foundation for informed decision-making, enabling the region to adapt to future climatic and hydrological uncertainties.

2. River Basin Profiling

2.1. Location and Extent

The Greater Pamba River Basin, located in southern Kerala, India, encompasses the combined catchment areas of the Pamba, Achankovil, and Manimala rivers, covering approximately 4,566 km². It spans the districts of Pathanamthitta, Alappuzha, and parts of Kottayam and Idukki. Geographically, the basin is situated between latitudes 9°02'N and 9°40'N and longitudes 76°19'E and 77°08'E, with the Pamba River flowing entirely within this range. The Achankovil River, which flows south of the Pamba Basin, overlaps with its range, while the Manimala River originates slightly to the north of the Pamba Basin, also within the same geographical range. The basin stretches from the highlands of the Western Ghats in the east to the low-lying Kuttanad wetlands and Vembanad Lake in the west. It is bordered to the north by the Meenachil River Basin and to the south by the Kallada River Basin. Ultimately, it drains into the Arabian Sea through the Thottapally Spillway, which plays a crucial role in flood regulation. This diverse region supports essential ecological and hydrological functions, sustaining agriculture, livelihoods, and biodiversity.

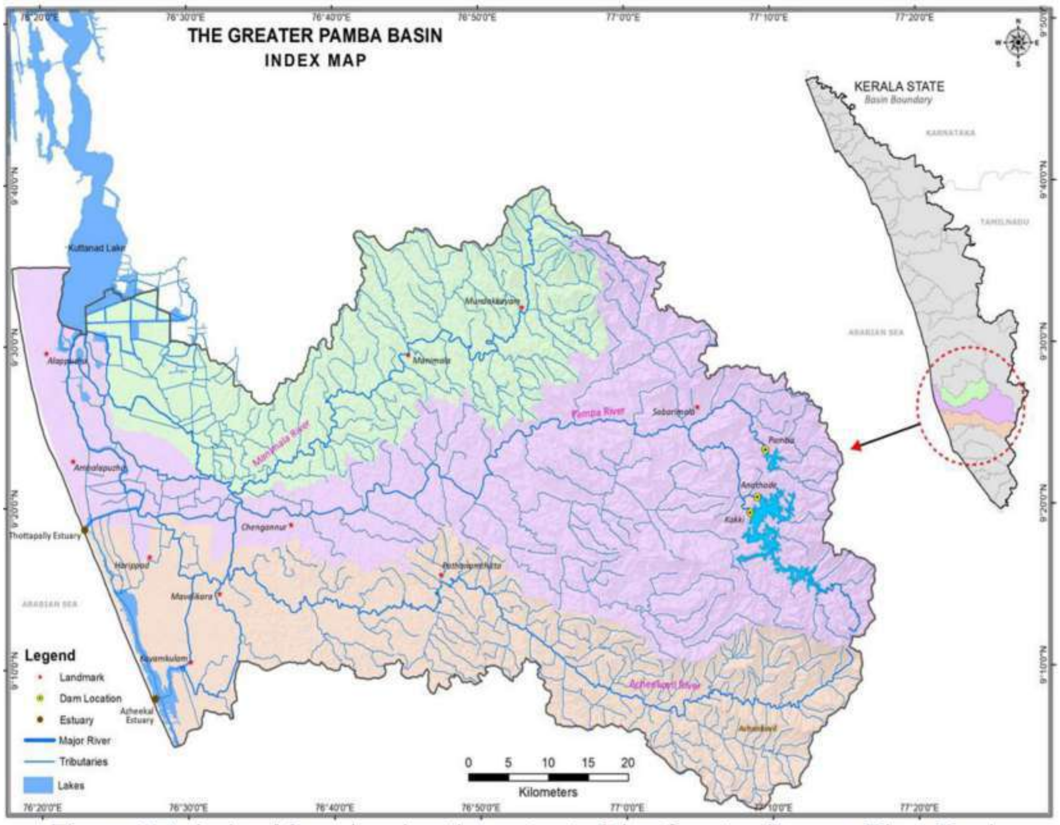


Figure 2.1: Index Map showing the extent of the Greater Pampa River Basin.

2.2. Topography of the Basin

The Greater Pamba River Basin, comprising the Pamba, Manimala, and Achankovil rivers, showcases a diverse topography and geology across its three physiographic zones: highlands, midlands, and lowlands. The eastern highlands, near the Western Ghats, are characterized by rugged terrain, steep slopes, dense forests, and a maximum elevation of 1000 m, which form the source of the rivers. This region is composed of Charnockite rocks from the Archaean group of crystalline rocks, contributing to the steep landscape. Moving westward, the middle zone is dominated by residual laterite soils formed from the weathering and decomposition of the underlying crystalline rocks, which are rich in iron and aluminium. These laterite soils support extensive agriculture and plantations. In contrast, the western lowlands, particularly Kuttanad region, are composed of flat alluvial plains, with elevations as low as 0.2 m, and some areas lie below mean sea level, these plains are composed of recent sand and silt deposits.

The lowlands are flat, alluvial, and prone to flooding, with wetlands and backwaters playing a critical role in water management and rice cultivation. The GPB is geographically defined by the Meenachil and Periyar river basins to the north, and the Pallikkal and Kallada river basins to the south. The basin features vast fertile plains that support extensive agriculture, with its rivers serving as crucial water sources. In the highlands and the eastern midlands, the rivers traverse a variety of rock types, including pyroxene granulites, charnockites, and khondalites, which form the primary lithological units. As the rivers flow through the midlands, at elevations between 7.5 and 75 meters above sea level, they predominantly pass through laterites and Holocene sediments. Further downstream, in the lowlands below 7.5 meters, the rivers meander through alluvial sands and clays of Holocene origin.

The drainage patterns of these rivers are characterized by dendritic and trellis forms at the higher altitudes. Upon reaching the coastal plains, the rivers adopt a northward flow and ultimately discharge into the Vembanad Lake at Pallathuruthy, near Alappuzha. This distinctive northward trend in the lowlands is attributed to the silting of the water body combined with a northward tilt of the terrain during the Late Pleistocene to Early Holocene period.

The upstream region of the basin consists predominantly of forested hills, while rubber plantations largely occupy the central portion. The downstream plains are extensively utilized for agricultural activities, with key crops including paddy, bananas, and coconut. The GPB includes several urban centres that play a significant role in the region's socio-economic activities. Major towns such as Pathanamthitta, Chengannur, Thiruvalla, and Mavelikkara are in the basin, serving as hubs for trade, culture, and administration. Additionally, smaller urban centres like Ranni, Kozhencherry, and Aranmula contribute to the basin's economic and cultural landscapes, with Aranmula being particularly notable for its traditional heritage.

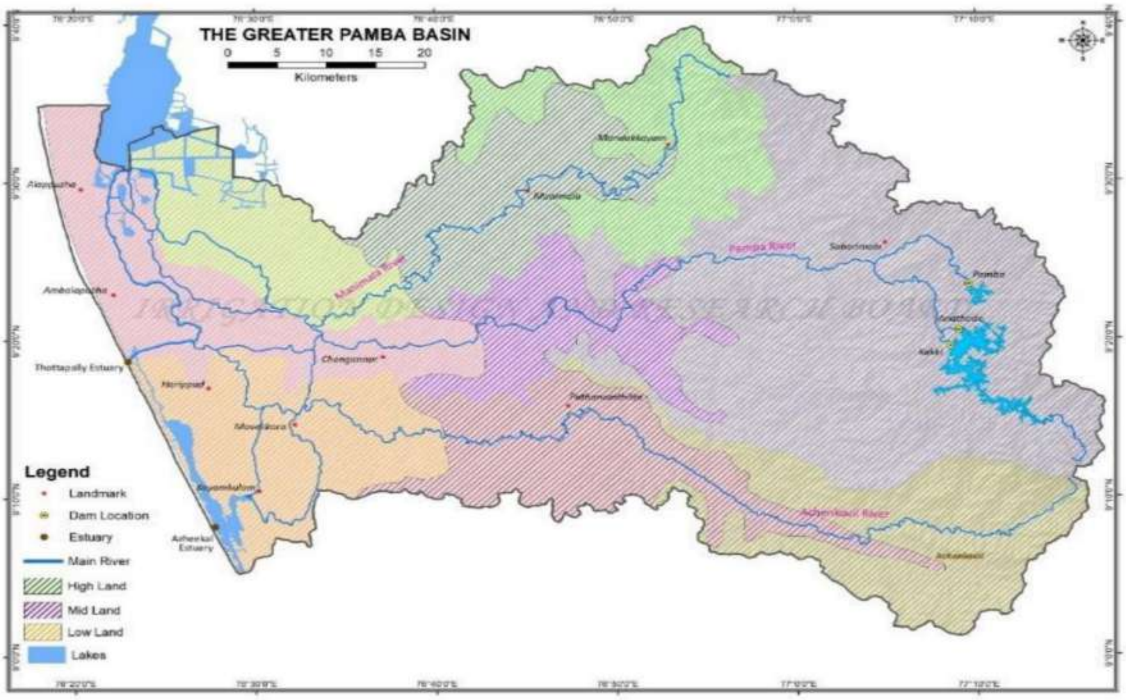


Figure 2.2: A map showing the Highlands, Midlands and Lowlands of Greater Pampa River Basin.

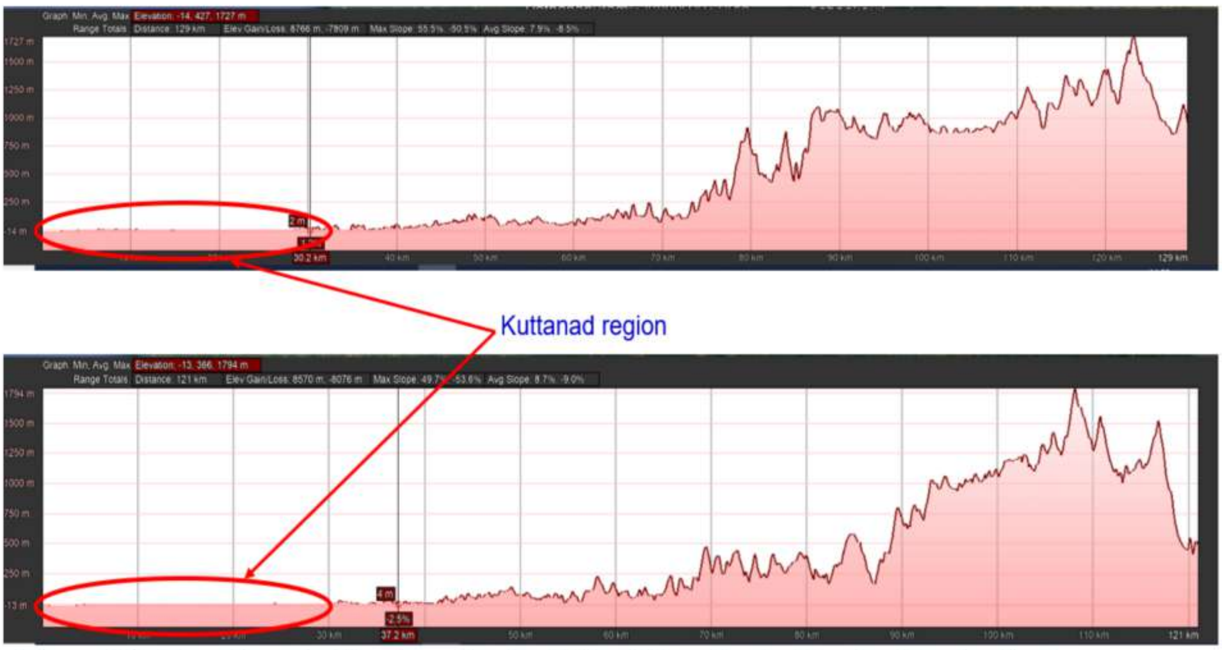


Figure 2.3: Elevation Profile along the East-West Direction in Greater Pamba Basin

2.3. Geology of the Basin

The Geology of the basin is comprised of geological formations ranging from Precambrian to Recent age. The Archean crystalline are overlined by Tertiary and Quaternary formations with two major periods of non-deposition or unconformity. The general Stratigraphic succession of Kerala is given below. The western part of the basin is situated close to the shore line is dominantly comprised of thick sedimentary formations comprised of coastal alluvium and semi consolidated subsurface formations that includes Warkalli, Quilon, Alleepy and Vailkkom aquifers. The Laterite is seen as cap rock spread over the coastal sediments as well as the crystalline on the eastern side. The elevated parts of the basin, particularly in the hilly regions highly weathered crystalline and laterites are seen exposed in many places. The soils derived from laterites are rich in iron and aluminium oxides and develop in areas with high rainfall and well-drained conditions. Laterites contribute to the unique reddish-brown colour of the soil, and they are often used as a construction material. The larger part of the basin comprised of crystalline group of rocks that includes charnokite gneiss, khondalite gneiss and migmatite variants. The calc-granulite and quartzite occur as bands within the para-gneisses and amid the charnockite group and magmatic gneiss. The migmatite gneiss is oriented along the southern part of the basin along the NW-SE linear stretches. The charnockite group shows great diversity in lithology comprising pyroxines, hornblende, magnetite, quartzite, hypersthene-diopside gneiss and cordierite gneiss. The charnockites have preponderance over all other crystalline rocks within the basin. The detailed geological map of the study area is shown in the Figure 2.4.

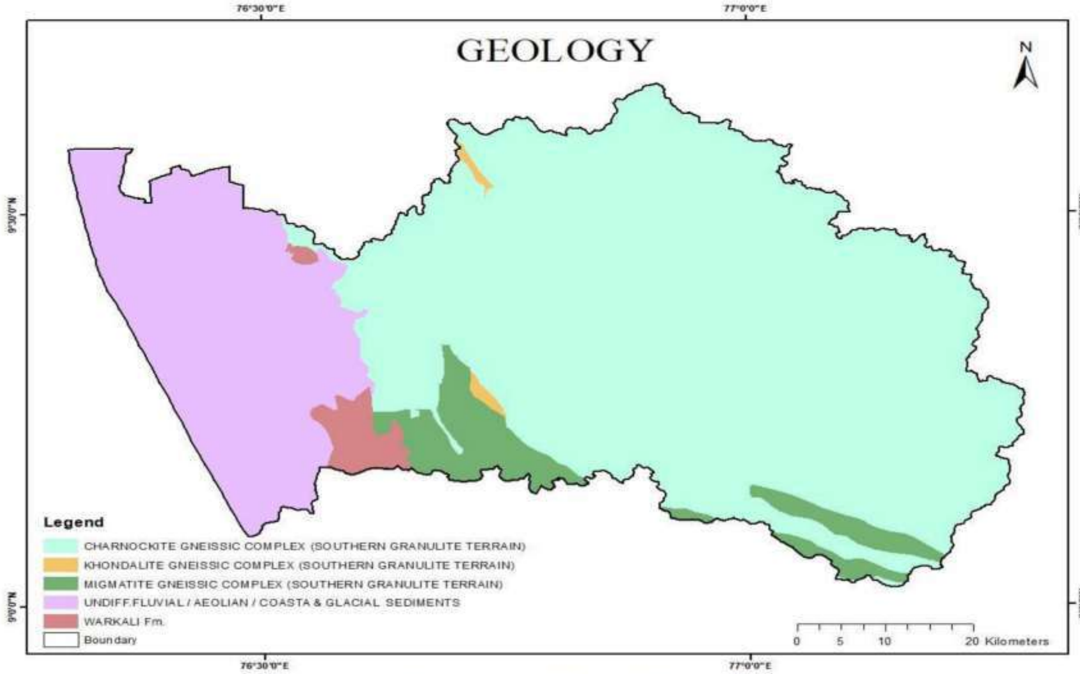


Figure 2.4: Geological Map of Study Area

Table 2.1: Generalized Stratigraphic Succession of Kerala (Paulose and Narayanaswami, 1968)

Recent to sub-recent	Soils and alluvium
	Beach sand deposits
	Lime shell deposits of backwaters
	Old and red Teri sands of Sub recent marine and lacustrine formations
	Peat beds with semi-carbonised woods
	Calcareous clays with shell etc.
	Laterite
	Unconformity
Warkalli Formation	Current-bedded friable variegated sandstone interbedded with plastic clay and variegated clays
	Carbonaceous and alum clays with (Mio-Pliocene) lignite seams.
	Gravel and pebble beds. Base marked by gibbsitic sedimentary clay
Quilon Formation (Middle Miocene)	Fossiliferous shell limestone alternating with thick beds of sandy clays, calcareous clays and sandstones. Base unknown
	Unconformity
Archaean	Crystalline rocks

2.4. Geomorphology of the Basin

The present Geomorphological features of the basin are the result of the interaction of geological and tectonic processes over the past. The Hydrogeomorphic features largely resulted from coastal and riverine process shaping the entire basin such as coastal plains, backwaters and estuaries, river deltas and denudational hills. The basin presents a variety of landforms, ranging from high lands, mid lands and coastal plains. The high lands and mid lands are made up of Precambrian crystalline rocks, while the low land are comprised of coastal sediments. The eastern segment has steep slopes with straight course rivers and drainage channels representing the youthful stage of the river system. The detailed geomorphological map of the study area is given in the Figure 2.5.

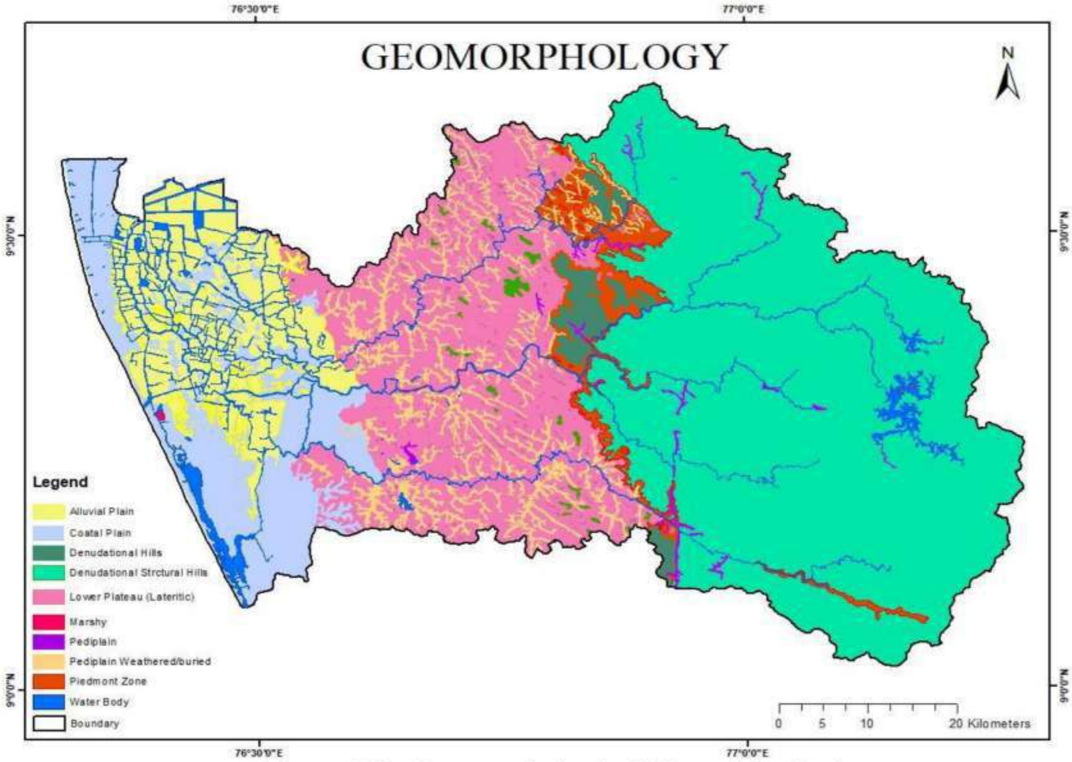


Figure 2.5: Geomorphological Map of Study Area

1) **Coastal Plain**: The western part of the basin is situated close to the Arabian Sea, is a coastal plain characterized by flat, low-lying terrain. This area is prone to tidal influences and is made up of alluvial deposits, marshlands, and backwaters. The coastal plain has been shaped by the deposition of sediments carried by rivers, as well as the rise and fall of sea levels over time. A Larger part of the coastal plain in and around Kuttanad region is lies below mean sea level.
2) **Backwaters and Estuaries**: The backwaters in the basin are among the most significant geomorphological features of the region. The most prominent of these is Vembanad Lake, the largest freshwater lake in Kerala. The backwaters, formed by the confluence of rivers and the Arabian Sea, create a network of shallow, brackish waters surrounded by mudflats and wetlands.
3) **Rivers and Deltas**: The Pamba River, originating in the Western Ghats is one of the most important rivers and major river systems in the basin. The river's deltaic system forms fertile plains and contributes significantly to the geomorphology of the basin. The floodplains of the river system that join the smaller rivers are prone to seasonal flooding and sediment deposition, creating a rich environment for agriculture and aquatic life.
4) **Denudational Hills**: The eastern part of the basin which lies near the Western Ghats, is characterized by denudational hills. The elevation increases gradually

as one moves eastward from the coastal plain. These hills are predominantly composed of granite and gneiss and are part of the broader Western Ghats Mountain system. The terrain here is more rugged and often associated with forests and wildlife reserves.

2.5. Land Use and Land Cover

The LULC map of the basin is shown in Figure 2.6. It shows the distribution of different land uses such as Agriculture, Built-up area, Crop Lands, Fallow Lands, Forest Deciduous, Forest Plantations, Grass Lands, Waste Lands, Waterbodies, Wetlands etc. The total area of the basin is 4507 km².

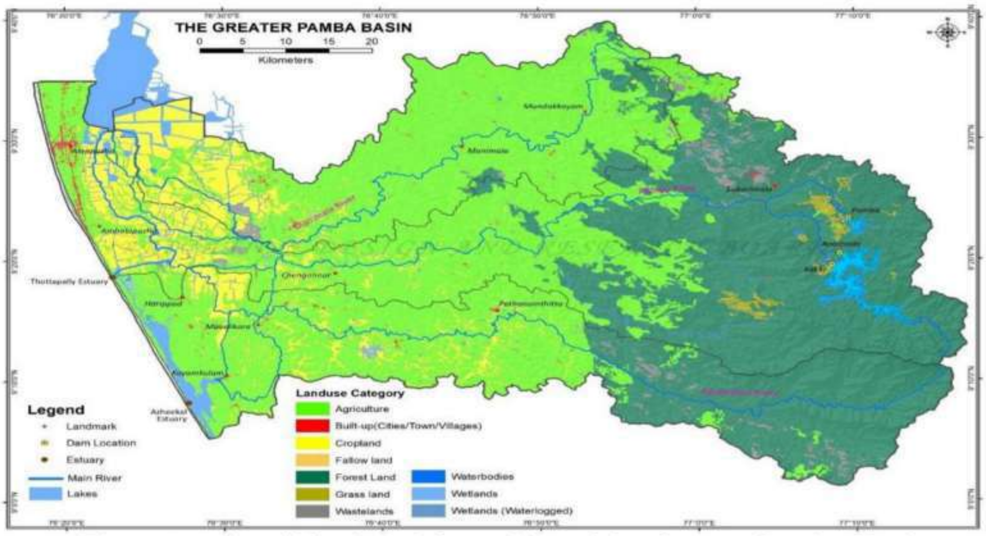


Figure 2.6: Land Use Land Cover Map of the Greater Pamba Basin

The area of the land use has been classified into Agriculture, Built-up area, Crop Lands, Fallow Lands, Forest Land, Grass Lands, Waste Lands, Waterbodies, Wet Lands, and Waterlogged Wet Lands. Table 2.2 shows the distribution of different land uses across the different basins in Greater Pamba Basin. Table 2.3,Table 2.4 and Table 2.5 show the different land uses across different physiographic zones in the Manimala, Pamba and Achankovil basins.

Table 2.2: Land use distribution across Greater Pamba basin

	Manimala	Pamba	Achankovil	Total
Agriculture	781.53	670.16	643.23	2094.79
Built-up	5.38	19.12	8.97	33.46
Cropland	177.07	186.48	115.11	478.65
Fallow land	2.04	0.03	3.48	5.56
Forest Land	61.23	1083.22	507.91	1652.36

Grass Land	0.44	25.50	0.12	26.06
Wasteland	14.09	45.89	25.49	85.49
Waterbodies	28.12	60.15	30.77	119.04
Wetland			1.56	1.56
Wetland Waterlogged	1.68	1.90	7.07	10.65
Grand Total				4507.63

Table 2.3: Land use distribution across different physiographic zones in Manimala basin

	Highland	Midland	Lowland	Total
Agriculture	302.72	363.71	115.09	781.53
Built-up	1.27	1.11	2.99	5.38
Crop Land	0.38	2.16	174.53	177.07
Fallow land	0.18		1.86	2.04
Forest Land	56.10	5.14		61.23
Grass Land	0.23		0.20	0.44
Wasteland	4.49	2.29	7.31	14.09
Waterbodies	0.77	5.07	22.27	28.12
Wetland				
Wetland Waterlogged		0.24	1.44	1.68

Agriculture dominates the land use in the Pamba Basin, covering 2094.79 km². The highest concentration is observed in the midland and lowland regions, particularly in the Manimala and Achankovil basins, where fertile soils and moderate slopes support extensive farming. In the Pamba basin, agricultural practices are also significant but distributed more evenly across all regions.

Table 2.4: Land use distribution across different physiographic zones in Pamba basin

	Highland	Midland	Lowland	Total
Agriculture	213.33	230.53	226.30	670.16
Built-up	1.90	0.80	16.42	19.12
Crop Land	0.62	4.26	181.60	186.48
Fallow land	0.00	0.00	0.03	0.03
Forest Land	1045.80	37.41	0.01	1083.22
Grass Land	24.36	0.56	0.59	25.50
Wasteland	34.47	1.33	10.09	45.89
Waterbodies	28.63	6.23	25.29	60.15

Wetland				
Wetland Waterlogged		0.02	1.88	1.90

Table 2.5: Land use distribution across different physiographic zones in Achankovil basin

	Highland	Midland	Lowland	Total
Agriculture	30.40	284.67	328.16	643.23
Built up	0.06	1.74	7.17	8.97
Crop Land	0.38	35.95	78.78	115.11
Fallow land	0.00	1.85	1.63	3.48
Forest Land	423.54	84.36	0.00	507.91
Grass Land	0.00	0.12	0.00	0.12
Wasteland	15.29	8.18	2.01	25.49
Waterbodies	0.71	3.91	26.15	30.77
Wetland	0.00	0.00	1.56	1.56
Wetland Waterlogged		0.44	6.62	7.07

The Pamba Basin, exhibits land use patterns across its highland, midland, and lowland regions. The total area of the basin spans 4507.63 km², with distributions of agriculture, forest land, built up areas, and other land use types. The percentage share for each type is shown in Figure 2.7.

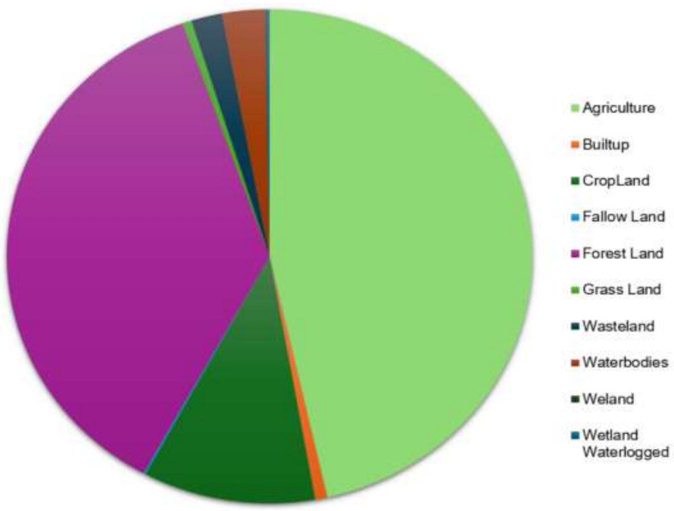


Figure 2.7: Percentage share for each LULC type.

Forest land is another significant land type, occupying 1652.36 km² of the basin. Most of this is concentrated in the highland region, particularly in the Pamba basin, which has over 1000 km² of forest cover. The Achankovil basin also contains substantial forested areas. Built up areas account for a smaller portion of land use, totalling 33.46 km². These are concentrated mainly in the lowland regions, indicating urbanization trends along riverbanks and flat terrains. Similarly, cropland and fallow land, collectively covering over 484 km², are primarily located in the lowland and midland regions, reflecting seasonal agricultural practices and areas left uncultivated.

The highland region is predominantly covered by forests, with 1525.44 km² dedicated to forest land, making it the most significant land use in this area. This extensive forest cover, especially in the Pamba and Achankovil basins shows the ecological importance of the highlands as biodiversity hotspots and sources of hydrological stability. Agriculture in the highlands is limited to 546.45 km², due to the challenges cause by steep terrain and shallow soils. Other land uses, such as wastelands and grasslands, occupy smaller areas, with water bodies contributing minimally to the region's land use. The midland region is a transitional zone with a more balanced distribution of land uses. Agriculture dominates here, covering 878.91 km², supported by fertile soils and favourable topography. Forest land in the midland accounts for 127.91 km², primarily in the Pamba basin, indicating some overlap with lower elevation forested areas. Built up areas and water bodies are modestly represented, reflecting moderate urbanization Wastelands and croplands are also present, indicating an underutilized land. The lowland region is characterized by intensive human activity, with agriculture occupying 669.56 km². The Kuttanad region with flat terrain, make it ideal for farming and settlement. Built up areas are concentrated here for 26.59 km², reflecting urbanization along rivers and coastal zones. Water bodies and wetlands are also significant, spanning 83.75 km², serving as habitats and sources of water for irrigation and drinking.

Water bodies, including wetlands and waterlogged areas, spanning 129.68 km². The agriculture and forests dominate, urbanization and land conversion for other purposes are evident, particularly in the lowland regions.

2.6. Soil distribution in the basin

The FAO Soil Map (HWSD) at 30m resolution was used to provide information on soil properties, including texture, permeability, which are critical for simulating runoff and other components of water balance. The model uses the soil map to define the runoff potential in each region. The soil map of the Pamba Basin classifies the region into distinct hydrologic soil groups based on infiltration capacity and runoff potential (Figure 2.8). The basin is predominated by Group C soils characterised by slow infiltration rates and high runoff potential. They are clay loam soils which leads to slower percolation and increased surface runoff. Group D soils have very slow infiltration rates and the highest runoff potential. These are heavy clay soils or soils with an impermeable layer near the surface, with low permeability. The highland regions in the eastern part of the basin are predominantly covered by Group D soils, reflecting the steep terrain and slower infiltration rates due to denser soils and natural vegetation. The midland regions show Group C soils, indicating moderate infiltration and runoff potential while the lowland regions near the western part exhibit Group C soils. Group B soil is present only in a small region south of the Vembanad Lake. Group B soils are typically characterized by relatively higher infiltration rates and lower runoff potential compared to Groups C and D. These soils are often sandy loam or silty loam in texture, which allows for more efficient percolation and groundwater recharge while reducing the volume of surface runoff. In areas where Group B soils are present, water is more likely to infiltrate into the soil profile, supporting both plant growth and sustainable water availability.

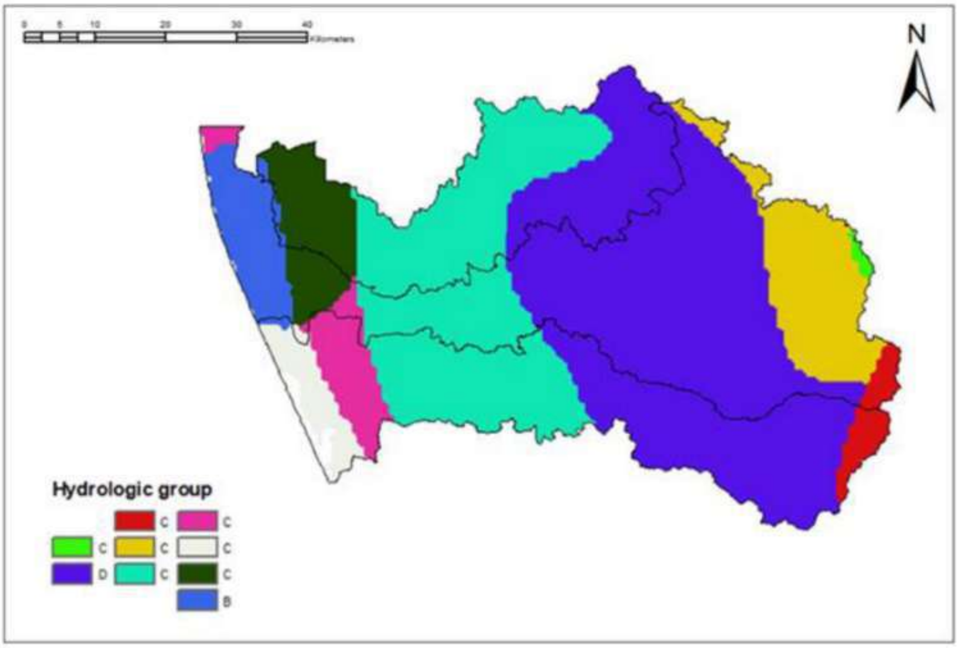


Figure 2.8: Soil map of the study area (Source: The FAO Soil Map (HWSD))

2.7. River System

The Greater Pamba River Basin in Kerala encompasses three major rivers: the Pamba, Achankovil, and Manimala, originating from the Western Ghats and flowing through diverse terrains before draining into the Arabian Sea. The Pamba River Basin, the largest of the three, spans an area of approximately 2,235 km², receives an average annual rainfall of 3,600 mm, and has an average discharge of 300–350 m³/s, making it a crucial water resource in the region. The Achankovil River Basin, covering about 1,488 km², experiences an average annual rainfall of 2,000–4,000 mm and has an estimated discharge of 150–200 m³/s, playing a vital role in the region's hydrology. The Manimala River Basin, the smallest of the three, has a catchment area of 843 km², receives an average annual rainfall of 2,000–3,500 mm, and records an average discharge of 80–120 m³/s. Together, these rivers form the lifeline of the basin, supporting its ecology, agriculture, and water resources, emphasizing the need for sustainable management and conservation.

2.7.1. Pampa River and Its Tributaries

The Pampa River, is the longest entirely within its boundaries, flowing 176 kilometres westward from its origin at Pulachimalai Hill in the Peerumedu Plateau of the Western Ghats at an altitude of 1,650 meters. It traverses the districts of Pathanamthitta and Alappuzha before merging with the Vembanad Lake and draining into the Arabian Sea. Key tributaries include Azhutta Ar, Kakki Ar, Kakkad Ar, Kal Ar, and Pazhayidam Aar, each playing vital roles in the river's ecosystem. Azhutta Ar, originating near Sabarimala, supports the water needs of pilgrims, while Kakki Ar, fed by the Kakki reservoir, is crucial for hydroelectric projects, irrigation, and drinking water. Kakkad Ar and Kal Ar sustain agriculture, replenish local water bodies, and support biodiversity. In Alappuzha, the distributary Varatta Ar, once significant for irrigation and drainage, has suffered ecological degradation due to urbanization.

The Pampa connects with the Vembanad Lake and the canal systems of Kuttanad, a vast wetland region spanning 1,100 square kilometres. This area benefits from the river's flow for agriculture and aquaculture. The river merges with the Achankovil and Manimala Rivers near Veeyapuram, forming a unique hydrological interaction. This confluence creates distributaries that flow into the Vembanad Lake and the Arabian Sea. A distinctive feature is the interaction near Keecheryvalkadavu, where a distributary of the Pampa joins the Manimala River before re-joining the Pampa upstream of the Nereettupuram Bridge. Downstream, the Pampa bifurcates, where one branch flowing into the Arabian Sea at Thottapally and the other into the Vembanad Lake at Kainakary.

The Pamba River Basin features several cross-structures essential for water management, flood control, and irrigation. In the upper basin, irrigation canals and check dams near Pathanamthitta support agriculture and ensure regulated water flow. The Pamba Irrigation Project plays a crucial role in sustaining farmlands, particularly in midland and lowland regions. Key bridges, such as those at Aranmula and Chengannur, enhance connectivity, facilitating both local transport and pilgrimage routes. In the downstream regions, structures like the irrigation regulators at Thakazhy and Champakulam manage water distribution for paddy cultivation in Kuttanad, a region highly dependent on controlled water levels. Additionally, the Thottapally Spillway, a major flood mitigation structure, helps divert excess floodwaters from Kuttanad into the Arabian Sea, reducing waterlogging and salinity intrusion in agricultural lands. Flowing through Ranni, Kozhencherry, and Chengannur in Pathanamthitta, the Pampa sustains agriculture, pilgrimage activities, and local water needs. As it enters Alappuzha, it nourishes the wetlands of Kuttanad, connecting to the Vembanad Lake, which spans 96 kilometres and supports agriculture, aquaculture, and livelihoods. The Pampa River's intricate network of tributaries, distributaries, and cross-structures makes it a vital component of Kerala's hydrology and ecology.

Figure 2.9:Map showing the extend of Pampa River Basin

2.7.2. Achankovil River and its Tributaries

The Achankovil River, originating from the Pasukida Mettu Peak in the Western Ghats at an altitude of 900 meters, flows through the Achankovil Reserve Forest in Kollam district. Spanning 128 kilometres, it traverses km through forested highlands,52 km of agricultural midlands, and 48 km of fertile wetlands, passing through towns like Aryankavu, Achankovil, Konni, Pathanamthitta, Pandalam, and Venmony, before merging with the Pamba River at Veeyapuram in Alappuzha district. The river supports biodiversity, agriculture, and livelihoods across its basin.

Key tributaries, including Rishimala, Puthanmala, and Ramakkaltheri Streams in the highlands which sustains the upstream flow, and Kallar and Pallikkal Streams in the midlands enhance water availability that support irrigation and water management in the areas such as Konni and Pandalam. The river nourishes the wetlands of Kuttanad, crucial for agriculture and sediment deposition, while water management structures like the Mani Ar Dam and Achankovil Regulator-Cum-Bridge aid in irrigation and flood control. Bridges such as the Achankovil Bridge and Veeyapuram Bridge enhance connectivity.

Challenges like seasonal flooding, sand mining, and urban encroachments threaten the river's health, particularly in areas like Pandalam, Chengannur, and Veeyapuram. Sustainable practices, including afforestation, flood mitigation, and water quality improvement, are vital to maintaining the river's ecological and economic significance.

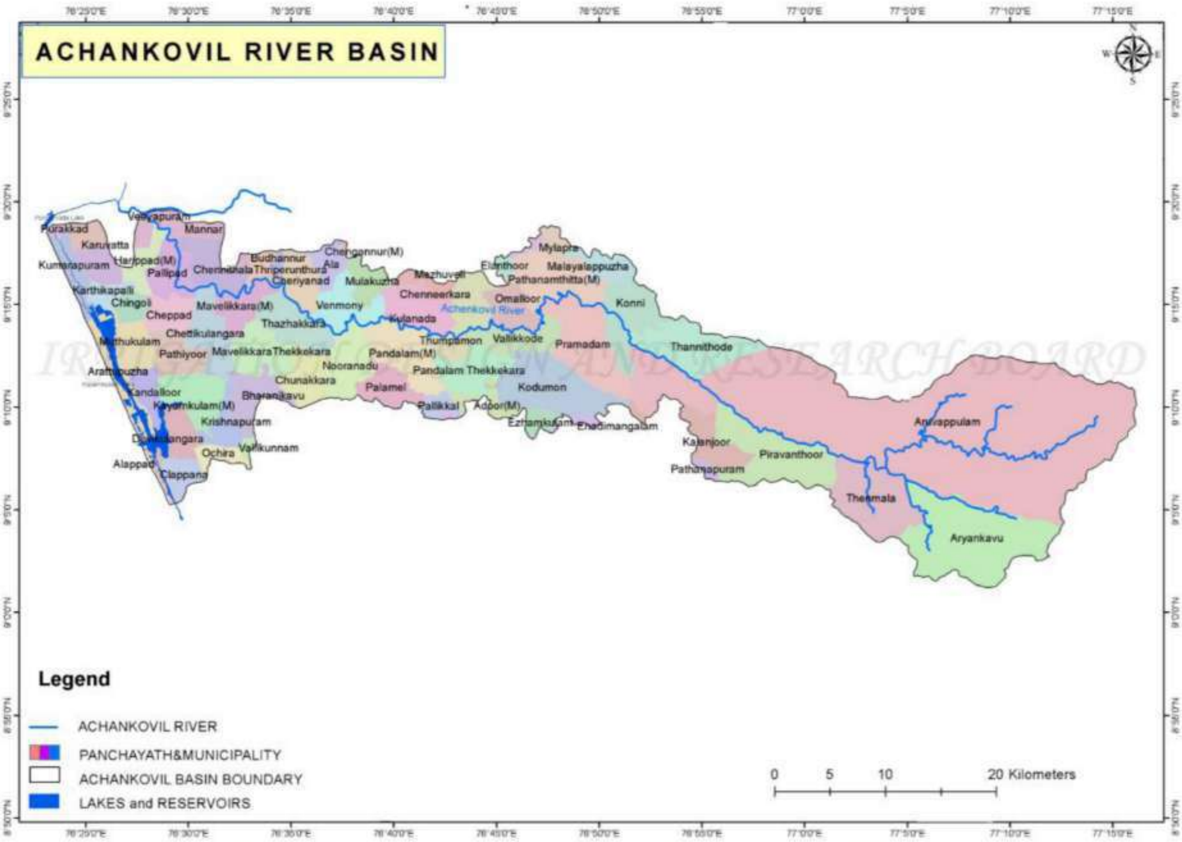


Figure 2.10: Map showing the extend of the Achankovil River Basin

The Manimala River, an independent and vital river in Central Kerala, originates from the Muthuvara Hills (Thattamala Hills) of the Western Ghats near Peerumedu in Idukki district at an elevation of 1,156 meters above mean sea level. Flowing westward for 132 kilometres, it traverses the districts of Idukki, Kottayam, Pathanamthitta, and Alappuzha, before merging with the Pampa River and Vembanad Lake at Kainakary in Alappuzha. Along its course, the river supports key towns such as Mundakkayam, Erumely, Manimala, Mallappally, Thiruvalla, and Chambakulam, providing essential water resources for agriculture, navigation, and local livelihoods.

A unique hydrological interaction occurs near the Keecheryvalkadavu Bridge, where a distributary of the Pampa River joins the Manimala River at approximately the 95-kilometer mark, re-joining the Pampa near the Nereettupuram Bridge at the 100-kilometer mark. Further downstream, after the Kidangara Bridge at the 110-kilometer mark, the river bifurcates into two branches, both of which eventually drain into the Vembanad Lake at Kainakary. These connections highlight the river's integral role in the hydrology of Central Kerala, particularly in the Kuttanad wetlands, where it supports agriculture and ecological balance.

The Manimala River is enriched by tributaries such as Puthanpalam Aar and Karimpa Ar, which contribute to its flow and sustain biodiversity. While the river does not host major reservoirs, smaller check dams and irrigation structures regulate its flow to meet agricultural demands. However, challenges such as sand mining, pollution, and urban encroachments threaten its ecological health. Sustainable practices focusing on afforestation, pollution control, and resource management are critical to preserving the Manimala River's role in supporting Kerala's environmental and socio-economic-systems.

Figure 2.11: Map Showing the extend of Manimala River Basin

2.8. Morphometric Analysis

Morphometric analysis, a geographical aspect of spatial science, focuses on the quantitative measurement and mathematical assessment of Earth's topographic features. Basin morphometry, a key component of this analysis, plays a role for hydrologists and geomorphologists in addressing environmental challenges such as soil erosion, slope instability, floods, landslides, and extreme surface runoff. Major morphometric parameters like stream order, length, bifurcation ratio, drainage density, basin shape, relief ratio, and elongation ratio provide essential insights into the hydrological and geomorphological behaviour of river basins. These analyses enable researchers to understand seasonal fluctuations in drainage basin characteristics, assess groundwater potential, and address soil erosion due to flash floods during peak flows (Mohan and Babu, 2017). Numerous studies have explored these aspects globally (Różycka and Migoń, 2021, Mangan et al., 2019, Shekar and Mathew, 2022). A significant gap exists in the morphometric analysis of rivers in Kerala. Most research in Kerala relies on traditional methods like field observations, surveys, and laboratory tests, with limited focus on morphometric parameters such as length, area, stream order, and drainage density.

2.8.1. Linear aspects of river basin morphometry

The total number of streams of Greater Pamba basin are 3923 of which 2417 (61.61%), 1002 (25.54%), 312 (7.95%), 186 (4.74%), 5 (0.13%), 1 (0.03%) stream belong to 1st, 2nd, 3rd, 4th, 5th, and 6th order respectively as shown in Table 2.6. The table also shows the number of streams in highland, midland and lowland areas.

Table 2.6: Linear aspects across different physiographic zones in Greater Pamba basin

Stream Order	Greater Pamba		Highland		Midland		Lowland	
	Count	%	Count	%	Count	%	Count	%
1	2417	61.61%	1133	59.01%	753	66.46 %	531	61.03%
2	1002	25.54%	498	25.94%	288	25.42 %	216	24.83%
3	312	7.95%	167	8.70%	70	6.18%	75	8.62%
4	186	4.74%	120	6.25%	20	1.77%	46	5.29%
5	5	0.13%	2	0.10%	2	0.18%	1	0.11%
6	1	0.03%			0	0.00%	1	0.11%
Total	3923		1920		1133		870	

First order streams dominate with 2417 (61.61%) of the total streams, indicating a high prevalence of smaller tributaries. The highland region contains 1133 (59.01%), showing a significant proportion of small and high-altitude tributaries. With 753 streams (66.46%), the midland region has the highest percentage of first order streams among the sub regions, suggesting a dense network of small streams. The lowland region contributes 531 streams (61.03%), reflecting a similar pattern to the highland but with fewer streams overall. The second order accounts for 1002 (25.54%), a significant reduction compared to first order streams. The Highland contains 498 (25.94%) second order streams, maintaining a similar pattern as the overall basin. Midland has 288 (25.42%), slightly lower than the highland but consistent in distribution. Lowland with 216 (24.83%), the percentage is slightly below the other regions.

There are 312 (7.95%) third order streams, marking a steep decline from second order streams. Highland represents 167 (8.70%), the highest percentage among the sub regions, reflecting stream consolidation in the uplands. Midland contains 70 (6.18%), showing fewer third order streams compared to the highland and lowland. Lowland with 75 (8.62%), the lowland percentage is close to the highland, likely due to the influence of confluences. The basin comprises 186 (4.74%), a sharp decrease as stream order increases. Highland contains 120 (6.25%), showing stream consolidation in higher altitudes. Midland is only 20 (1.77%), significantly lower, indicating limited stream progression in this region. Lowland contributes 46 (5.29%), reflecting the influence of tributary confluence in the downstream areas.

The highland is dominated by first order (59.01%) and second order (25.94%) streams. The area contains the highest percentage of third order (8.70%) and fourth order (6.25%) streams, indicating a well-established network consolidating in higher orders. Minimal fifth and sixth order streams suggest the highland primarily feeds into lower regions. In the Midland highest percentage of first order streams (66.46%), indicating a dense tributary network. Decline in higher order streams, with only 1.77% being fourth order and no sixth order streams, reflects limited stream progression or transitions to lowland areas. The lowland reflects balanced distribution between first (61.03%), second (24.83%), and third order (8.62%) streams. Higher percentage of fourth order (5.29%) and presence of fifth (0.11%) and sixth order (0.11%) streams indicate the region's role as a terminal area for the river system.

Lower order streams in a higher number due to its upper western ghat mountain region. Also, higher number of streams in upper reaches indicates the occurrence of young topography adjacent to the stream concerned. The sudden decrease in 3rd and 4th order of streams indicates a major morphological change as shown in Figure 2.12.

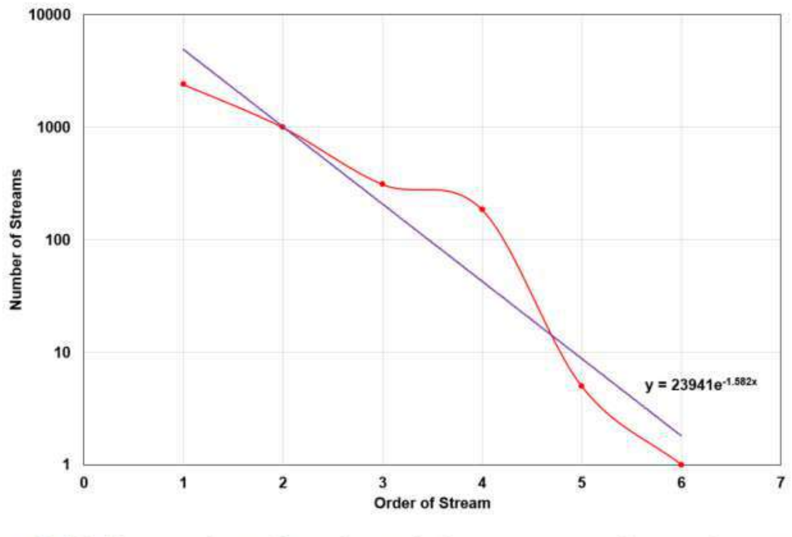


Figure 2.12: Regression of number of stream segments on stream order

Higher number of streams throughout the different orders indicates its high erosion characteristics. It is proved from flood characteristic of Pamba River basin. The high number of lower order streams (1st, 2nd and 3rd order) increase the amount of water received which ultimately creates huge water flux in lower reaches of basin. The consistent decrease in number of streams in relation to stream order throughout the basin indicates the dominance of erosional landform throughout the basin in midland and high land regions. The relief parameters of the basin are given in Table 2.7.

Table 2.7: Aerial parameters across different basins in Greater Pamba basin

Aerial Parameters	Achankovil	Pamba	Manimala
Basin Area (km²)	963.07	2061.00	1128.23
Basin Perimeter (km)	267.30	441.48	310.04
Basin Length (km)	74	95	59
Relief Parameters			
Maximum Elevation (m)	1550	1650	1150
Minimum Elevation (m)	1.50	3.50	1.0

The Pamba basin is the largest, with a basin area of 2061 km² and a perimeter of 441.48 km, indicating an expansive catchment and a more complex basin. The Manimala River basin, with an area of 1128.23 km² and a perimeter of 310.04 km, is intermediate in size. The Achankovil River basin is the smallest, covering an area of 963.07 km² with a perimeter of 267.30 km, reflecting a compact and relatively confined basin. The Pamba basin, stretching 95 km, is the longest, suggesting a well-developed drainage network. The Achankovil basin, at 74 km, exhibits moderate linearity, while the Manimala basin is the shortest, with a length of 59 km, indicating a more compact drainage structure. The Pamba basin reaches the highest elevation at 1650 m, Achankovil basin at 1550 m, and the Manimala basin at 1150 m. All three basins have minimum elevations below sea level, with the Pamba at 3.5 m, the Achankovil at 1.5 m, and the Manimala at 1 m. This variation in elevation highlights the presence of low-lying areas, which can influence flooding. The Pamba basin's large area, length, and elevation range highlight the hydrological significance.

The other linear parameters of the basin are shown in the Table 2.8. This includes the stream length, mean stream length, Mean stream length, stream length ratio, bifurcation ratio. The parameters are calculated for each basin as well for lowland, midland and highland.

Table 2.8: Linear parameters across different basins in Greater Pamba basin

	Stream Length (km)			Mean Stream Length		
Stream Order	**Achankovil**	**Pamba**	**Manimala**	**Achankovil**	**Pamba**	**Manimala**
1	554.05	1077.22	614.00	0.97	0.91	0.93

2	247.40	567.96	328.60	1.14	0.96	1.70
3	136.35	210.50	141.14	3.25	0.93	3.21
4	36.61	162.16	52.07	12.20	0.94	4.73
5	79.02	108.36	106.37	79.02	36.12	106.37
6	0.00	66.57	0.00	0.00	66.57	0.00
	Stream Length Ratio			**Bifurcation Ratio**		
Stream Order	**Achankovil**	**Pamba**	**Manimala**	**Achankovil**	**Pamba**	**Manimala**
1	0.45	0.53	0.54	2.65	2.00	3.41
2	0.55	0.37	0.43	5.17	2.62	4.39
3	0.27	0.77	0.37	14.00	1.31	4.00
4	2.16	0.67	2.04	3.00	57.33	11.00
5	0.00	0.61	0.00	0.00	3.00	0.00
6	0.00	0.00	0.00			

The mean bifurcation ratio for Achankovil is 4.96, for Pamba, it is 13.25, and for Manimala, it is 4.56. The Pamba Basin exhibits the highest total stream length across all stream orders, with 1077.22 km in the first order streams, indicating a dense river network. The Achankovil Basin, with a total first order stream length of 554.05 km, shows a moderate network density, while the Manimala Basin, at 614.00 km, falls in between. For fifth order streams, the lengths are 79.02 km (Achankovil), 108.36 km (Pamba), and 106.37 km (Manimala), indicating a reduction of over 85% compared to first order streams. Figure 2.13 shows the variation of the order of streams with the length of stream in different basins.

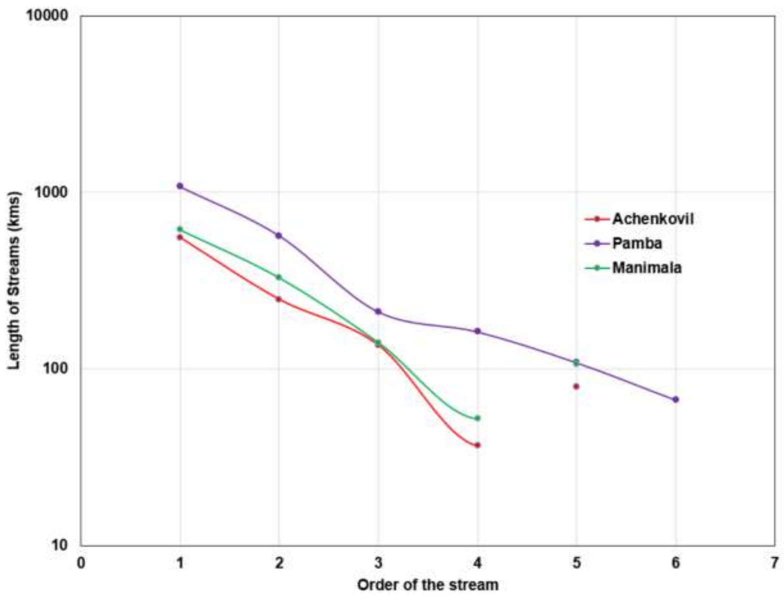


Figure 2.13: Variation of the order of stream with the length of stream in different basins

The linear parameters are calculated altogether for the Greater Pamba basin, dividing it into highland, midland and lowland regions. The values are shown in Table 2.9The mean bifurcation ratio for highland is 6.43, for the midland is 2.85, and for the lowland is 5.99.

Table 2.9: Linear parameters for different physiographic zones across Greater Pamba basin

	Stream Length (km)			Mean Stream Length		
Stream Order	**Highland**	**Midland**	**Lowland**	**Highland**	**Midland**	**Lowland**
1	693.99	228.96	487.62	0.55	0.30	0.92
2	380.81	104.19	246.69	0.69	0.36	1.14
3	259.32	22.32	104.05	1.42	0.32	1.39
4	112.29	7.64	64.43	0.88	0.38	1.40
5	108.36	108.36	66.70	21.67	21.67	33.35
6	0.00	66.57	42.25	0.00	0.00	0.00
	Stream Length Ratio			**Bifurcation Ratio**		
Stream Order	**Highland**	**Midland**	**Lowland**	**Highland**	**Midland**	**Lowland**
1	0.55	0.46	0.51	2.27	2.61	2.46
2	0.68	0.21	0.42	3.04	4.11	2.88
3	0.43	0.34	0.62	1.43	3.50	1.63
4	0.97	14.18	1.04	25.40	4.00	23.00
5	0.00	0.61	0.63	0.00	0.00	0.00
6	0.00	0.00	0.00			

The total stream length in the highland region is the longest among the three regions, 693.99 km. This indicates a more intricate network of streams, likely due to the more rugged and steep terrain of the highlands. The midland region follows 228.96 km, while the lowland region, has a total stream length of 487.62 km, which is close to the highland value. These differences suggest that the lowland region has longer, meandering streams compared to the highland, where the rivers are typically shorter but steeper. The mean stream length, the highland region has a mean of 0.55 km, indicating that, on average, each stream segment in the highland region is shorter. The midland region's mean stream length is significantly lower at 0.30 km, showing a much smaller average stream segment length in this region. The lowland region has a mean stream length of 0.92 km, which is the longest among the three regions. This supports the idea that the lowland areas allow for more extensive river meandering, contributing to longer streams on average.

The stream length ratio, which compares the total length of streams to the total number of stream segments. The highland region has a stream length ratio of 0.55, slightly higher than the midland's 0.46 and the lowland's 0.51. The bifurcation ratio is used to evaluate the branching patterns of the drainage network, with higher values indicating more complex river networks. The highland region has a bifurcation ratio of 2.27, which is lower than the midland region's ratio of 2.61 and the lowland region's ratio of 2.46. This suggests that the highland region has a relatively less complex network of tributaries, with fewer branches extending from each stream. The lowland and midland regions, on the other hand, exhibit a higher degree of branching, which could be due to flatter terrain and more opportunities for stream splitting as water flows across the landscape. The mean bifurcation ratio follows a similar trend. The data shows that the highland regions may face challenges related to soil erosion and flash flooding, the midland and lowland regions require focused attention on drainage management and flood prevention.

2.8.2. Aerial aspects of river basin morphometry

The aerial parameters for the Achankovil, Pamba, and Manimala basins, including drainage density, length area relation, form factor ratio, basin shape, elongation ratio, texture ratio, circulatory ratio, drainage texture, compactness coefficient, stream frequency, infiltration number, length of overland flow, and drainage intensity, are calculated and presented in Table 2.10. The aerial parameters are calculated separately for Achankovil, Pamba, and Manimala basins as well as highland, midland and lowland regions.

Table 2.10: Arial parameters across different basins in Greater Pamba basin

	Achankovil	Pamba	Manimala
Drainage Density km/km²	1.09	1.06	1.10
Length Area Relation	86.36	136.32	94.97
Form Factor Ratio	0.18	0.23	0.32
Basin Shape	5.69	4.38	3.09
Elongation Ratio	0.47	0.54	0.64
Texture Ratio	2.15	2.68	2.13
Circulatory Ratio	0.17	0.13	0.15
Drainage Texture	3.13	4.93	2.93
Compactness Coefficient	2.43	2.74	2.60
Stream Frequency	0.87	1.06	0.80
Infiltration Number	0.95	1.12	0.89
Length of overland Flow km²	0.46	0.47	0.45
Drainage Intensity	0.79	0.99	0.73
Constant of Channel Maintenance km² /km	0.91	0.94	0.91

Drainage density is the expression of the closeness of spacing of channel within a basin as per Horton (1945). It provides a numerical measurement of runoff potentiality and landscape dissection, is fairly similar across the three basins. Achankovil and Manimala have drainage densities of 1.09 km/km^2 and 1.10 km/km^2**,** respectively, while Pamba has a slightly lower value of 1.06 km/km^2. These relatively high values suggest that all three basins are moderately to highly dissected landscapes, which are indicative of a well-developed drainage network. The value considers as an important parameter determining the travel time of water. The length area relation, which reflects the total stream length relative to the area of the basin, shows significant differences. Pamba has the highest value at 136.32, followed by Manimala at 94.97, and Achankovil at 86.36. The higher value for Pamba suggests that it has a larger network of smaller tributaries, potentially leading to increased stream density and more frequent flooding risks during heavy rainfall events.

The form factor ratio and basin shape indicate overall shape and drainage efficiency of the basins. Smaller the value of form factor, more elongated is the basin. The value '0' indicates elongated characteristics of basin and '1' indicates near circular characteristics of basin with high peak flow. It indicates the flow characteristics of a basin (Castillo et al. 1988). The form factor ratio, which indicates how elongated or compact a basin is, is lowest in Achankovil as 0.18, 0.23 for Pamba, and highest in 0.32 for Manimala. A lower form factor indicates a more compact basin, which is associated with faster runoff and a higher likelihood of flooding in Achankovil. The higher value for Manimala suggests that the basin is more elongated, with a larger area for water to be stored or spread out, potentially resulting in slower runoff. The basin shape parameter is highest in Achankovil with a value of 5.69, 4.38 for Pamba, and 3.09 for Manimala, the lowest. The higher basin shape value indicates that Achankovil is more elongated and irregular in shape, which could impact the hydrological response to storms and affect the distribution of floodwaters. Flood flows of elongated basin can be easily managed than that of circular basin.

Constant of channel maintenance (CCM) is defined as the reciprocal of drainage density as property to define overland flow (Schumm 1956). Indirectly, it can be expressed as a required minimum area for the maintenance and development of a channel (Dutta and Roy 2012). The lower value of CCM indicates higher flood potentiality and young geomorphological adjustment. The CCM is fairly consistent across all three basins, with Pamba having a value of 0.94, 0.91 for Achankovil, and 0.91 for Manimala. This suggests that the stream channels in these regions are capable of maintaining a stable flow, which is essential for riverine health. The length of overland flow, which represents the distance water travels before entering a stream, is highest in Pamba at 0.47 km^2, 0.46 km^2 for Achankovil at and slightly lower, 0.45 km^2. in Manimala. This implies that surface runoff in Pamba may be somewhat more extensive than in the other basins. The areal parameters calculated for highland, midland and lowland regions in the Greater Pamba basin is shown in Table 2.11.

These values imply that the lowland region is more prone to rapid runoff, flooding, and erosion due to its dense drainage network and compact shape. The highland exhibits quicker runoff due to its near circular shape and intricate stream network, while the midland, with its sparse drainage density and elongated shape, may face challenges in efficient water distribution and slower hydrological responses.

Table 2.11: Aerial parameters for different physiographic zones across Greater Pamba basin

	Highland	Midland	Lowland
Drainage Density km/km²	0.71	0.47	1.22
Length Area Relation	141.16	95.37	79.08
Form Factor Ratio	0.99	0.43	0.55
Basin Shape	1.01	2.33	1.83
Elongation Ratio	1.12	0.74	0.83
Texture Ratio	1.57	1.33	1.53
Circulatory Ratio	0.04	0.04	0.09
Drainage Texture	2.66	2.01	2.50
Compactness Coefficient	4.82	4.73	3.41
Stream Frequency	0.97	1.00	1.05
Infiltration Number	0.69	0.47	1.27
Length of overland Flow km²	0.70	1.06	0.41
Drainage Intensity	1.36	2.11	0.86
Constant of Channel Maintenance km² /km	1.40	2.11	0.82

2.8.3. Relief aspects of river basin morphometry

The maximum relief of any basin and the maximum altitudinal difference is termed as absolute and relative relief, respectively. It is the best indicator of erosional stages of any river basin. Normally, the mountain plain front river basin has higher basin relief than plateau plain front river basin (Thomas et al. 2010). The relief aspects for the Pamba, Manimala and Achankovil basins are given in Table 2.12.

Table 2.12: Relief parameters of different basins in Greater Pamba basin

	Achankovil	Pamba	Manimala
Maximum Elevation (m)	1550.00	1650.00	1150.00
Minimum Elevation (m)	1.50	3.50	1.00
Basin Relief	1543.00	1649.00	1149.00
Relief Ratio	20.85	17.36	19.47
Ruggedness Number	1.69	1.75	1.27

The maximum elevation is highest in the Pamba basin, with the value 1650.00 meters, followed by the Achankovil basin, having the value 1550.00 meters, and the Manimala basin, where the value is 1150.00 meters. The elevation of the basin has been shown in Figure 2.14.

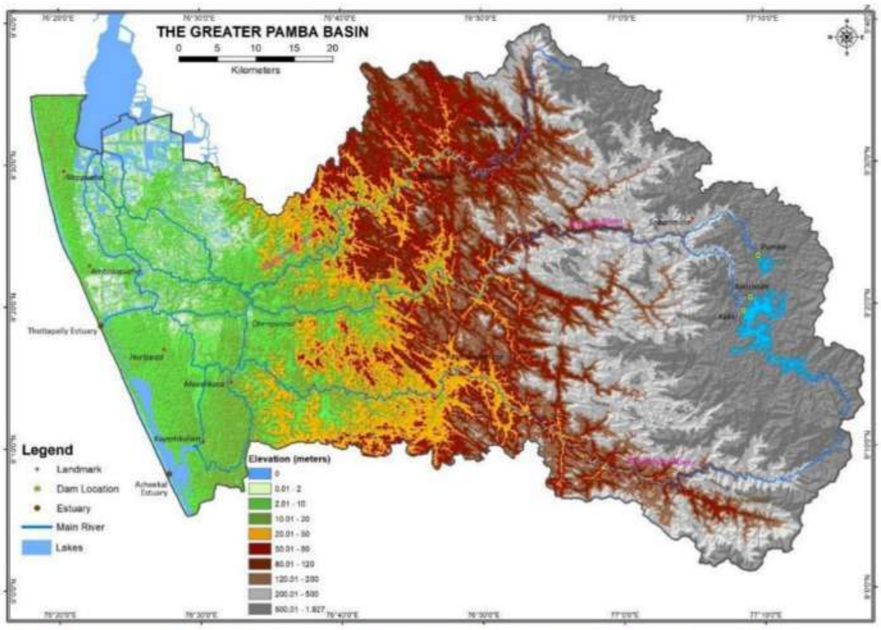


Figure 2.14: Elevation characteristics in the Greater Pamba basin

This indicates that Pamba has the most elevated terrain, which could influence higher runoff potential and precipitation capture. Similarly, the minimum elevation shows a slight variation, with Pamba having the lowest point at 3.50 meters, followed by Achankovil at 1.50 meters, and Manimala at 1.00 meters, suggesting differences in the extent of lowland areas among the basins.

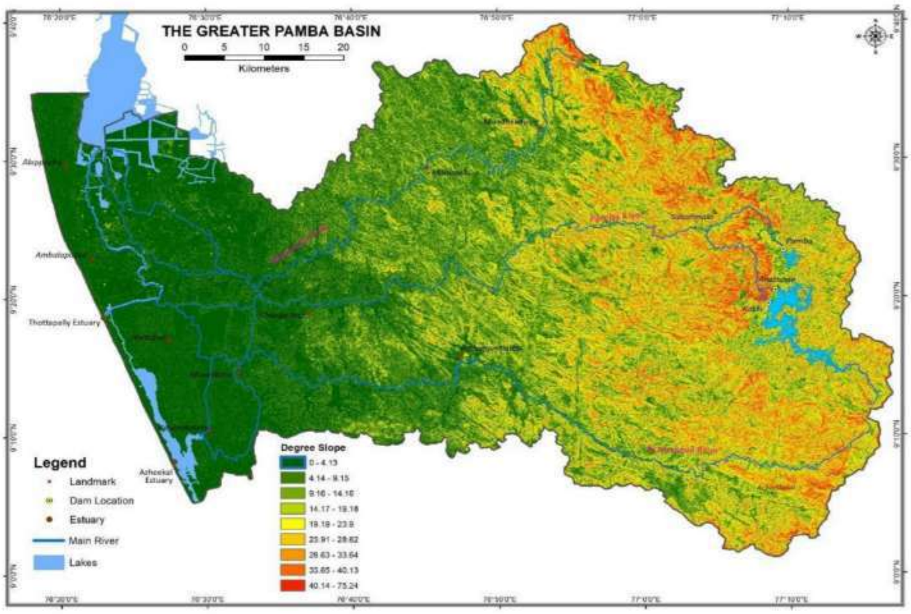


Figure 2.15: Slope characteristics in the Greater Pamba basin

Figure 2.15 shows the slope characteristics of Greater Pamba River basin. Basin relief characteristics of basin are indicative of young stages of geomorphic development and huge potentiality for further erosion. The abrupt changes of basin relief in mountain plain conjunction of Pamba Manimala and Achankovil river basin are indicative of prone to geomorphological hazards. Relief ratio denotes the ratio between total reliefs to the length of the principal drainage line (Lindsay and Seibert 2013). The value depends upon different factors of areal and relief characteristics of basin. The relief ratio, an indicator of the basin's steepness, is highest in the Achankovil basin, having the value 20.85, while the Manimala basin has the value 19.47, and the Pamba basin has the lowest value, 17.36. The higher relief ratio in Achankovil suggests steeper slopes, which may lead to quicker runoff and higher sediment transport. The ruggedness number, which combines relief and drainage density to describe the terrain's ruggedness, is highest in the Pamba basin, with the value 1.75, followed by the Achankovil basin, having the value 1.69, and the Manimala basin, where the value is 1.27. A higher ruggedness number indicates a more uneven and dissected terrain, implying higher runoff velocity and erosion potential in the Pamba and Achankovil basins compared to the Manimala basin. Table 2.13 shows the relief parameters calculate for the high land, midland and lowland regions of the basin.

Table 2.13: Relief Parameters for different physiographic zones across Greater Pamba basin

	Highland	**Midland**	**Lowland**
Maximum Elevation	1650.00	67.00	67.00
Minimum Elevation	67.00	26.00	3.50

Basin Relief	1583.00	41.00	25.00
Relief Ratio	33.68	0.80	0.64
Ruggedness Number	1.13	0.02	0.03

The study of the Greater Pamba River basin, using linear, areal, and relief parameters from ArcGIS, reveals a highly intricate drainage network with over 3000 streams. Agriculture and forests dominate land use in the Pamba Basin, with agriculture concentrated in the midland and lowland regions, while forest cover is significant in the highlands. The stream order distribution in the basin highlights a dominance of first order streams, particularly in the highland and midland regions, reflecting a dense network of smaller tributaries. The Achankovil Basin, with its compact size and mature drainage, suggests faster runoff and greater erosion potential. The Manimala Basin, with elongated streams and lower bifurcation ratios, reflects a simpler, less developed drainage system, potentially supporting larger water bodies but less prone to erosion. The Pamba Basin, with its high drainage density, stream frequency, and compact shape, is most susceptible to rapid runoff, flooding, and erosion, particularly during heavy rainfall. The Achankovil and Pamba basins, with higher relief ratios and ruggedness numbers, are more prone to rapid runoff and erosion.

2.9. Cross drainage structures

2.9.1. Cross-Structures and River Management

The Pamba River Basin features a network of water management structures that play a crucial role in flood control, irrigation, and salinity prevention. The Pamba River itself has 29 bridges, 5 causeways, and several check dams and vented cross-bars (VCBs), including the Pandarakkayam VCB, KWA VCB, and Arattukadavu VCB, which regulate water flow and prevent salinity intrusion. These structures also enhance river connectivity and protect agricultural lands from flooding. In the Achankovil River, water resource management is facilitated through 7 regulators, 47 VCBs, and 15 check dams, which ensure sustainable water availability for irrigation, domestic use, and ecological balance. Among these, the Thirkkunnapuzha Lock in Thirkkunnapuzha Panchayath, the Govindamuttam Regulator in Kayamkulam Municipality, and the Pathiyoor Regulator and Valiyapathiyoor Regulator in Pathiyoor Panchayath, Alappuzha, are prominent. Additionally, the Ayirannikudi Bridge Cum Regulator in Nooranad Panchayath, along with the Karippuzha Regulator West and Karippuzha Regulator, also located in Pathiyoor Panchayath, play a significant role in supporting irrigation, water supply, and agricultural activities across the region. The Manimala River Basin, though smaller compared to the Pamba and Achankovil, plays a crucial role in local water management. Some of the key VCBs and check dams along the river regulate seasonal flow variations, ensuring a steady water supply for irrigation and domestic use.

Table 2.14: List of Regulators in Achankovil River Basin

Name	Latitude	Longitude	District	Panchayath
Thirkkunnapuzha Lock	9.258297952	76.41286298	Alappuzha	Thirkkunnapuzha
Govindamuttam Regulator	9.167433	76.496717	Alappuzha	Kayamkulam Municipality
Pathiyoor Regulator	9.193583	76.500633	Alappuzha	Pathiyoor Panchayath
Valiyapathiyoor Regulator	9.2116	76.497283	Alappuzha	Pathiyoor Panchayath
Ayirannikudi Bridge Cum Regulator	9.231667	76.640083	Alappuzha	Nooranad
Karippuzha Regulator West	9.251333	76.5009	Alappuzha	Pathiyoor Panchayath
Karippuzha Regulator	9.251467	76.504133	Alappuzha	Pathiyoor Panchayath

2.9.2. Vented cross bars

There are 47 VCBs located in the Achankovil River. Out of these, 38 are in Pathanamthitta district and 9 are in Alappuzha district. The list of VCBs is provided in Table 2.15.

Table 2.15: List of VCB Structures

Name	Latitude	Longitude	District	Panchayath
Manakkuppa VCB	9.222611	76.79975	Pathanamthitta	Vallicodu
Vettakulam VCB	9.224056	76.79406	Pathanamthitta	Vallicodu
Njakkunilam VCB in Thalayarathodu	9.216306	76.79061	Pathanamthitta	Vallicodu
Vettukad VCB in Thalayarathodu	9.218778	76.78906	Pathanamthitta	Vallicodu
Ammoommathodu VCB near Vazhamuttom	9.240472	76.78869	Pathanamthitta	Vallicodu
Edatharappady VCB	9.225417	76.78864	Pathanamthitta	Vallicodu
Njarammoottilpady VCB in Thalayarathodu	9.221056	76.78717	Pathanamthitta	Vallicodu
Naduvathodi VCB in Thalayarathodu	9.221139	76.78514	Pathanamthitta	Vallicodu
Valakuzhy VCB in Kodumon Valiyathodu	9.219056	76.78236	Pathanamthitta	Vallicodu
Narikuzhy VCB in KodumonValiyathodu	9.214083	76.78119	Pathanamthitta	Vallicodu
Pulayanchira VCB in KodumonValiyathodu	9.211667	76.77719	Pathanamthitta	Vallicodu

Mlamthadomela VCB in EdatharaMlamthadom Valiyathodu-1	9.183583	76.86131	Pathanamthitta	Aruvappulam
Edatharaela VCB in EdatharaMlamthadom Valiyathodu	9.187417	76.86114	Pathanamthitta	Aruvappulam
Mlamthadomela VCB in EdatharaMlamthadom Valiyathodu-2	9.18275	76.86092	Pathanamthitta	Aruvappulam
Thazhathepadypaalam VCB in Edathara Mlamthadom Valiyathodu	9.181889	76.86058	Pathanamthitta	Aruvappulam
Mlamthadam VCB	9.178833	76.86017	Pathanamthitta	Aruvappulam
Kizhavalloorpalam VCB in Kizhavalloor Attutheeramthodu	9.242944	76.8375	Pathanamthitta	Konni
Oottuparaela VCB in Kottayamthodu	9.204889	76.82056	Pathanamthitta	Pramadom
VCB in Lakoorelathodu Near Rajiv Gandhi Indoor Stadium	9.239222	76.812	Pathanamthitta	Pramadom
Mallasseryela VCB in Lakoor Valiyathodu	9.242833	76.80922	Pathanamthitta	Pramadom
ValloorpadyNilamelela VCB in V-Kottayam Valiyathodu	9.217583	76.80575	Pathanamthitta	Pramadom
Nilamelela VCB in V-Kottayam Valiyathodu	9.221139	76.80297	Pathanamthitta	Pramadom
Kaniyamchal VCB	9.251472	76.80022	Pathanamthitta	Pramadom
Ammoommathodu VCB	9.238972	76.79942	Pathanamthitta	Vallicodu
Pramadom VCB in Ammoommathodu	9.242806	76.79153	Pathanamthitta	Vallicodu
Madathilpady VCB in Mukkadappuzhathodu	9.273028	76.81242	Pathanamthitta	Pathanamthitta Municipality
Kalliyickalpady VCB in Mammannuthodu	9.264333	76.81017	Pathanamthitta	Pathanamthitta Municipality
Choozhiyanipadam VCB	9.284972	76.79589	Pathanamthitta	Mylapra
Mylapra VCB in MylapraValiyathodu	9.273111	76.79472	Pathanamthitta	Mylapra
Periyompadamela VCB in AnaparaMukkuzhythodu	9.267472	76.79178	Pathanamthitta	Pathanamthitta Municipality
Ezhiyathupady VCB in KumbickalKandomthodu	9.234667	76.76575	Pathanamthitta	Omalloor

Kudilukuzhy VCB in KudilukuzhyAdiyanithdou	9.298694	76.77922	Pathanamthitta	Naranganam
Puthusserypady VCB in V-Kottayam Thodu	9.299972	76.80739	Pathanamthitta	Pramadom
Attachackalela VCB in Meenmoottil para Attachackalvaliyathodu	9.258083	76.84383	Pathanamthitta	Konni
Kizhakkupuramela VCB in Meenmoottil para Attachackalvaliyathodu	9.266889	76.84236	Pathanamthitta	Konni
Thanamuttomela VCB in Valiyathodu	9.24575	76.74594	Pathanamthitta	Omalloor
Pulinchani VCB	9.202028	76.86642	Pathanamthitta	Aruvappulam
Padappakkal VCB	9.194083	76.86494	Pathanamthitta	Aruvappulam
Mandanni Palam (AmbidavamPuncha)	9.23	76.62808	Alappuzha	Nooranad
Munduchaal cheep	9.220444	76.61783	Alappuzha	Nooranad
Vettiyar bridge V C B	9.225778	76.61628	Alappuzha	Nooranad
Petty and Para V C B	9.227333	76.61617	Alappuzha	Nooranad
Koprathukavupalam	9.223139	76.63547	Alappuzha	Nooranad
KizhakeAnjililimoodu VCB (Left)	9.193806	76.62217	Alappuzha	Nooranad
kizhakeAnjilimoodu VCB (Right)	9.191361	76.62181	Alappuzha	Nooranad
Padinjare Anjili moodu VCB	9.192028	76.61972	Alappuzha	Nooranad
Annikunnam Bridge cum VCB	9.205444	76.61525	Alappuzha	Nooranad

2.9.3. Check Dams

Table 2.16: List of Check Dams

Name	Latitude	Longitude	District	Panchayath
Attipara Nirathupara	9.190111	76.958194	Pathanamthitta	Aruvappulam
Alunkal Forest check dam	9.18325	76.95525	Pathanamthitta	Aruvappulam
Thalamanom Checkdam	9.2235	76.93875	Pathanamthitta	Thannithodu

CFRDI Checkdam	9.231194	76.869417	Pathanamthitta	Konni
Kottarathilkadavu Check dam	9.220167	76.8575	Pathanamthitta	Konni
Checkdam in Kumbazha estate 2nd division -2	9.281722	76.855833	Pathanamthitta	Malayalappuzha
Checkdam in Kumbazha estate 2nd division 1	9.2815	76.855694	Pathanamthitta	Malayalappuzha
Checkdam at Konni RBC	9.245583	76.844556	Pathanamthitta	Konni
Checkdam at Vettoor	9.250139	76.826	Pathanamthitta	Malay Alappuzha
Vettoor Checkdam across Achankovil River	9.250611	76.825889	Pathanamthitta	Konni
Checkdam at Kallarakkadavu	9.25825	76.789889	Pathanamthitta	Pathanamthitta Municipality
Vettikalilkadavu Checkdam	9.253111	76.789139	Pathanamthitta	Pathanamthitta Municipality
Omalloor Checkdam	9.236139	76.753806	Pathanamthitta	Omalloor
Checkdam d/s of Omalloor LI Scheme	9.236194	76.753694	Pathanamthitta	Omalloor
Kaipattoor Checkdam	9.232194	76.753	Pathanamthitta	Omalloor
Checkdam	9.228333	76.71	Pathanamthitta	Thumpamon

2.10. Irrigation Schemes- Pamba Irrigation Project (PIP)

The Pamba Irrigation Project (PIP) aims to utilize the tail-race water from the Sabarigiri Hydroelectric Project for irrigation in Pathanamthitta and Alappuzha districts. The tailrace water is first diverted into the Kakkad River, where it is utilized by several Small Hydroelectric Projects (SHEPs). Finally, it is picked up at Maniar by a barrage, from where it is further distributed through a canal system along the left bank of the river. The project was declared complete in 1993 and provides irrigation for 21,135 hectares of land in the taluks of Ranni, Kozhencherry, Mallappally, and Thiruvalla (Pathanamthitta district), Chengannur, Mavelikara, Karthikappally, and Kayamkulam (Alappuzha district). The ayacut area lies between the Manimala River and the Achankovil River, eventually reaching the Onattukara region and the eastern fringes of the Kuttanad paddy fields

2.11. Drinking Water Projects

2.11.1. Kerala Water Authority Drinking Water Schemes

The Greater Pamba River Basin serves as a vital source of drinking water for the Pathanamthitta and Alappuzha districts of Kerala. The Kerala Water Authority (KWA) manages major drinking water supply schemes in the region, benefiting approximately 30 lakh people. The primary intake points are located along the Pamba, Achankovil, and Manimala rivers, supplying water to 50 drinking water projects under KWA. The Pamba River supports 15 major drinking water schemes, while the Manimala and Achankovil Rivers support 15 and 19 schemes, respectively. These schemes, operated by the Kerala Water Authority, function year-round to provide water for regions in Pathanamthitta and Alappuzha districts. The list of KWA schemes is given in Table 2.17:

Table 2.17: List of KWA Schemes in the Greater Pamba Basin

Sl. No	River Basin	Type of Water Supply Infrastructure	Source of water	Capacity of Water Supply Infrastructure (MLD)	Geographic Coverage and Service Area
1	Pamba	UIDSSMT - Aug of WSS to Alappuzha Municipality and 9 Adjoining Panchayath, 62 MLD Water Treatment Plant at Karumadi	Pamba	62	Alappuzha Municipality, Aryad, Mannancherry, Ambalappuzha South, Ambalappuzha North, Punnapra South, Punnapra North
2	Achankovil	CWSS to Kayamkulam Municipality and Arattupuzha Panchayath, 12 MLD Water Treatment Plant at Pathiyoor	Achankovil	12	Kayamkulam municipality and Arattupuzha Panchayath
3	Pamba	UWSS to Chengannur Muncipality	Pamba	2.25	Chengannur Muncipality
4	Pamba	AUWSS to Chengannur Muncipality	Pamba	2.5	Chengannur Muncipality
5	Achankovil	CARWSS to Chennithala and Mannar Panchayath	Pamba	15	Chennithala, Mannar
6	Achankovil	ARWSS to Cheriyanad Panchayath	Achankovil	2.5	Cheriyanad Panchayath
7	Pamba	Intake well (KIIFB- WSS to Ala, Puliyoor, Budhannoor, Pandanadu, Mulakkuzha, Venmony panchayaths and	Pamba	35	Chengannur Municipality,Ala,Puliyoor, Budhanoor,Pandanad,Mulakkuzha,

		Chengannur municipality in Alappuzha district)			Venmony & Cheriyanad panchayaths
8	Pamba	Intake well and Water Treatment Plant (KIIFB-WRD025-29- Kuttanadu Drinking Water Project Phase II in Alappuzha District)	Pamba	44	Nedumudi, Kainakary,Ramankary, Chambakulam,Thakazhy, Edathua,Muttar,Thalavady, Neelamperoor,Veliyanadu, Veeyapuram,Kavalam,Pulinkunnu
9	Achankovil	ARWSS to Nooranad, Palamel, Thamarakulam and Chunakkara	Achankovil	10	Nooranad, Palamel, Thamarakulam and Chunakkara
10	Achankovil	UWSS to Mavelikara	Achankovil	4.5	Mavelikara, Thekkekara, Chettikulangara, Thazakkara
11	Manimala	Intake well - CARWSS to Madappally, Vakathanam, Karukachal	Manimala	2.25	Karukachal, Madappally & Vakathanam
12	Manimala	Intake well - RWSS to Vellavoor	Manimala	0.1	Vellavoor Part
13	Manimala	Intake well- RWSS to Nedukunnam & Kangazha	Manimala	1.36	Nedumkunnam, Kangazha & Vellavoor Part
14	Pamba	Intake Well & WTP at Kallisserry-UWSS to Thiruvalla Changanassery Municipality	Pamba	25	Thiruvanvandoor, Kuttoor, Thiruvalla & Changanassery Muncipality
15	Manimala	Intake well at Kattode & WTP at Thiruvalla-Kuttanad Water Supply Scheme	Manimala	33	Thiruvalla Muncipality, Vazhappallyy, Thrikkodithanam, Kurichy, Paippad, Veliyanad, Thalavady, Edathua & Muttar
16	Manimala	Intake well at Ganapathikunnu	Manimala	3	Kaviyoor Kunnamthanam Panchayaths

17	Pamba	CRWSS to Nedumbram Niraanm Kadapra and Peringara Panchayaths intake well at Pulikkezhu	Pamba	14	Nedumbram Niraanm Kadapra and Peringara Panchayaths
18	Pamba	WSS to Kuttandu (WTP at Neerettupuram) intake well at Neerettupuram	Pamba	14	Muttar, Thalavady and Ramankary Panchayaths
19	Manimala	WSS to Eraviperoor and Puramattom	Manimala	1.3	Eraviperoor and Puramattom Panchayaths
20	Manimala	WSS to Mallappally intake well near Mallappally bridge	Manimala	1.2	Mallappally Panchayath
21	Manimala	WSS to Anicadu intake well near Kavaanal Kadavu	Manimala	1.8	Anicadu Panchayath
22	Manimala	WSS to Kallooppara (Old) intake well near Azhakanal Kadavu	Manimala	1.4	Kallooppara Panchayath
23	Manimala	WSS to Kottangal intake well at Puthoor pady	Manimala	1.5	Kottangal Panchayath -Part
24	Pamba	WSS to Koipuram	Pamba	2.2	Koipuram Panchayath
25	Pamba	WSS to Thottapuzhassery	Pamba	1.1	Thottapuzhassery Panchayath
26	Pamba	WSS to Ayiroor WTP	Pamba	5	Ayiroor Panchayath
26	Manimala	WSS to Ezhumattoor	Manimala	1.3	Ezhumattoor Panchayath
27	Manimala	Intake well at Prayattukadavu & Booster PH at Thottappuzha-RWSS to Eraviperoor	Manimala	1.2	Eraviperoor Panchayath
29	Manimala	Intake well at Paduthode & Booster PH at Karamala-RWSS to Puramattom-Vennikkulam	Manimala	1.3	Puramattom Panchayath
30	Manimala	Intake well at Pallikkayam & Slow sand filter at Thuruthicadu-RWSS to Kallooppara new	Manimala	1.4	Kallooppara Panchayath
31	Manimala	Intake well at Sasthankoikkal & Booster PH at Poomkurunji-RWSS to Perumpara	Manimala	0.57	Kottangal Panchayath-Part

32	Manimala	RWSS to Mundakkayam	Manimala	0.45	Mundakkayam Panchayath(Part)
33	Manimala	RWSS to Parathodu	Manimala	0.6	Parathodu Panchayat (Part)
34	Manimala	WSS to Manimala and adjoining Villages	Manimala	9	Manimala, Vazhoor, Vellavoor, Pallickathodu, Chirakkadavu part (Cheruvally Village) Panchayats
35	Manimala	WSS to Chirakkadavu, Kanjirappally and Elikkulam.	Manimala	9 MLD	Chirakkadavu, Kanjirappally and Elikkulam Panchayats
36	Pamba	WSS to Erumely panchayat.	Pamba	10	Erumely Panchayat
37	Achankovil	Mini WSS to Achankovil	Achankovil		
38	Achankovil	UWSS to Pathanamthitta	Achankovil	6	Pathanamthitta
39	Achankovil	RWSS to Elanthoor MAlapuzhassery	Achankovil	4.5	Elanthoor, Malapuzhassery
40	Achankovil	RWSS to Kozhencherry	Achankovil	5	Kozhencherry
41	Achankovil	RWSS to Konni Thazhom	Achankovil	3.5	Konni
42	Achankovil	RWSS to Vallicodu Kodumon	Achankovil	5.5	Vallicode, Kodumon
43	Achankovil	RWSS to Konni Medical college	Achankovil	5	Konni Medical college
44	Achankovil	RWSS to Malayalapuzha	Achankovil	1.65	Malayalappuzha
45	Achankovil	WSS Adoor and Adj. Panchayaths	Achankovil	12.5	Adoor Municipality, Erathu
46	Kallada	RWSS to Kadambanadu	Kallada	4	Kadambanad
47	Achankovil	UWSS Pandalam	Achankovil	8	Pandalam Municipality
48	Pampa	CARWSS to Ranni, Pazhavangadi, Vadasserikkara	Pampa	7.5	Ranni, Pazhavangadi, Vadasserikkara
49	Pampa	RWSS Vechuchira	Pampa	2.25	Vechoochira
50	Pampa	RWSS to Perunadu	Pampa	8	Perunad

2.11.2. Challenges Faced by KWA

Several regions within the basin experience severe water scarcity, particularly during drought seasons. Panchayats such as Aryad, Mannancherry, Palamel, Karukachal, and Madappally frequently face acute shortages. Chengannur Municipality lacks a dedicated water supply system, while Nedumudi, Kainakary, Ramankary, Chambakulam, Thakazhy, Edathua, Muttar, Thalavady, Neelamperoor, Veliyanadu, Veeyapuram, Kavalam, and Pulinkunnu suffer from water quality issues with no alternative sources for treated water.

Another critical challenge is the inadequate capacity of water treatment plants, which struggle to meet demand. A major operational issue affecting all schemes is the accumulation of clay, silt, and sand near well-cum-pump houses, leading to frequent pump breakdowns and damage to raw water pumping systems. Periodic removal of these deposits is essential to maintaining functionality. Additionally, reduced water availability during the summer further exacerbates these issues, making sustainable water management a priority.

Several regions within the Pamba Basin experience severe water scarcity, particularly during drought seasons. Panchayats such as Aryad, Mannancherry, Palamel, Karukachal, and Madappally frequently face acute shortages. Chengannur Municipality lacks a dedicated water supply system, while Nedumudi, Kainakary, Ramankary, Chambakulam, Thakazhy, Edathua, Muttar, Thalavady, Neelamperoor, Veliyanadu, Veeyapuram, Kavalam, and Pulinkunnu suffer from water quality issues with no alternative sources for treated water.

A key issue is determining whether these challenges arise primarily from hydrological factors or infrastructure inadequacies (e.g., insufficient wells, reduced well yield, lack of water treatment plants). The inadequate capacity of water treatment plants exacerbates the problem, as it struggle to meet rising demand. Operational challenges include the accumulation of clay, silt, and sand near well-cum-pump houses, leading to frequent pump breakdowns and damage to raw water pumping systems. Periodic removal of sediment deposits is critical to maintaining functionality. Furthermore, reduced water availability during summer worsens these issues, highlighting the urgent need for sustainable water management solutions to ensure long-term water security in the basin.

2.12. Hydropower Projects and Dams in Pamba Basin

The Pamba River basin features a total of 16 water structures, comprising 10 dams, four weirs, and two barrages. The dams - Kakki, Anathode, Pamba, Moozhiyar, Upper Moozhiyar, Kullar, Gavi, Meenar I & II, and Veluthodu dam, collectively hold a gross storage capacity of 508.22 MCM (Table 2.18). The weirs consist of Azhutha, Kochu Pamba, Ranni-Perinad, and Perumthenaruvi, while the barrages consist of Maniyar and Thottappally Spillway.

2.13. Power Generation by KSEB

The Kerala State Electricity Board (KSEB) operates several major hydroelectric projects in the Pamba Basin including the Sabarigiri, Kakkad, and Ranni-Perunad small hydroelectric projects. The Sabarigiri Hydroelectric Project (SHEP), commissioned in 1966, is the second-largest hydroelectric project in Kerala. The Sabarigiri Hydroelectric Project includes 3 main dams (Kakki, Anathode, and Pamba) and 5 small dams (Upper Moozhi Ar, Kullar, Meena Ar I, Meena Ar II, and Gavi). It was originally designed with an installed capacity of 300 MW, which was later upgraded to 340 MW through a Renovation, Modernization, and Upgradation (RMU) program between 2005 and 2009. The power station is located at Moozhi Ar in Ranni Taluk.

The Kakkad Hydroelectric Project, located in Pathanamthitta district and operated by the Kerala State Electricity Board (KSEB), has an installed capacity of 50 MW. Additionally, the Ranni-Perunad Small Hydroelectric Project is a tailrace scheme for the Mani Ar Hydroelectric Project, which is operated by M/s Carborundum Universal. This project has an installed capacity of 4 MW (2 × 2 MW) and was commissioned on February 16, 2012. Water discharged after power generation is released back into the Pamba River.

2.14. Reservoirs

The Pamba and Kakki reservoirs are large reservoirs which are part of the Sabarigiri Hydro Electric Project (SHEP). The Basin relies on these reservoirs—Pamba and Kakki-Anathode—for water storage and regulation structures for hydropower generation. Pamba Reservoir, created by the Pamba Dam on the Pamba River, transfers water to the Kakki-Anathode Reservoir via a 3.21 km underground tunnel (3.6 m x 3.6 m, 3207.7 m long) and then conveyed to the powerhouse at Moozhi Ar. It is further augmented by smaller dams, including Kullar, Gavi, Meenar-I, and Meenar-II, along with a pumping scheme at Kochu Pamba Weir. The reservoir can rise to a Full Reservoir Level (FRL) of +986.33 m, ensuring a reliable water supply for power generation. The Kakki Dam is a concrete gravity dam, whereas Pamba and Anathode Dams are masonry gravity dams

The Kakki Reservoir, formed by the Kakki dam and Anathode dam, receives water from the Pamba Reservoir and its own catchment, serving as the intake source for the powerhouse. The Upper Moozhi Ar Dam, commissioned in 1979, acts as an augmentation dam for this system. Key features include a flood control system at the Anathode Flanking Dam and the ability to utilize water from high-altitude catchments, including Devar Mala (+1760 m elevation) and Sundara Mala (+1816 m elevation). The SGHEP power station at Moozhi Ar operates with a net head of 714.76 m, utilizing both major and minor reservoirs constructed between 1979 and 1991 to enhance efficiency.

The reservoirs in GPB are primarily used for power generation. Following power generation, the tailrace water is released into the Moozhiyar reservoir, formed by the Moozhiyar dam. The Kakkad HEP and the Pamba Irrigation scheme, covering an ayacut of 21135 Ha, utilize the tailrace water from the Sabarigiri HEP. The primary reservoir for the Kakkad project is located on the Moozhiyar, while the Veluthode reservoir, formed by the Veluthode dam, serves as the secondary reservoir. The Pamba Irrigation Scheme involves the Maniyar barrage, which diverts water into the main canal with a length of 207 km and distributaries spanning 251 km.

Table 2.18: Reservoirs in the GPB

Name	Type	Function
Pamba	Dam	Dam
Kakki	Dam	Dam
Anathode	Flanking Dam	Augments Kakki reservoir
Upper Moozhiyar	Diversion structure	Diverts water to the Kakki reservoir
Kullar	Diversion structure,	Diverts water to the Pamba reservoir
Gavi	Diversion structure,	Diverts water to the Pamba reservoir
Meenar I	Diversion structure	Diverts water to the Pamba reservoir & diversion is routed through Meenar II
Meenar II	Diversion structure,	Diverts water to the Pamba reservoir
Moozhiyar	Dam	Primary reservoir for Kakkad HEP
Veluthode	Dam	Divert water to the tunnel carrying water from Moozhiyar reservoir to Kakkad Power Station

2.15. Dams in the Sabarigiri Hydroelectric Project

The Sabarigiri Hydroelectric Project consists of several major dams, including Pamba Dam (Pamba River), Kakki Dam (Kakki River), Anathode Dam (Kakki River), Peruthenaruvi Weir (Pamba River), Moozhi Ar Dam (Moozhi Ar River), Karikkayam Dam (Pamba River), Alunkal Dam (Pamba River), Kochupamba Dam (Pamba River), Veluthode Dam (Kakkad River), Meenad Dam (Meena Ar River), Kullar Dam (Kullar River), and Gavi Dam (Gavi Ar River).

2.16. Azhutha Diversion Scheme

The Azhutha Diversion Scheme diverts water from the 16.84 km² catchment area of the Azhutha River, a tributary of the Pamba River, to the Idukki Reservoir to enhance the power potential of the Idukki Hydroelectric Project. As part of this scheme, the Azhutha Dam was constructed as an augmentation dam by KSEB.

2.17. River Gauge Stations

2.17.1. River Gauge Stations in Pamba River

The Pamba River Basin is equipped with several river gauge stations strategically located to monitor water levels and flow. The river gauge stations in the Pamba River basin are Ambalapuzha, F.C.S Kurdamnnil, Moozhi Ar, Nilackal, Perunthenaruvi, Vadasserikkara, Thannithodu, Kochupamba and Koruthodu. These gauges play a critical role in monitoring hydrological parameters and supporting water resource management in the basin. A list of the Gauging Stations in the Pamba Basin is given in Table 2.19 and illustrated in Figure 2.16.

Table 2.19: List of gauging Stations in the Pamba Basin

Sl.No	Station	Chainage from Origin (km)
1	Koruthodu	50.8
2	Kochu Pamba	28.9
3	Tannithodu	47.8
4	Vadasserikkara	75.7
5	Perunthenaruvi	53.4
6	Nilackal	56.6
7	Moozhi Ar	58.5
8	FCS Kurdamannil	88.62
9	Ambalappuzha	146.85

2.17.2. River gauging stations in Manimala River

The Manimala River features three key gauging stations located at strategic points along its course to monitor water flow and levels. The first station is at Mundakkayam, positioned at 19.92 km from the river's origin. The second station, located at Manimala, 51.8 km downstream, while the third station is at Vallamkulam, 89.56 km from the origin. These gauging stations listed in Table 2.20 provide crucial data for understanding river dynamics and managing water resources across the river's stretch.

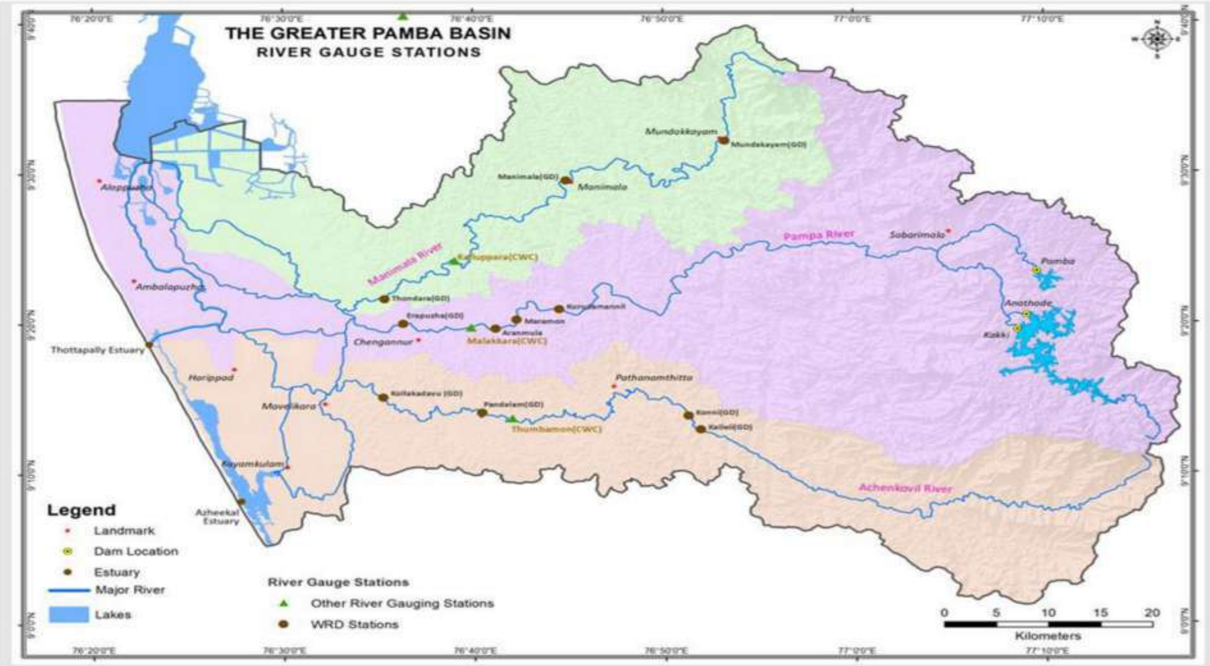


Figure 2.16: A map showing the River Gauge Stations

Table 2.20: List of River Gauges in Manimala Basin

Sl No	Location / name of River Gauge Station	Chainage from Origin
1	Mundakkayam	19.92 km
2	Manimala	51.8 km
3	Vallamkulam	89.56 km

2.18. Ground Water Monitoring

Groundwater Department has a dedicated network of monitoring wells comprised of open wells, piezometers (bore wells), shallow piezometers (phreatic aquifers) and tube wells. The monthly water level measurements are taken from the wells to understand the groundwater levels of these well during a particular month. In addition to the monthly monitoring wells, some piezometers are fitted with DWLR, enabling daily water level measurements. The number of monitoring wells spread across the three-river basins falls into the four districts as below (Figure 2.17). There are about 304 monitoring wells under State Groundwater Department which are located in the Pampa, Manimala and Achankovil river Basin. The district-wise distribution of wells is given in Table 2.21. It is important to note that eastern part of the basin is covered by the forest land and does not have any monitoring wells. A pictorial representation of the distribution of wells in the basin is given in Figure 2.17.

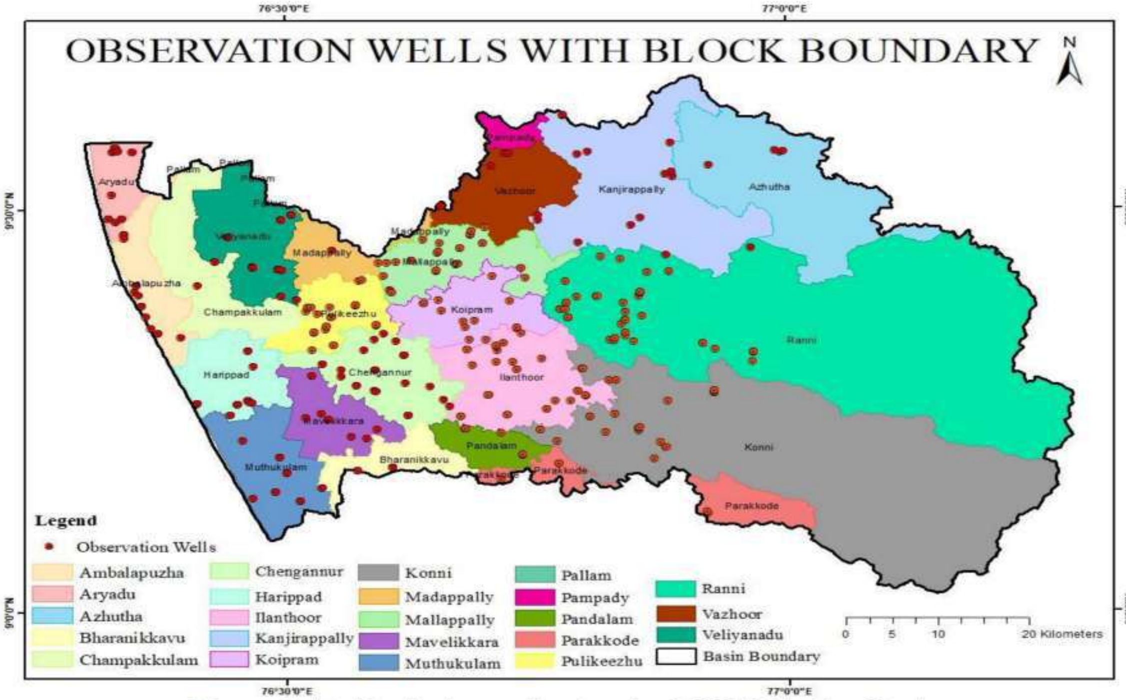


Figure 2.17: Monitoring well network of SGWD in the Study area

Table 2.21: Detailed monitoring well network of SGWD

Sl No	District	No of Observation Wells
1	Pathanamthitta	166
2	Alappuzha	113
3	Kottayam	21
4	Idukki	4
	Total	304

2.18.1. High Frequency Groundwater Level Monitoring Stations

To monitor micro groundwater changes in the basin, the groundwater department has established 21 RTDAS (Real Time Data Acquisition Stations). The digital water level recorders fitted with a telemetry system have capability to record 4 groundwater level data in 6 hours intervals. These monitoring stations will be useful to understand the daily micro water level fluctuations in response to extreme climatic events and recharge and discharge conditions of the basin. The high frequency data would also be useful to understand the coastal changes, occurrence of drought and urban flooding which is prevalent in many parts of the basin. The map showing the RTDAS locations is given in the Figure 2.18.

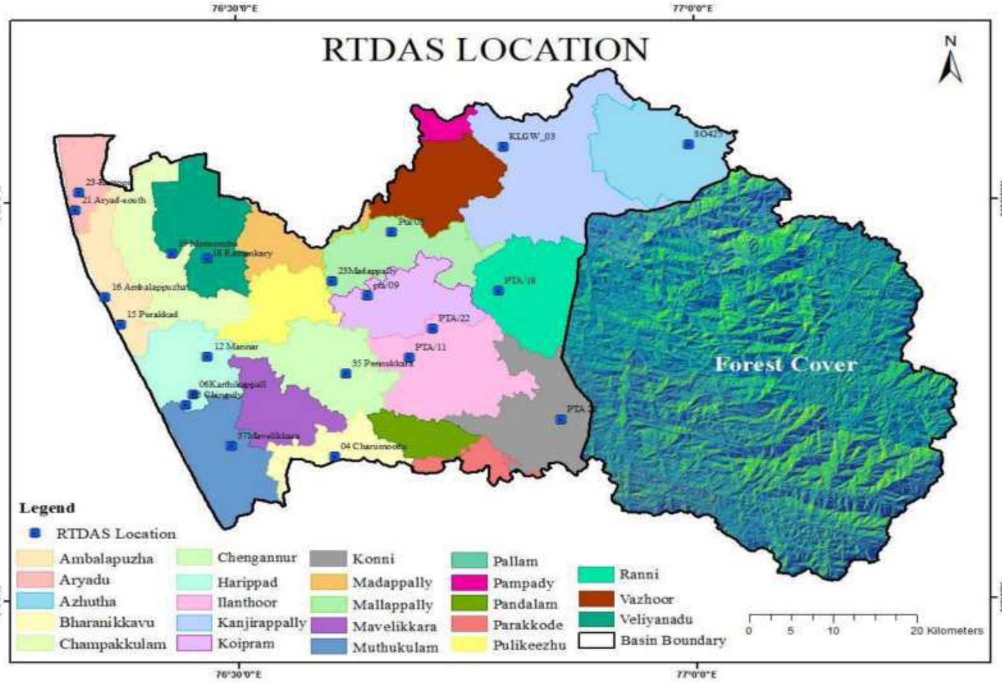


Figure 2.18: Average Groundwater Level Map of the Basin

The Central Ground Water Board is currently installing groundwater monitoring piezometers in the coastal area of Alappuzha district as part of its ongoing program. This project is expected to be completed in the next year, and once finalized, these piezometers will be equipped with a real-time groundwater level and quality data acquisition system.

Additionally, CGWB is conducting an aquifer management study in the coastal area of Alappuzha district under the NAQUIM 2.0 programme to delineate saline and freshwater zones in the aquifer. This study will culminate in an Integrated Aquifer Management Plan by the end of 2026.

2.19. Water Quality

2.19.1. 'Thelineer Ozhukum Nava Keralam' campaign

A campaign with public participation for making the water sources in the state pollution free has been launched in the state.

- Objectives
  - Water Sanitation: To keep all the water bodies in the state clean and tidy.
- Sub-objectives

- Check the sanitary condition of water bodies in all the local bodies in the state and identify the contaminated areas.
- Make a list of large bodies of water, ponds, streams, creeks, and polluting sources, mainly with the participation of the people
- Based on this, samples from sources of serious contamination are subjected to preliminary water quality testing to determine the level of contamination.
- Clean the contaminated areas through a public cleaning campaign.
- Develop a scientific alternative system of action with public participation to eliminate polluting sources.
- Establishment of Local Self Government Level Action Plan to prevent dumping of waste through polluting sources and to treat the waste in such sources scientifically.
- To plan scientific solid-liquid waste projects with the participation of local bodies under the leadership of Local Governments and in 86 collaboration with all the affiliated agencies of various departments with half co-ordination and public participation.
- To achieve sustainability by providing liquid waste management systems at the household-institutional public level and to enable local bodies to achieve complete sanitation status by providing liquid waste systems along with solid waste.

- Approach
  - Implement a sustainable program for prevention of water pollution in each local government body with the participation of the people through the coordination of various departments under the leadership of the Local Self Government Institutions
  - Implement 'Freshwater Navakeralam' as a public education program with the participation of students, government agencies concerned for waste disposal, youth and voluntary organizations with the participation of local bodies.
  - Raise awareness among the general public about the need for clean treatment of water resources, the need for scientific liquid waste management and the declining availability of drinking water through intensive intensive information dissemination campaign.

2.19.2. Water Quality Monitoring Infrastructure

1. Achankovil River

The Achankovil River is formed from the streams of Rishimala River, Pasukidamettu River and the Ramakkaltheri River. Kallar River is its main tributary. It is flowing through Kollam, Pathanamthitta and Alappuzha districts. The river travels nearly 128 Km and has a basin area of 1484 km^2 and finally joins the Pamba River at Veeyapuram village near Mavelikara in Alappuzha District. The NWMP sampling stations are located at Kallarakkadavu (Stn code: 3465), Thumpamon (Stn code: 1342), Pandalam (Stncode: 3466) and Chennithala (Stncode: 1443), SWMP stations are Aruvappulam (Stn code: K10), Konni (Stn code: K11), Kumbazha (Stn code: K12) and Pallippad (Stn code: K13).

2. The Pamba River

The Pamba River originates from the Pulachi Malai Hills of the Peerumedu Plateau in the Western Ghats. It has a length of 176 Km and is the third longest river in Kerala. River Pamba is famous due its association with the largest Pilgrim Centre, Sabarimala Sree Dharma Sastha Temple. It has a total basin area of 2235 km² and flows through Ranni, Ayroor, Pathanamthitta, Kozhanchery, Chengannur, Kuttanad and Ambalappuzha taluks and finally reaches the Vembanad Lake. Kuttanad, the important rice cultivating area in Kerala gets the irrigation water from Pamba River. The NWMP River stations are located at Chengannur near Chengannur Town (Stn code: 1156), Thakazhy near Thakazhy Bridge (Stn code: 1341), Pamba Down in Parumala (Stn code: 1565), Mannar (Stn Code 5205), and Veeyapuram (Stn code: 5207). The SWMP sampling stations include Kochupampa (Stn code: K19), Kakkiyar (Stn code: K20), Pamba upstream(U/S) (Stn code: K21), Njunangar (Stn code: K22), Vadasserikkara (Stn code: K23), Athikkayam (Stn code: K24), Ranni (Stn code: K25), Kozhencherry (Sin code: K26), Edathua (Stn code: K27) and Pulinkunnu (Stn code: K28), Pallathuruthy (K154).

3. The Manimala River

The Manimala River originates from the Muthuvara hills near Peerumedu in Idukki district. It flows through Kottayam and Pathanamthitta districts and finally joins Pamba River at Muttar in Alappuzha. It has a length of about 92 Km and flows through a catchment area of about 847 km². Erumely, Manimala, Mundakkayam, Chambakulam etc. are the important towns on the banks of this river. The NWMP River stations are located at Thondara (Stn code: 1384) and Kallooppara (Stn code: 1340). SWMP river stations are located at Yendhayar (Stn code: K35), Kottikkal (Stn code: K36), Erumely (Stn code: K37), Pazhayidam (Stn code: K38), Valakkayam (Stn code: K39), Manimala (Stn code: K40), Mallappally (Stn code: K41), Thottabhagam (Stn code: K42).

2.19.3. Ongoing & Proposed Initiatives:

The list of ongoing and proposed projects are listed in Table 2.22.

Table 2.22: List of Ongoing & Proposed projects

Sl.No	STP Location	STP Installed Capacity	Utilization	Status
		Pathanamthitta		
1	Sewage Treatment Plant at Sannidhanam (5MLD) Maintained by Travancore Dewaswom Board	5 MLD (UASB and SBR)	3.5 MLD	Operational (pH-8.8, TSS - 344mg/l, BOD - 4.9 mg/l,TDS - 526 mg/l, oil and grease -BDL,COD - 60,total coliform - Nil, Faecal Coliform - Nil, Total Coliform- 196 cfu/100 ml as per analysis report dated 31.05.2024)

2	Sewage Treatment Plant at Pamba (3.5MLD) Maintained by Travancore Dewaswom Board	3.5 MLD (Coagulation & Settling)	3.5 MLD	Operational (pH-9, BOD - 45 mg/l, TSS 152 mg/l, COD - 224 mg/l, Total Coliform- 425 cfu/100 ml as per analysis report.)
		Alappuzha		
3	DEWATS system, Chathanad (For 50 houses in slum area)	25 KLD (Anaerobic Baffle Reactor)	25 KLD	Operational (pH - 8.5, BOD - 12 mg/l, SS - 20, g/l, Oil and grease BDL as per the analysis report.
4	STP at General Hospital	0.24 MLD	0.1 MLD	Electro Coagulation
		Kottayam		
5	STP for Houseboat (0.09 MLD) at Kumarakom maintained by DTPC, Kottayam.	0.09 MLD (Activated Sludge Process)	0.09 MLD	Operational (pH- 7, BOD - 14 mg/l, SS -18 mg/l, oil & grease-BDL as per the analysis report
		Idukki		
6	Sewage Treatment Plant at Comfort Station. Adimaly Grama Panchayat, Idukki	0.01 MLD		STP is under inspection (not in a working condition)
7	Construction of 6 KLD ETP for Kumali Slaughter House Kumali GP, Idukki	0.06 MLD		Slaughter House is not functioning.
8	60 KLD STP at Taluk Hospital Adimaly, Adimaly Block Panchayath, Idukki	0.006 MLD		Operational MBBR

2.19.4. Ground Water Quality Monitoring

Kerala State Pollution Control Board has 5 groundwater monitoring stations in Alappuzha and Kottayam districts under National Water Quality Monitoring Programme NWMP. Groundwater is monitored twice (April and October) in a year by KSPCB. Well stations at Fathima Puram (station code 2308) Karoor (station code 2309), Vaikom (station code 2310) and Vadavathur (station code 2311) located in Kottayam District. Well station at Sarvodaya Puram (station code 2313) located in Alappuzha District. There are no groundwater monitoring stations in Idukki and Pathanamthitta and hence no groundwater quality data is available in these districts.

2.20. Environmental Status

The Greater Pamba River Basin is a biodiversity-rich ecosystem facing significant threats from human interventions and environmental degradation. Quantitative analyses highlight critical variations in biodiversity, vegetation, and the distribution of flora and fauna, underscoring the urgency of conservation efforts.

2.20.1. Biodiversity in the River Basin

The Greater Pamba River Basin is a biodiversity hotspot, harbouring 433 plant species, including 410 angiosperms, 3 gymnosperms, and 20 pteridophytes. Endemism stands at 17.5%, significantly lower than the 45.6% observed in the Western Ghats-Sri Lanka biodiversity hotspot. The flora consists of 91 evergreen, 80 deciduous, 53 semi-evergreen, and 48 wetland species, contributing to the basin's ecological richness. However, habitat destruction, pollution, and invasive species threaten biodiversity.

The basin supports 79 freshwater fish species across 31 families, including 13 estuarine species. Commercially important species such as Etroplus spp., mullets, carps, and Macrobrachium rosen bergi make up 72% of the total fish population. However, 25% of Kerala's freshwater fish species face extinction due to river flow obstructions, loss of riparian canopy, agrochemical pollution, and destructive fishing practices. Seasonal flow reductions and sand mining further fragment habitats and reduce fish diversity.

2.20.2. Aquatic and Riparian Vegetation

The basin's aquatic vegetation includes species like Hydrilla Verticillata, Eichhornia crassipes, and Salvinia molesta, along with planktonic organisms such as Anabena and Microcystis, which are vital to aquatic ecosystems. However, invasive weeds like Cabomba furcata, particularly in areas like Aranmula, obstruct water flow and suppress native vegetation. These species thrive in nutrient-rich waters caused by sewage and agrochemical runoff, disrupting the ecological balance.

Riparian vegetation, essential for stabilizing riverbanks and maintaining biodiversity, is declining due to sand mining, deforestation, and construction activities. The loss of riparian canopy has led to soil erosion and promoted invasive species, while the removal of vegetation has resulted in the loss of 17 rare, endangered, or threatened (RET) species, further fragmenting habitats and reducing ecological connectivity.

2.20.3. Challenges to Biodiversity

The Greater Pamba River Basin faces numerous ecological challenges that threaten its health and biodiversity. Rampant sand mining destabilizes riverbeds, severely impacting fish spawning grounds and aquatic habitats. Deforestation has led to the loss of riparian vegetation, exacerbating soil erosion and creating conditions favourable for invasive species. The construction of barriers and check dams further obstructs natural river flow, restricting fish migration and disrupting ecological connectivity. Additionally, pollution from agrochemicals, untreated sewage, and industrial effluents enriches the river with nutrients, promoting the unchecked growth of invasive weeds like Cabomba furcata, Salvinia molesta, and Hydrilla, which alter the basin's natural ecosystem dynamics. The cumulative impact of these challenges has led to declining biodiversity. Fish diversity is severely affected, with 25% of freshwater fish species in Kerala under threat. The basin's 17.5% endemism reflects the alarming decline in unique species. Invasive species dominate nutrient-rich zones, further degrading habitats and altering the natural vegetation composition.

The environmental challenges of the Greater Pamba River Basin highlight the need for sustainable management and focused conservation efforts. Restoring riparian vegetation, regulating sand mining, controlling pollution, and mitigating invasive species are critical to preserving the basin's ecological health and biodiversity.

2.20.4. Inland Biodiversity in Kuttanad

As per the Kerala State Biodiversity Action Plan, stagnation in marine fish production and the increasing demand for fish and fish products in national and international markets have necessitated the development of inland fish production. The inland water bodies, covering 117,122 ha, and coastal wetlands, spanning 40,876 ha (Wetland Atlas of Kerala, 2011), offer immense potential for fish and shellfish production. However, the inland water resources for fish production in Kerala have yet to be optimally utilized.

The State has made conscious efforts to increase inland fish production through projects like 'Subhikshakeralam.' Inland fish production holds significant promise for the future in Kerala, but the insufficient availability of good-quality fish seeds has been identified as a major challenge. To address this issue, the department has made efforts to strengthen existing hatcheries, nurseries, and fish farms while also constructing new units with the available infrastructure.

The area utilized for fish farming in ponds increased from 5,325 ha to 5,700 ha in 2019-20. The number of cage culture units rose from 80 to 1,800, mussel farming units increased from 2,000 to 3,500, and Recirculatory Aquaculture System/Aquaponics units grew from 100 to 500. Additionally, zero water exchange shrimp farming was carried out over a 200-ha area. The practice of one paddy, one fish farming in the Kole lands of Thrissur and Malappuram districts expanded from 1,600 ha to 4,500 ha, while in the Kuttanad region, it increased from 2,100 ha to 5,350 ha.

2.21. Socio Economic Status

2.21.1. Agriculture-based Economy

The economy in the Pamba basin is largely based on agriculture, with the fertile lands along the river supporting the cultivation of rice, vegetables, and fruits, along with cash crops like rubber, coconut, and spices (particularly cardamom). Farmers in the basin rely heavily on the seasonal monsoon, and any disruption to rainfall or water availability can significantly affect crop yields, leading to economic vulnerability. Agriculture is often practiced on a small-scale, with many farmers having limited access to modern farming technologies or capital, contributing to financial stress.

2.21.2. Fishing and Water Resources:

Fishing, both inland and river-based, plays a crucial role in the livelihood of communities near the river. Small-scale and artisanal fisheries are common, providing food and employment. However, water pollution, sand mining, and decreasing fish stocks are challenges faced by these communities, further impacting their socio-economic stability.

2.21.3. Urbanization and Tourism

The Pamba Basin includes regions with both rural and urban populations. Cities like Pathanamthitta (Kerala) and parts of the nearby town of Kottayam are witnessing rapid urbanization, bringing in economic opportunities in industries, trade, and services. The river is also a major site for religious and cultural tourism. The famous *Sabarimala Temple*, one of the largest pilgrimage sites in India, is located in the upper reaches of the Pamba River. Pilgrims contribute significantly to the local economy during the annual pilgrimage season. However, tourism also brings challenges like environmental degradation, pollution, and an increasing cost of living.

2.21.4. Access to Education and Health

While Kerala generally has good health and education indices compared to other Indian states, rural areas within the Pamba basin can still face challenges in accessing quality healthcare and education. The government has made strides in improving infrastructure, but there is still a disparity in urban and rural areas when it comes to access to social services.

2.21.5. Poverty and Inequality

Like many rural regions in India, parts of the Pamba basin have high levels of poverty, and the economic status of households can vary widely. Many communities, especially those reliant on traditional agriculture and fishing, face cycles of poverty. Rural populations, particularly marginalized groups, may experience limited access to resources and opportunities for upward mobility, contributing to social inequality.

2.22. Climate Change and Environmental Stress

Climate change is increasingly affecting the socio-economic status of communities in the Pamba Basin. Erratic rainfall patterns, floods, and droughts can disrupt agriculture and water supply, leading to income instability and food insecurity.

The basin is also facing environmental challenges like deforestation, pollution, and loss of biodiversity, which impact the overall health of the region and its economy.

The socio-economic status of the Pamba Basin is shaped by a mix of agricultural dependency, fishing, tourism, and urbanization. While the region benefits from fertile lands and a vibrant cultural heritage, it also faces challenges such as poverty, environmental degradation, and climate change impacts. Addressing these issues requires a balanced approach that promotes sustainable development, improves access to education and healthcare, and preserves the ecological health of the basin. By focusing on inclusive growth and environmental preservation, the region can build a more resilient and prosperous future for its communities.

2.23. Summary

The current scenario of the Greater Pamba River Basin has been assessed, focusing on its geomorphology and topography. The physical characteristics of the basin, including variations in elevation, slope patterns, and landforms, have been described to better understand its natural setting. Structural interventions such as dams, reservoirs, canals, and other water management infrastructure have been mapped, along with an analysis of their roles in flood control, irrigation, and water supply.

A detailed examination of the river system within the basin has been conducted, analyzing its tributaries, drainage patterns, and connectivity. Morphometric parameters, such as stream order, drainage density, and bifurcation ratio, have been calculated to assess the basin's hydrological behavior. Index properties, which represent the basin's shape and flow characteristics, have also been determined. Additionally, the various irrigation systems within the basin have been evaluated, highlighting their importance in supporting agriculture. The existing hydrometeorological network, including rainfall gauges, stream gauges, and weather stations, has been mapped to assess the availability of data for effective water management, alongside a discussion on groundwater monitoring systems.

The socio-economic and environmental status of the basin has also been examined, providing a comprehensive understanding of the resources within the area. A detailed assessment of water availability in the basin has been carried out using the SWAT-based hydrological model for more accurate water availability estimations. The findings of this detailed study are presented in the following chapter.

3. Water Resource Assessment

3.1. Introduction

Water resource assessment is a fundamental process for evaluating the availability, distribution, and sustainability of water within a river basin. It involves a comprehensive analysis of inflows, outflows, and changes in water storage over a defined period, providing critical insights into the basin's hydrological response. A well-structured water balance assessment is essential for understanding water availability, identifying potential deficits or surpluses, and ensuring sustainable water management.

Effective water resource management relies on a detailed understanding of the water balance, enabling the identification of water-stressed regions, seasonal variations, and the impacts of anthropogenic activities such as irrigation, urbanization, and industrial water use. Additionally, water resource assessment plays a vital role in addressing key challenges related to water allocation, flood control, drought management, and ecosystem sustainability. As climate variability continues to intensify, accurate assessment and monitoring of water resources are crucial for predicting and mitigating extreme hydrological events, ensuring long-term resilience in water management strategies.

3.2. Hydro-met parameters including Rainfall and Run-off – Surface Water

The study explores the statistical characteristics of monthly rainfall distribution, specifically focusing on the probability density function (PDF) plotted against total rainfall for each month. The observed trends include a decrease in the amount of rainfall coupled with an increase in total rainfall within a shorter time span. Additionally, the distribution is identified as leptokurtic and positively skewed. This analysis aims to provide a scientific understanding of these phenomena and their implications for the regional climate.

3.2.1. Statistical Analysis of Monthly Rainfall Distribution: Leptokurtic and Positively Skewed Trends

Monthly Rainfall Distribution: The probability density function (PDF) serves as a valuable tool for understanding the distribution of monthly rainfall. By plotting the PDF against total rainfall for each month, researchers can discern the probability of different rainfall amounts occurring. In this context, a leptokurtic distribution indicates a higher likelihood of extreme values, while positive skewness suggests an asymmetry with a longer tail on the right side, favoring higher rainfall values.

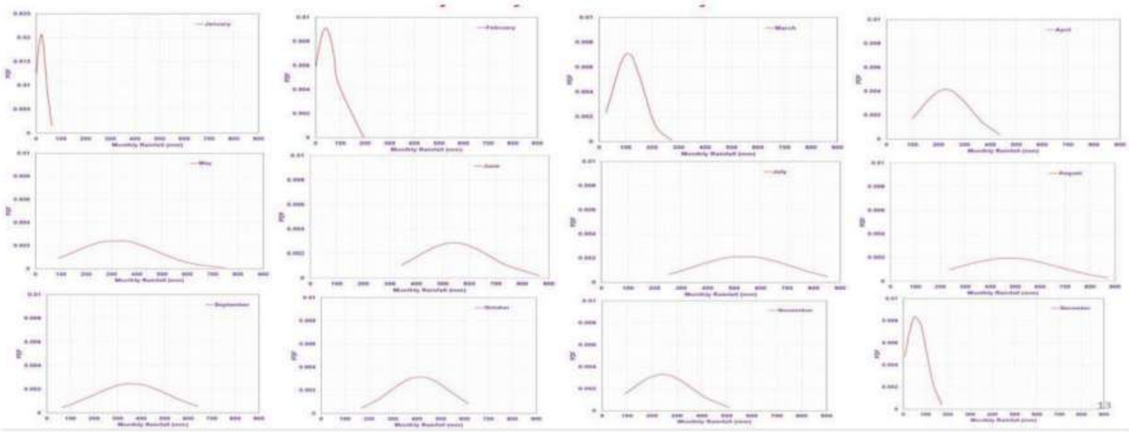


Figure 3.1: Probability density function (PDF) plotted against total rainfall

Decreased Amount of Rainfall: The observation of decreased rainfall suggests a shift in the overall magnitude of monthly precipitation. This reduction could be attributed to various factors, including changes in atmospheric circulation patterns, alterations in regional climate systems, or broader global climate change influences. Scientific investigations into these factors are essential for a comprehensive understanding of the observed decrease in monthly rainfall.

Total Rainfall Increase in a Shorter Span of Time: The notable increase in total rainfall within a shorter time span indicates a shift in the temporal distribution of precipitation. This phenomenon may be linked to altered weather patterns, increased variability, or climate change impacts. Understanding the drivers behind this temporal concentration of rainfall is crucial for assessing the resilience of ecosystems, the sustainability of water resources, and potential implications for local communities.

Leptokurtic Distribution: A leptokurtic distribution, as identified in the monthly rainfall data, implies a more peaked and heavier-tailed distribution compared to a normal distribution. In the context of rainfall, this suggests an increased probability of extreme events, both in terms of heavy rainfall and prolonged dry periods. The heightened kurtosis indicates a greater concentration of values around the mean, with more frequent occurrences of extreme deviations, emphasizing the importance of resilience in water management and infrastructure planning.

Positive Skewness: The positively skewed distribution indicates an asymmetry in the monthly rainfall data, with a longer tail on the right side. In this context, the rightward skewness suggests a higher likelihood of experiencing above-average rainfall amounts. This skewness may be associated with climate variability, changes in atmospheric circulation, or broader climatic influences affecting the region. Understanding the drivers of positive skewness is crucial for adapting to potential shifts in precipitation patterns and mitigating associated risks.

The observed decrease in the amount of rainfall combined with an increase in total rainfall within a shorter time frame poses challenges for water resource management, agriculture, and infrastructure planning. The shift in precipitation patterns may impact the availability of water resources, potentially leading to water scarcity or flooding events. Moreover, the increased frequency of extreme events, as indicated by the leptokurtic distribution, emphasizes the need for adaptive strategies to address the heightened variability in monthly rainfall.

Climate Change and Anthropogenic Influences: To comprehensively understand the observed changes in monthly rainfall, it is essential to consider broader climate change and anthropogenic influences. Climate change may alter atmospheric circulation patterns, intensify extreme weather events, and contribute to shifts in regional precipitation. Anthropogenic factors, such as land use changes and greenhouse gas emissions, can further amplify these trends. Robust scientific investigations into these factors are crucial for developing informed strategies to mitigate and adapt to changing rainfall patterns.

3.2.2. Monsoon rainfall analysis

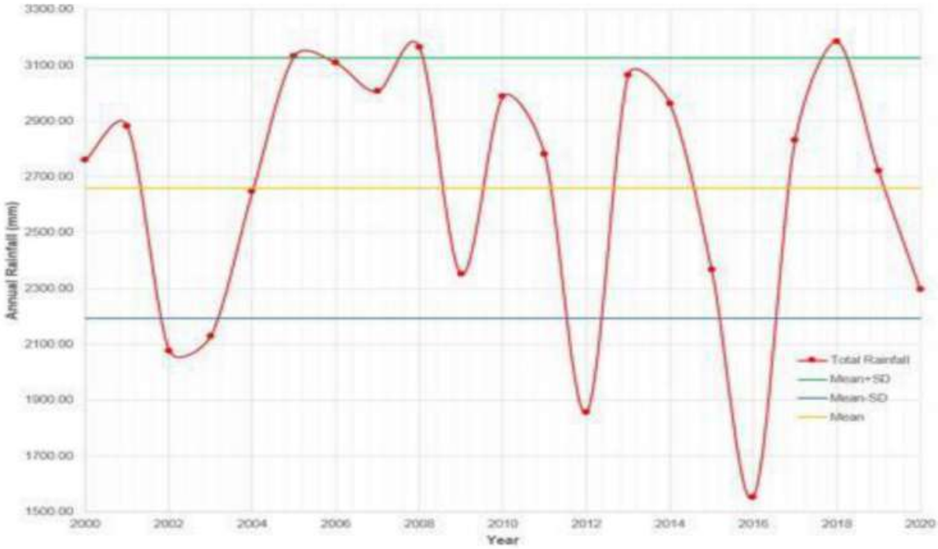


Figure 3.2:Monsoon Rainfall Analysis

The monsoon is a critical climatic phenomenon influencing precipitation patterns in various regions, and the Pamba Basin, located in the southwestern part of India, is no exception. This analysis delves into the scientific exploration of monsoon rainfall data from 2000 to 2020, focusing on the Pamba Basin. The key observations include an annual average of 2690 mm, significant variability ranging between 2100 and 3000 mm, and notable deviations from the mean, indicating a dynamic and potentially changing monsoon pattern.

Average Monsoon Rainfall: The average annual monsoon rainfall in the Pamba Basin over the studied period (2000-2020) stands at 2690 mm. This value provides a baseline for understanding the typical precipitation received in the region during the monsoon season.

Precise measurement and analysis of this average are crucial for establishing benchmarks and identifying deviations that may signal shifts in climatic conditions.

Variability in Rainfall: The observed variability in monsoon rainfall within the Pamba Basin is substantial, ranging between 2100 and 3000 mm. This wide range underscores the region's susceptibility to fluctuations in precipitation levels. Such variability can be influenced by numerous factors, including atmospheric conditions, oceanic patterns, and local geographical features. Understanding the sources of this variability is vital for predicting and adapting to changing rainfall patterns.

Deviation from the Mean: Some years exhibit total monsoon rainfall that surpasses the mean plus one standard deviation. This departure from the mean signal's periods of exceptional rainfall intensity. Scientifically, assessing such deviations requires a thorough understanding of the statistical distribution of rainfall data. Deviations beyond one standard deviation may indicate anomalies warranting investigation into the factors contributing to these extreme events.

Trends in Monsoon Rainfall: Analysis reveals alternating trends in monsoon rainfall in the Pamba Basin. While some years witness an increasing trend, others show a decreasing pattern. Understanding the cyclical nature of these trends is essential for predicting future climatic conditions and their potential impacts on ecosystems, agriculture, and water resources.

Factors Influencing Monsoon Variability: Several factors contribute to the observed variability in monsoon rainfall within the Pamba Basin. One primary driver is the Indian Ocean Dipole (IOD), a climate phenomenon characterized by temperature anomalies in the Indian Ocean. Positive IOD phases can enhance monsoon rainfall, while negative phases may lead to drier conditions. El Niño and La Niña events in the Pacific Ocean also play a role, influencing atmospheric circulation patterns and impacting monsoon dynamics in the region.

Implications for Water Resources and Agriculture: The substantial variability in monsoon rainfall poses implications for water resources and agricultural practices in the Pamba Basin. Years with below-average rainfall may lead to water scarcity, affecting both domestic water supply and agricultural irrigation. Conversely, above-average rainfall years may increase the risk of flooding, soil erosion, and landslides. Understanding these implications is crucial for developing adaptive strategies and sustainable water management practices.

Climate Change Considerations: The observed patterns of alternating trends and increased variability in monsoon rainfall in the Pamba Basin raise questions about the potential influence of climate change. Scientific investigations into long-term climate data, coupled with climate models, can help discern whether these observed patterns align with projected climate change scenarios. Rising global temperatures and changing atmospheric conditions can impact regional monsoon patterns, emphasizing the importance of ongoing research in this field.

3.2.3. Regional Maximum Rainfall

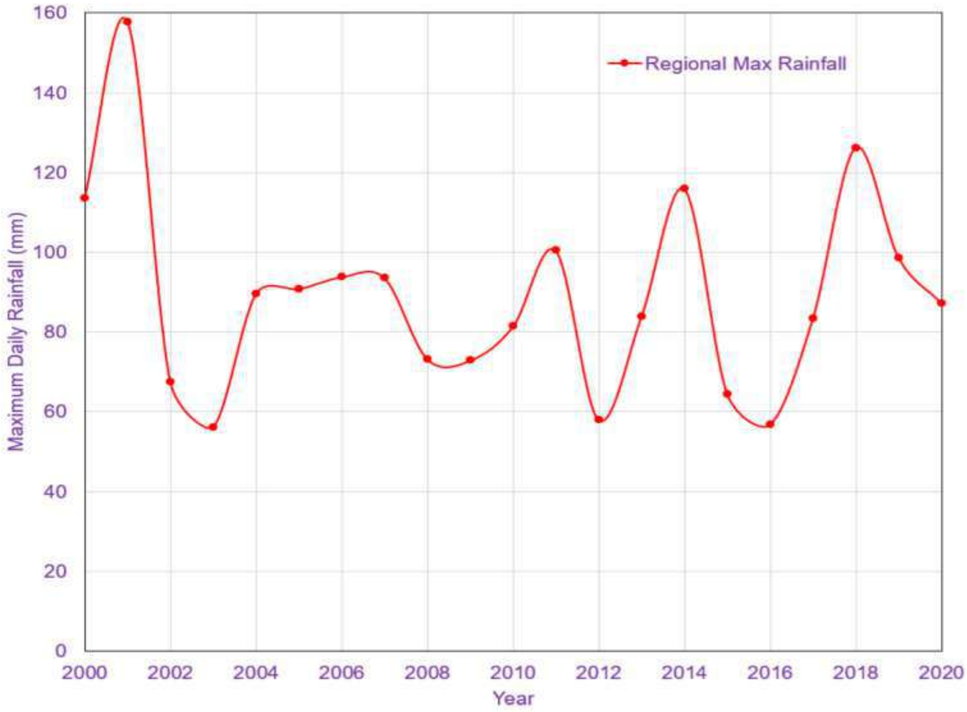


Figure 3.3: Regional Maximum Rainfall

The study of maximum daily rainfall is crucial for understanding the intensity and variability of precipitation events in a given region. This analysis focuses on the Pamba Basin, exploring the temporal trends in maximum daily rainfall from 2000 to 2020. The observed data reveals a dynamic pattern, with the maximum daily rainfall decreasing from 116 mm in 2000 to 50 mm in 2003, followed by annual fluctuations ranging between 60 mm and 100 mm. This study aims to provide a scientific perspective on the observed trends, emphasizing their implications for local hydrology and potential links to larger climate patterns.

Temporal Trends in Maximum Daily Rainfall: The temporal trends in maximum daily rainfall in the Pamba Basin from 2000 to 2020 showcase a distinctive pattern. In 2000, the recorded maximum daily rainfall was 116 mm, a value that gradually decreased to 50 mm in 2003. However, subsequent years exhibited a cyclic pattern characterized by fluctuations in the range of 60 mm to 100 mm. This dynamic behavior warrants a closer scientific examination to identify potential drivers and implications.

Factors Influencing Maximum Daily Rainfall: Several factors contribute to the observed variations in maximum daily rainfall. Local topography, atmospheric conditions, and broader climatic phenomena all play integral roles. The Western Ghats, which surround the Pamba

Basin, can influence precipitation patterns through orographic lifting, contributing to the variability in maximum daily rainfall. Additionally, large-scale climate phenomena such as the Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO) can impact atmospheric circulation and moisture availability, influencing the intensity of rainfall events.

Hydrological Implications: Understanding the temporal trends in maximum daily rainfall is crucial for assessing hydrological implications in the Pamba Basin. High-intensity rainfall events can lead to flash floods, soil erosion, and increased runoff. The observed cyclic pattern of fluctuations in maximum daily rainfall suggests a dynamic hydrological response to changing atmospheric conditions. This variability can impact local water resources, soil stability, and overall watershed health.

Climate Change Considerations: The observed changes in maximum daily rainfall patterns may also raise questions about potential links to climate change. While a comprehensive attribution analysis requires sophisticated modeling and long-term data, alterations in extreme rainfall events are consistent with expectations in a warming climate. Warmer air holds more moisture, potentially leading to more intense rainfall events. Scientific investigations into the connections between local trends and broader climate change scenarios are necessary for a comprehensive understanding.

Statistical Analysis: To rigorously assess the observed trends, a statistical analysis is crucial. Time-series analysis, including trend detection methods and statistical significance tests, can provide insights into the robustness of the observed cyclic pattern. Analyzing the variability and identifying periodicities within the data can further enhance our understanding of the cyclical nature of maximum daily rainfall trends in the Pamba Basin.

Cyclic Patterns: The recurring cyclic pattern in maximum daily rainfall observed in the Pamba Basin suggests the presence of systematic variations over time. The cyclic nature may be indicative of natural climate variability, regional climatic oscillations, or other cyclical influences. Time-domain and frequency-domain analyses can be employed to characterize the periodicities and identify potential drivers behind this cyclic behavior.

Impact on Ecosystems and Agriculture: The variability in maximum daily rainfall has direct implications for local ecosystems and agriculture. Ecosystems adapted to specific precipitation regimes may face challenges in coping with more intense rainfall events, leading to potential disruptions in biodiversity and ecosystem services. Agriculture, dependent on predictable rainfall patterns, may experience challenges in planning and water resource management.

Adaptive Strategies: The observed cyclic pattern of maximum daily rainfall highlights the need for adaptive strategies in the Pamba Basin. Infrastructure planning, flood preparedness, and sustainable water management practices should consider the dynamic nature of rainfall patterns. Adaptive measures could include the development of early warning systems, resilient infrastructure, and community engagement to enhance preparedness for extreme rainfall events.

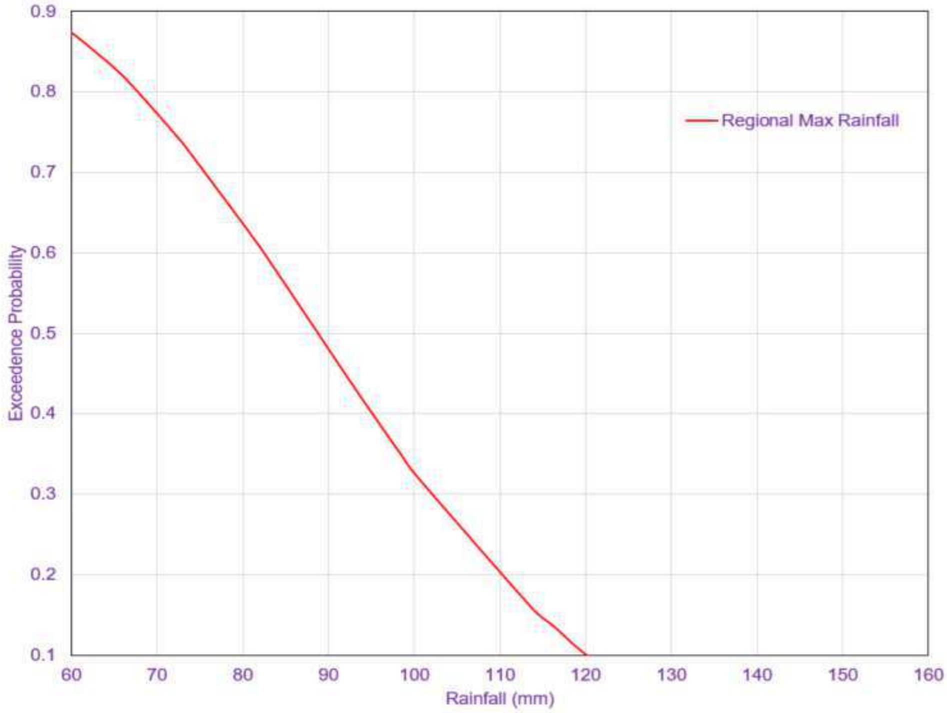


Figure 3.4: Exceedance Probability

The study of regional maximum rainfall and its relationship with exceedance probability is a fundamental aspect of hydrology and climatology. By analyzing the probability distribution of extreme rainfall events, scientists can make informed assessments about the likelihood of specific rainfall magnitudes occurring. In this context, the regional maxima, representing the highest observed rainfall values, are plotted against the exceedance probability. This analysis is instrumental in understanding the frequency and intensity of extreme rainfall events within a specific region. The given data presents regional maxima of 60 mm with an exceedance probability of 0.88 and 120 mm with a probability of 0.1.

Exceedance Probability Concept: Exceedance probability is a statistical measure that quantifies the likelihood of a particular event surpassing a given threshold. In the context of regional maximum rainfall, it provides information about the probability of observing rainfall values equal to or exceeding a certain magnitude. The probability values, ranging from 0 to 1, indicate the relative rarity of the events, with higher probabilities corresponding to less extreme events and lower probabilities indicating more extreme conditions.

Regional Maxima and Probability Distribution: The regional maxima represent the highest observed rainfall values within a specified region and time period. These values are crucial for understanding extreme precipitation events and assessing their impact on local hydrology, infrastructure, and ecosystems. The relationship between regional maxima and exceedance probability is often analyzed through probability distribution functions, providing a comprehensive view of the frequency and intensity of extreme rainfall events in a given area.

Graphical Representation: The graphical representation of regional maxima against exceedance probability is typically done using probability plots or probability density functions (PDFs). In these plots, the x-axis represents the exceedance probability, ranging from 0 to 1, while the y- axis represents the corresponding regional maxima. These plots allow for the visualization of the probability distribution of extreme rainfall events, aiding in the identification of patterns and trends.

Given Data Analysis: In the provided data, the regional maxima of 60 mm is associated with an exceedance probability of 0.88, indicating that this level of rainfall is relatively common, occurring with a high probability. Conversely, the regional maxima of 120 mm is linked to a probability of 0.1, suggesting that this level of rainfall is much less common, representing a more extreme event. These values serve as reference points for assessing the rarity and frequency of extreme rainfall in the region under consideration.

Interpretation and Implications: The data implies that rainfall events of 60 mm have a high likelihood of occurrence, with an exceedance probability of 0.88. This could correspond to more frequent, yet substantial, rainfall events that may be important for local water resources and ecosystems but may not necessarily be classified as extreme. On the other hand, the regional maxima of 120 mm, associated with a probability of 0.1, indicates a lower likelihood of occurrence, suggesting that such intense rainfall events are rarer but can have significant consequences when they do occur.

Modeling Extreme Rainfall Events: To gain a deeper understanding of the regional maxima and exceedance probability relationship, scientists often employ statistical models such as the Generalized Extreme Value (GEV) distribution. This distribution is particularly suitable for modeling extreme events and allows for the estimation of parameters that describe the shape, location, and scale of the probability distribution.

Regional Climate and Topography Influence: The probability distribution of extreme rainfall events is influenced by regional climate characteristics, topography, and local atmospheric conditions. Coastal areas, mountainous regions, and locations prone to specific weather patterns may exhibit distinct probability distributions for extreme rainfall. Understanding these regional nuances is crucial for accurate modeling and prediction.

Climate Change Considerations: In the context of climate change, shifts in regional climate patterns may alter the probability distribution of extreme rainfall events. Changes in atmospheric moisture content, temperature, and circulation patterns can influence the frequency and intensity of extreme precipitation. Scientific research in this area is essential for assessing the potential impacts of climate change on regional hydrology and the likelihood of more intense rainfall events.

Risk and Resilience Planning: The analysis of regional maxima against exceedance probability provides valuable information for risk and resilience planning. Infrastructure design, flood management strategies, and emergency preparedness can benefit from a thorough understanding of the probability distribution of extreme rainfall events. Decision-makers can use this information to develop adaptive measures that account for the likelihood of various rainfall magnitudes.

3.3. A General Appraisal of the Runoff Pattern in the Greater Pamba Basin

The floods in the Pamba region, particularly during the 2018 and 2019 events, were significantly influenced by high-intensity, low-duration rainfall. These rainfall events caused rapid accumulation of water in a short period, overwhelming the drainage capacity of the region's rivers and streams, leading to flash floods and widespread inundation. The 2018 floods were a combination of intense rainfall, particularly during the monsoon season. Some areas of the Pamba basin received more than 200 mm of rainfall within a few hours, leading to a rapid rise in river levels. The flash floods resulted in significant damage to infrastructure, agriculture, and homes, particularly in the lowland and midland areas like Kuttanad. The lack of adequate drainage capacity and the saturation of the soil from previous rains exacerbated the flood severity. In 2019, another series of high-intensity, short-duration rainfall events affected the Pamba region, although the scale of flooding was not as severe as 2018. The region experienced localized but intense rainfall that overwhelmed urban drainage systems and led to flooding in several low-lying areas, particularly in Kuttanad. Heavy rainfall lasting a few hours during this period caused rapid runoff, and due to the topography and the characteristics of the river system, the floodwaters quickly spread, causing damage to crops, homes, and infrastructure.

Five major gauging stations have been identified on the streams of Greater Pamba Basin, where continuous high-quality observations are available over the recent period (2010 – 2020). The Manimala gauging station records streamflow for the Manimala River, Kurdamannil and Earrapuzha stations record the flow in the Pamba river and the Kalleli and Pandalam stations monitor flow in the Achankovil river. The flow measured are shown in Figure 3.5. The Manimala stream is seen to dry in the summer months. Extreme flow events have been recorded in the years of 2018 and 2019.

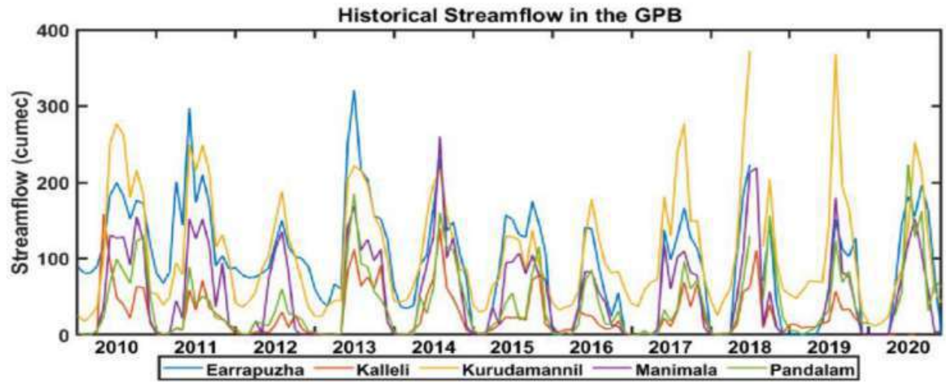


Figure 3.5:Historical flow in WRD stations in Greater Pamba Basin

The GPB typically experiences its most severe flooding during the monsoon season, particularly in August and September, when heavy and sustained rainfall causes the rivers to overflow their banks. These floods can severely disrupt disaster relief and management efforts, leading to significant damage to homes, infrastructure, and agricultural lands. Kerala, in recent years, has faced catastrophic flooding events, with the 2018 flood being one of the worst in the state's history, highlighting the region's vulnerability to such extreme events. The extreme events in the catchment was studied using the Standardized Runoff Index (SRI), which compares monthly runoff with historical runoff to identify events that significantly vary from the historical normal (Figure 3.6). SRI values over 2 indicate extreme water excess events, while values below -2 indicate significant water scarcity events. Both extreme wet and dry events are observed in the data indicating the vulnerability of the catchment to climate extremes, which can get exacerbated in the future with climate change.

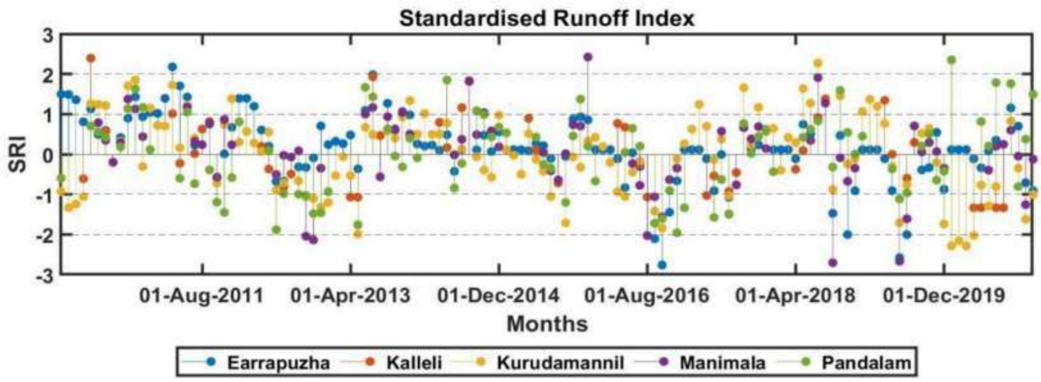


Figure 3.6:Extreme events in GPB analysed using SRI for the WRD gauges

3.4. Hydrological Modelling of the Greater Pamba Basin

Hydrological models are employed to assess the water balance of a basin, as they provide a structured framework for simulating the complex interactions between various hydrological processes. These models integrate data on precipitation, temperature, land use, soil characteristics, and topography to predict water fluxes and storage changes across spatial and temporal scales. By simulating scenarios of land use change, climate variability, and water management interventions, hydrological models support evidence-based decision-making for sustainable basin management. These models can be broadly classified into conceptual, empirical, and physically-based models, with varying degrees of complexity and data requirements. The Soil & Water Assessment Tool (SWAT) is a physically-based, distributed hydrological model widely used for water balance assessment in basins of varying sizes and complexities. SWAT is a process-based hydrological model operating on a daily time steps. It is designed to evaluate the impacts of land use, management practices, and environmental changes on key outputs such as water, sediment, and agricultural chemical yields within watersheds. Key model components include meteorological factors (precipitation, temperature, wind speed), hydrology (surface runoff, infiltration, groundwater flow), soil temperature and properties, plant growth dynamics, and the transformation and transport of nutrients, pesticides etc. Additionally, the model incorporates land management processes to assess their influence on hydrological and ecological outcomes.

3.5. The SWAT hydrological model

SWAT is a comprehensive model developed for simulating surface and groundwater quality and quantity at scales ranging from small watersheds to entire river basins. It is extensively utilized to evaluate the environmental impacts of land use, land management practices, and climate change. A defining feature of SWAT is its hierarchical representation of watersheds. The watershed is divided into sub watersheds, each of which is further subdivided into Hydrological Response Units (HRUs). HRUs are non-spatially contiguous units characterized by unique combinations of land use, soil type, management practices, and topographical features. This modular structure allows for a detailed and flexible representation of spatial heterogeneity. This approach ensures that SWAT can simulate complex interactions between environmental and anthropogenic factors SWAT models watershed hydrology with a focus on the water balance, which serves as the foundation for all simulated processes. The water balance directly influences plant growth and the movement of water, sediments, nutrients, pesticides, and pathogens throughout the watershed. SWAT divides watershed hydrology into two primary phases: the land phase and the in-stream (or routing) phase. The land phase manages the input and transport of water, sediments, nutrients, and pesticides from the land surface to the main channels of each subbasin. In contrast, the in-stream phase tracks the flow and transport of these elements through the channel network to the watershed outlet.

The hydrologic cycle in SWAT is driven by climate inputs that provide moisture and energy, such as daily precipitation, maximum and minimum temperatures, solar radiation, wind speed, and relative humidity. These inputs govern the water balance within the watershed, which is a key determinant of hydrological behaviour. SWAT can either use observed meteorological data directly or simulate it using statistical patterns derived from monthly observations. This flexibility ensures the model's adaptability to varying data availability.

Key hydrological processes simulated by SWAT include:

- Canopy Storage: The interception and storage of precipitation by plant canopies.
- Surface Runoff and Infiltration: The partitioning of precipitation into overland flow and water infiltrating into the soil.
- Evapotranspiration (ET): Water loss to the atmosphere through evaporation and plant transpiration.
- Lateral Flow and Tile Drainage: The horizontal movement of water within soil layers and through artificial drainage systems.
- Redistribution in the Soil Profile: Movement of water within the soil layers, affecting storage and availability.
- Groundwater Recharge and Return Flow: Contributions to shallow and deep aquifers and the subsequent release of water back to surface systems.
- Pumping and Consumptive Use: Human extraction of water for various purposes.

Additionally, SWAT incorporates snow and soil temperature dynamics, which are critical for cold-region hydrology. The model calculates snow accumulation and melt when temperatures fall below freezing and includes soil temperature effects on water movement and organic decay rates. A single plant growth model is utilized to simulate water and nutrient uptake, biomass production, and transpiration for all types of land cover. This comprehensive hydrological framework enables SWAT to predict complex interactions between climate, land use, and management practices across diverse watershed conditions.

The SWAT integrates a plant growth model to simulate the removal of water and nutrients from the soil's root zone, transpiration processes, and the production of biomass and crop yield. This functionality ensures that SWAT can model the interplay between vegetation and the hydrological cycle, which is critical for understanding nutrient dynamics and water balance in agricultural and natural systems. Sediment transport is predicted using the Modified Universal Soil Loss Equation (MUSLE), which calculates sediment yield as a function of surface runoff and land cover conditions.

The model also simulates the movement and transformation of key water quality constituents, including nitrogen, phosphorus, pesticides, and sediment, within the watershed. These processes are critical for evaluating nonpoint source pollution and its impact on water quality at multiple spatial scales. SWAT allows users to define specific management practices for each HRU, enabling the evaluation of various conservation strategies, such as nutrient management, buffer strips, or crop rotations.

In the routing phase, the model captures the movement of water, sediment, nutrients, and pesticides from the land phase into the main channel network, where they are transported through streams and reservoirs. For reservoirs, SWAT incorporates a detailed water balance that accounts for inflow, outflow, direct rainfall on the water surface, evaporation, seepage losses from the reservoir bottom, and diversions. This comprehensive treatment of reservoir dynamics ensures realistic simulations of water storage and release. The equations governing these processes are detailed in the SWAT theoretical documentation and hence are not expanded in this document. To summarise, SWAT is useful for assessing the water balance due to its comprehensive process-based structure. Further, by running simulations under different scenarios (climate change, land use alterations, or water management policies), SWAT can provide insights into how these factors influence the water balance and overall basin hydrology. This makes it a valuable tool for policymakers aiming to ensure sustainable water use, mitigate the impacts of hydrological extremes, and improve water allocation strategies within a basin. Given its ability to capture the intricate interactions between climate, land use, soil characteristics, and hydrological processes, SWAT is employed in this study to assess the water balance of the GPB. By leveraging high-resolution spatial and temporal datasets, SWAT facilitates a detailed understanding of the basin's hydrology, enabling informed decision-making for sustainable water management and conservation practices in the region.

3.6. Data used

For the development of the SWAT model for the GPB, high-resolution datasets were utilised to capture the spatial and temporal variability of the region. SWAT model requires spatial datasets for defining the catchment characteristics and weather variables for simulating the water balance components in the catchment. These datasets include information on topography, land use/land cover, soil characteristics, and climate parameters, ensuring that the model accurately represents the hydrological processes in the basin. Below are the details of the datasets used in this study:

3.6.1. Digital Elevation Model (DEM):

Data used: 30m SRTM DEM, 30m CartoDEM, 30m FabDEM (Forest and Buildings removed Copernicus DEM)

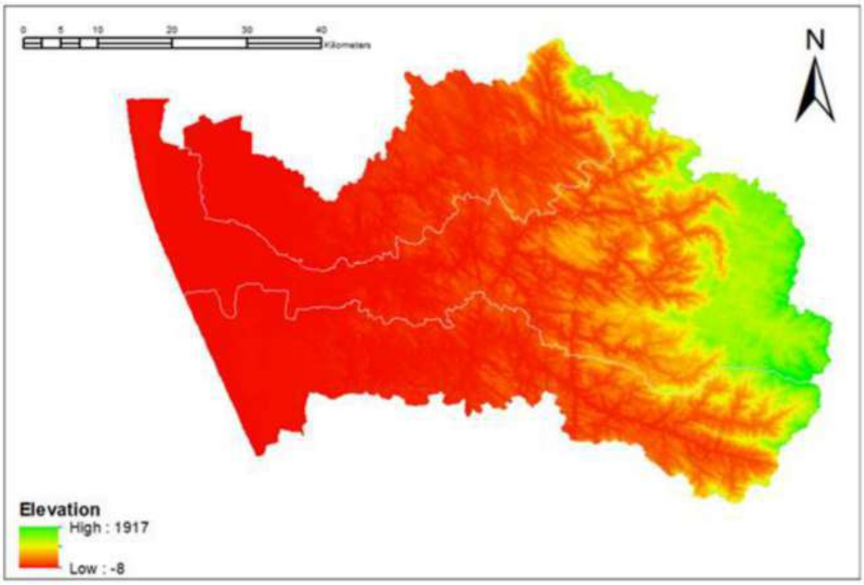


Figure 3.7:DEM of the study area (Source: Copernicus FabDEM)

The Digital Elevation Model (DEM) of the Pamba River Basin shows topographical variation, with elevation ranging from -8 meters in the lowlands towards the coast to 1,917 meters in the highlands (Figure 3.7). The western lowland area, falling in the Allappuzha district, are predominantly flat and lie near sea level, making them suitable for agriculture, urbanization. The DEM data is used by the model in delineating the streams and the basin boundary. The stream network is identified by first measuring the flow direction vectors and calculating the flow accumulations. Thus, accuracy of the dataset is important in developing the basin boundaries and the stream network.

The midlands, serve as a transitional zone with rolling terrain and moderate slopes, supporting mixed plantations and built-up areas. The eastern highlands are characterised by steep slopes and mountainous terrain, dominated by forests.

3.6.2. Land Use Land Cover (LULC) map:

Data used: The NRSC Hybrid Land Use Land Cover (2014–2015) dataset

The NRSC Hybrid Land Use Land Cover (2014–2015) dataset, created by merging with the Global Irrigated Area Map (GIAM), was used to represent land use patterns at a 30m spatial resolution. This combination ensures accurate representation of agricultural and rest of land cover dynamics in the basin.

The Pamba River Basin, located in Kerala, India, encompasses a diverse range of land use and land cover types. The land use map of the Pamba River Basin demonstrates a wide variety of land use and land cover categories across the region (Figure 3.8). It highlights the spatial distribution of agricultural practices, vegetation types, water bodies, and built-up areas.

Agricultural areas are distinctly categorised, showcasing lands utilised for different crop patterns. Natural vegetation is represented by regions of scrubland/ degraded forests, and forests, including both evergreen and deciduous forests, along with plantation/orchard areas. Water bodies refer to rivers, lakes, and reservoirs.

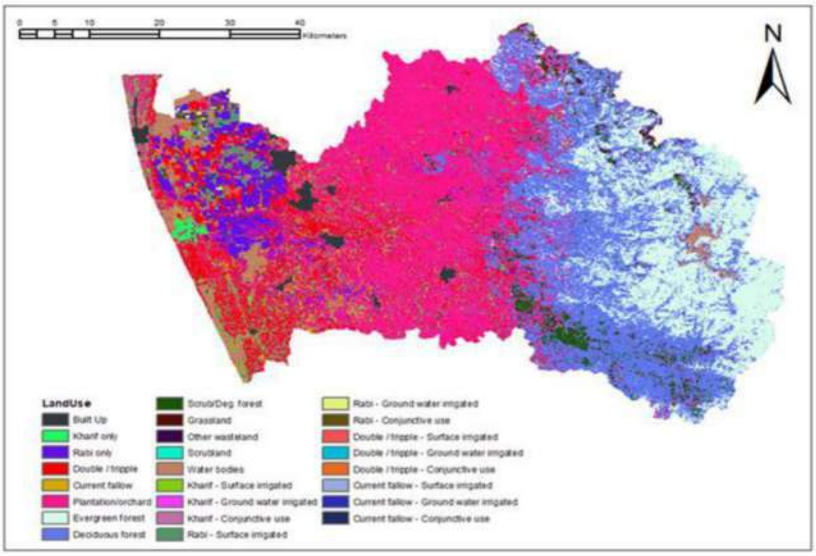


Figure 3.8: Land use map of the study area

(Source: NRSC Hybrid Land Use Land Cover (2014–2015))

3.6.3. Soil map:

Data used: The FAO Soil Map (HWSD)

The FAO Soil Map (HWSD) at 30m resolution was used to provide information on soil properties, including texture, permeability, which are critical for simulating runoff and other components of water balance.

The model uses the soil map in defining the runoff potential in each region. The properties for each soil group are added to the SWAT database, so that the model can accurately represent the physical characteristics of the soil in the region. The soil map of the Pamba Basin classifies the region into distinct hydrologic soil groups based on infiltration capacity and runoff potential (Figure 3.9). The basin is predominated by Group C soils characterised by slow infiltration rates and high runoff potential. They are clay loam soils which leads to slower percolation and increased surface runoff. Group D soils have very slow infiltration rates and the highest runoff potential. These are heavy clay soils or soils with an impermeable layer near the surface, with low permeability. The highland regions in the eastern part of the basin are predominantly covered by Group D soils reflecting the steep terrain and slower infiltration rates due to denser soils and natural vegetation. The midland regions show Group C soils, indicating moderate infiltration and runoff potential while the lowland regions near the western part exhibit Group C soils. Group B soil is present only in a small region south of the Vembanad Lake. Group B soils are typically characterized by relatively higher infiltration rates and lower runoff potential compared to Groups C and D. These soils are often sandy loam or silty loam in texture, which allows for more efficient percolation and groundwater recharge while reducing the volume of surface runoff. In areas where Group B soils are present, water is more likely to infiltrate into the soil profile, supporting both plant growth and sustainable water availability.

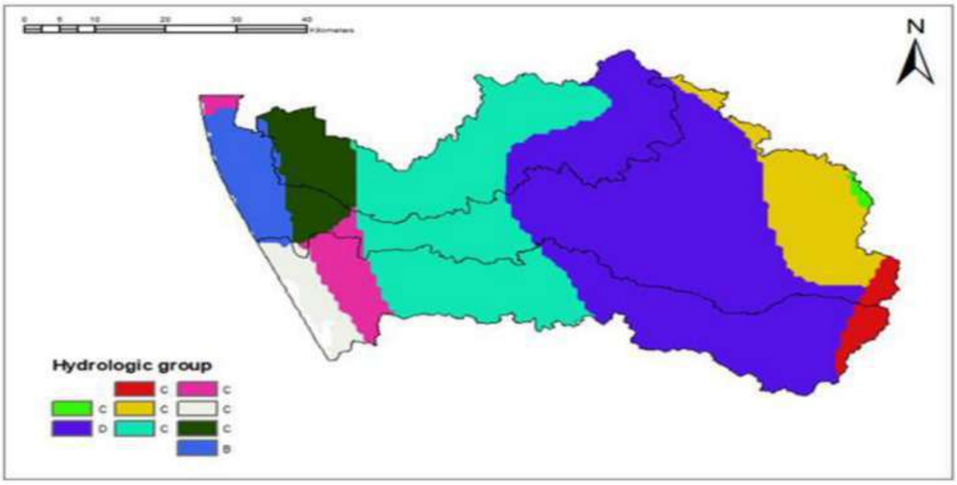


Figure 3.9: Soil map of the study area

(Source: The FAO Soil Map (HWSD))

3.6.4. Weather data:

Data used: IMD Gridded Rainfall data (0.25° x 0.25°) and IMD Gridded Temperature data (1° x 1°)

The IMD Gridded Rainfall data (0.25° resolution) is a high-resolution precipitation data crucial for modelling hydrological processes. The dataset contains daily scale rainfall intensities on a grid level across India from 1901 – 2023. The IMD Gridded Temperature data (1° resolution): captures the temperature variability across the basin, which influences ET rates and other climate-driven processes. The dataset includes daily maximum temperatures and daily minimum temperatures for the period 1951 - 2023. The SWAT model requires solar radiation, wind speed, and relative humidity as additional weather inputs; however, historical data for these variables are not readily available for Kerala. Consequently, these parameters were not directly provided to the model. The model has a built-in weather generator that generates these variables from the input precipitation and temperature data.

3.6.5. Methodology

Hydrologic modelling using SWAT requires data related to topography, land use, soil, and weather data as input in order to assess the water balance of the basin. The current study used 30 m x 30 m resolution DEM data derived from FabDEM for delineating the watershed as well for defining the stream network, area and slope of the sub basins. However, before finalising the DEM, we did a comparative evaluation of the DEM (30m SRTM DEM, 30m CartoDEM, 30m FabDEM) and the procedure adopted is detailed as follows (Figure 3.10). Accurate delineation of river networks is crucial in watershed analysis as it directly impacts the precision of sub-basin delineation, watershed boundary mapping, and the identification of drainage hierarchies. These elements are fundamental for effective water resource management, flood modelling, sediment transport studies, and ecological assessments. In this study, three DEMs - Cartosat DEM, SRTM DEM, and FABDEM - were analysed and verified to assess their performance in capturing natural stream networks and their application in watershed delineation and related hydrological analyses. These DEMs were systematically evaluated to determine their accuracy and effectiveness in representing key geomorphological features critical for hydrological modelling and watershed management. The following figures present the stream network delineated towards the downstream of the Pamba basin, the region where there was a difference in the delineations generated by the 3 DEMs.

The FabDEM exhibited superior performance in capturing the intricacies of natural stream networks and was particularly adept at delineating watershed boundaries, sub-basins, and other hydrological features with higher fidelity compared to the Cartosat and SRTM DEMs. The evaluation was particularly significant for the Pamba River Basin, which is characterized by a complex and highly interconnected river network in its deltaic region. While the Cartosat and SRTM DEMs failed to fully capture these complexities, FabDEM demonstrated a remarkable ability to represent the intricate hydrological patterns of the region.

By comparing the stream network delineated from each DEM against the actual natural river network, it was confirmed that FabDEM's resolution and processing methodology provided a more detailed and reliable representation, enabling enhanced hydrological modelling and better decision-making processes for sustainable watershed management. This analysis underscores the critical role of high-resolution and accurate DEMs in capturing hydrological features, particularly in regions with complex geomorphologies, thereby supporting robust and precise hydrological and environmental assessments.

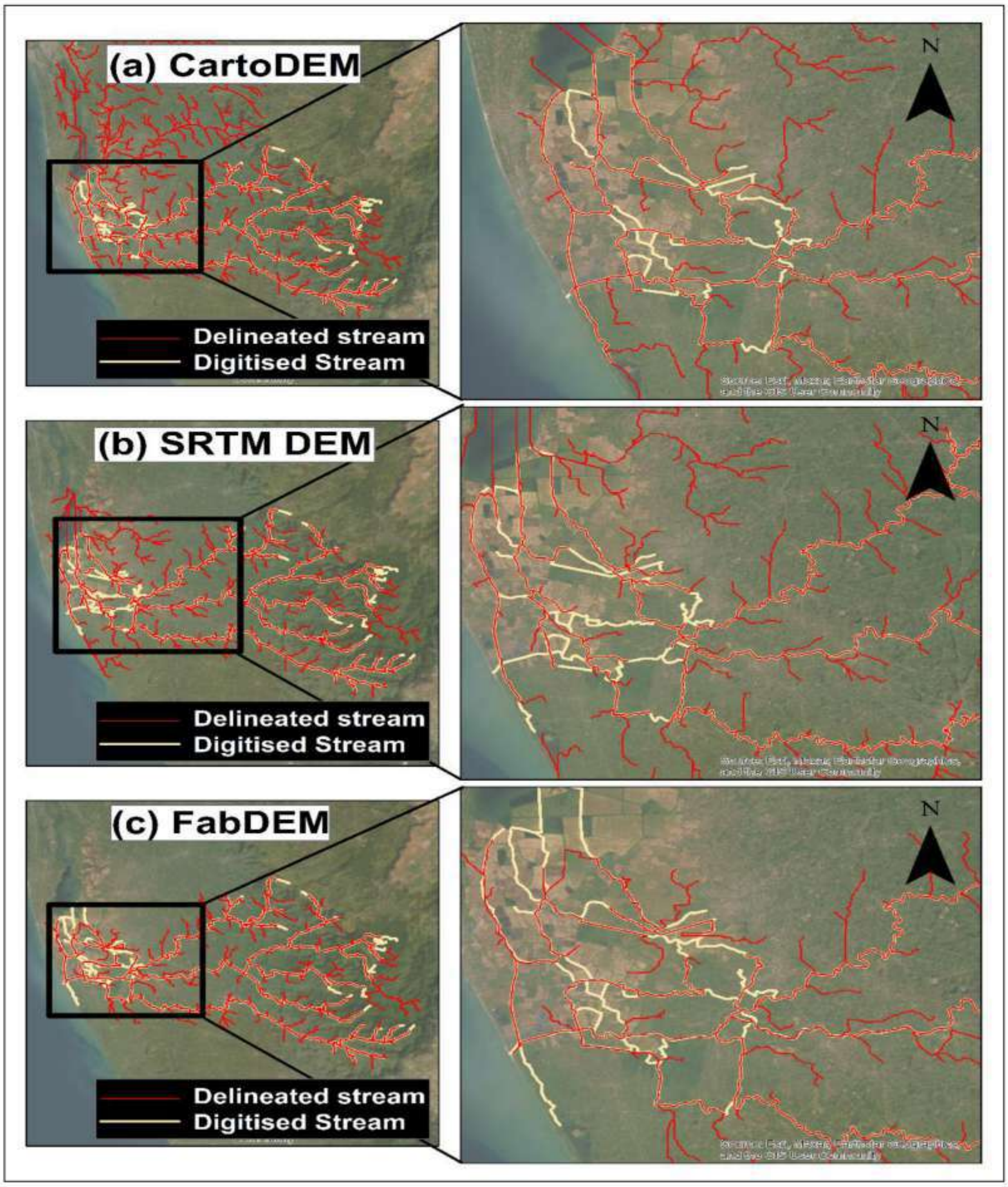


Figure 3.10: Streams delineated for the GPB using different DEM data

Upon finalising the DEM, the input datasets comprising of DEM, land use and soil map were coregistered to the projection of WGS-84, UTM zone 43 N for the SWAT setup. Apart from DEM, land use and soil data, SWAT requires daily precipitation, minimum and maximum air temperature, solar radiation, wind speed, and relative humidity as input data for hydrologic simulation. The study applied ArcSWAT 2012.10.26 an ArcGIS interface for SWAT for modelling the hydrological water balance of GPB. The Pamba basin model was delineated with a threshold of 5 km2 generating 386 subbasins and 2686 HRUs.

After setting up the basin in the SWAT model, the historical climate data is added as weather input into the model. Historical daily rainfall, daily maximum temperature and daily minimum temperature data from IMD were added to the model. The model run with raw climate data indicate significant underestimation of flow in the eastern subbasins in the GPB. The IMD gridded data input to the model was analysed to identify the source of the uncertainty. The rainfall climatology of subbasins on the windward side of the Western Ghat mountain ranges shows characteristics similar to the rain gauge stations on the leeward side of the Western Ghat mountain ranges, with peak rainfall during the North-East monsoon months (Figure 3.11). To alleviate this issue, the IMD rainfall grids on the Western Ghat mountain ranges were removed, and the grids just west of the removed grids were reassigned to the eastern subbasins. The effect of reassignment was analysed for flow at the Manimala gauge, and the NSE was seen to increase from 0.57 to 0.67.

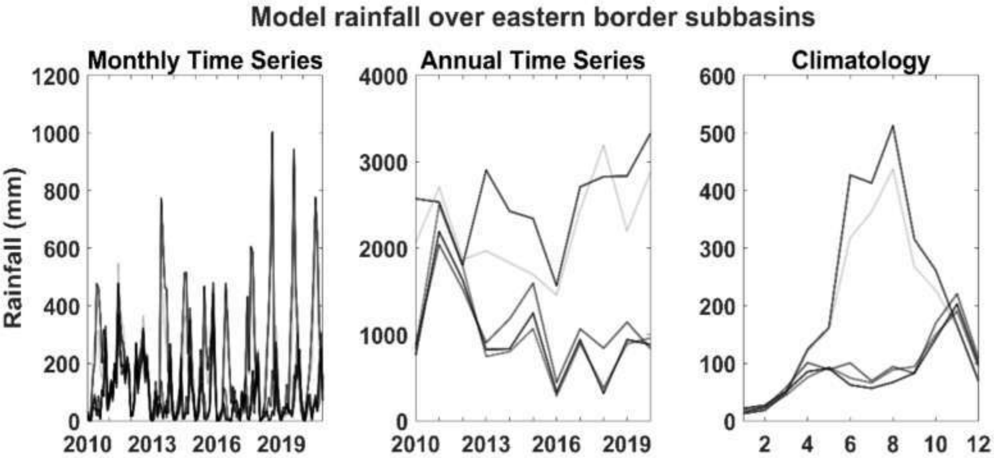


Figure 3.11: IMD Gridded Rainfall over the eastern subbasins in the model

Once the model is developed, the calibration and validation process in the SWAT is a crucial step to ensure that the model accurately represents real-world hydrological and environmental systems. SWAT operates with process-based input parameters that must remain within realistic uncertainty ranges to maintain physical plausibility. Calibration involves adjusting these parameters to optimize the model's agreement with observed data, while validation verifies that the calibrated model performs well under independent data conditions.

The first step in calibration is determining the most sensitive parameters for a given watershed or sub watershed. Sensitivity analysis identifies the rate of change in model outputs in response to variations in input parameters. This helps to prioritise the parameters for calibration. The sensitivity analysis performed not only identifies the key parameters affecting model performance but also provides insights into the hydrological processes dominating the watershed. For instance, in watersheds like GPB, where surface runoff is the primary hydrological component, parameters like curve number (CN2) and soil available water capacity (SOL_AWC) might emerge as highly sensitive. By focusing on these parameters during calibration, modelers can significantly reduce output uncertainties. Sensitivity analysis serves as a foundation for subsequent calibration and validation. It ensures that calibration targets the most influential parameters, improving the model's efficiency and accuracy. Validation then tests the model against independent datasets to confirm its reliability. Together, these processes enhance the predictive capability of SWAT.

3.6.6. Results

Sensitivity analysis in the SWAT model is a critical process that identifies the parameters significantly influencing model outputs, namely runoff. The following table provides the list of parameters that were selected to perform the sensitivity analysis. Based on the provided table, the parameters can be categorized into hydrology, soil, vegetation and land use, channel and routing, and climate-related parameters as follows:

Hydrology Parameters - These parameters influence groundwater, baseflow, and runoff generation:

- V__GWQMN.gw: Threshold depth of water in the shallow aquifer required for return flow.
- V__GW_REVAP.gw: Groundwater "revap" coefficient.
- V__GW_DELAY.gw: Groundwater delay time.
- V__RCHRG_DP.gw: Deep aquifer percolation fraction.
- R__REVAPMN.gw: Threshold depth of water in the shallow aquifer for "revap" to occur.
- V__ALPHA_BF.gw: Baseflow alpha factor.

Soil Parameters - These parameters govern infiltration, percolation, and soil water retention:

- R__SOL_AWC(..).sol: Available water capacity of the soil layer.
- R__SOL_K(..).sol: Saturated hydraulic conductivity.
- R__SOL_BD(..).sol: Bulk density of the soil layer.
- V__SOL_CRK.sol: Crack volume potential of the soil.
- R__SLSOIL.hru: Slope length.

Vegetation and Land Use Parameters - These parameters affect ET and canopy processes:

- V__ESCO.hru: Soil evaporation compensation factor.
- V__CANMX.hru: Maximum canopy storage.
- V__EPCO.hru: Plant uptake compensation factor.
- R__OV_N.hru: Manning's n value for overland flow.
- V__DEP_IMP.hru: Fraction of impervious areas in the HRU

Channel and Routing Parameters - These parameters control water movement in streams and routing:

- V__CH_K1.sub: Effective hydraulic conductivity in tributary channels.
- R__CH_S1.sub: Channel slope of tributaries.
- R__CH_S2.rte: Channel slope of the main channel.
- V__CH_K2.rte: Effective hydraulic conductivity in the main channel.
- V__CH_N2.rte: Manning's n value for the main channel.
- V__CH_N1.sub: Manning's n value for tributary channels.

Climate-Related Parameters - These parameters are linked to snowmelt and temperature impacts:

- V__SFTMP.bsn: Snowfall temperature threshold.
- V__SMTMP.bsn: Snowmelt base temperature.
- V__SMFMN.bsn: Minimum melt factor for snow.
- V__SMFMX.bsn: Maximum melt factor for snow.
- V__TIMP.bsn: Snowpack temperature lag factor.
- V__SURLAG.bsn: Surface runoff lag coefficient.

The results of sensitivity analysis (Table 3.1) indicate that the Hydrology parameters dominate the sensitivity rankings, especially those related to groundwater processes (GWQMN, GW_DELAY). Soil parameters like SOL_AWC and SOL_K significantly impact infiltration and percolation, affecting runoff generation. Vegetation and land use parameters such as ESCO and CANMX influence ET and canopy water retention, highlighting their importance in hydrological simulations. Channel and routing parameters impact streamflow velocity and loss through channel processes. Climate-related parameters have a lower rank, reflecting minimal sensitivity in non-snow-dominated basins.

Table 3.1: Global sensitivity test for identifying sensitive parameters in the model

Parameter Name	t-Stat	P-Value	Rank
7:V__GWQMN.gw	-37.01	0.00	1
1:R__CN2.mgt	24.16	0.00	2
4:V__GW_REVAP.gw	-17.31	0.00	3
3:V__GW_DELAY.gw	-12.81	0.00	4
17:V__ESCO.hru	9.61	0.00	5

15:V__CANMX.hru	-3.49	0.00	6
10:R__SOL_AWC(..).sol	-3.40	0.00	7
12:R__SOL_K(..).sol	3.39	0.00	8
18:V__EPCO.hru	-3.25	0.00	9
21:V__CH_K1.sub	-2.31	0.02	10
19:R__CH_S1.sub	2.27	0.02	11
29:V__SMFMN.bsn	-1.94	0.05	12
11:R__OV_N.hru	-1.73	0.08	13
9:R__SOL_BD(..).sol	1.44	0.15	14
20:R__CH_S2.rte	1.28	0.20	15
5:V__RCHRG_DP.gw	1.12	0.26	16
13:R__LAT_TTIME.hru	-1.04	0.30	17
2:V__ALPHA_BF.gw	0.98	0.33	18
33:V__GDRAIN.mgt	-0.98	0.33	19
22:V__CH_K2.rte	0.98	0.33	20
31:V__DDRAIN.mgt	0.98	0.33	21
26:V__SFTMP.bsn	0.69	0.49	22
32:V__TDRAIN.mgt	-0.69	0.49	23
27:V__SMTMP.bsn	0.58	0.56	24
30:V__TIMP.bsn	-0.52	0.60	25
34:V__DEP_IMP.hru	-0.48	0.63	26
6:R__REVAPMN.gw	0.46	0.65	27
16:V__CANMX.hru	-0.40	0.69	28
24:V__CH_N2.rte	-0.38	0.70	29
23:V__CH_N1.sub	0.32	0.75	30
14:R__SLSOIL.hru	0.21	0.83	31
28:V__SMFMX.bsn	-0.20	0.84	32

8:V__SOL_CRK.sol	-0.13	0.90	33
25:V__SURLAG.bsn	0.12	0.91	34

The results of simulations of the uncalibrated model at the various control locations is provided in Figure 3.12. The hydrographs display the comparison between observed and simulated streamflows for multiple subbasins (Earrapuzha, Kalleli, Kurudamannil, Manimala, and Pandalam) in the GPB from 2010 to 2020, along with subbasin rainfall as a contextual driver. Key performance metrics, such as Nash-Sutcliffe Efficiency (NSE) and correlation coefficients (Corr), indicate varying model accuracy across the subbasins. Earrapuzha and Manimala demonstrate relatively good model performance with NSE values of 0.57 and 0.67, respectively, and high correlation coefficients (>0.80), signifying the uncalibrated model's capability to capture seasonal patterns and peak flows. In contrast, Kalleli exhibits poor model performance (NSE = 0.07, Corr = 0.47), indicating limitations in simulating streamflow dynamics, possibly due to localized factors associated with inability to capture the rainfall variation or insufficient calibration. Kurudamannil and Pandalam present moderate performance (NSE = 0.39 and 0.40, respectively), capturing general trends but showing discrepancies during certain peak and low-flow periods.

Following sensitivity analysis, the top 15 parameters were selected for calibration. The SWAT model calibration was performed using SWAT-CUP, a calibration and uncertainty analysis tool, employing the SUFI-2 (Sequential Uncertainty Fitting, Version 2) algorithm. This process involved iterative adjustments of sensitive parameters to minimise discrepancies between observed and simulated outputs while simultaneously assessing prediction uncertainty. Parameters such as the SCS Curve Number (CN2), groundwater threshold depth (GWQMN), etc. were identified as critical through sensitivity analysis and calibrated within realistic ranges to optimise the model's performance. Calibration focused on replicating streamflow dynamics, including seasonal variations, peak flows, and baseflows, using observed data over the defined calibration period. The Figure 3.13 and Table 3.2 are presented to show the calibration results at various locations in the GPB. The 95 Percent Prediction Uncertainty (95PPU) band is presented in the Figure 3.13 along with the observed data at the IDRB Gauging stations. The 95PPU provides an understanding of the parameter uncertainty in the calibration procedure.

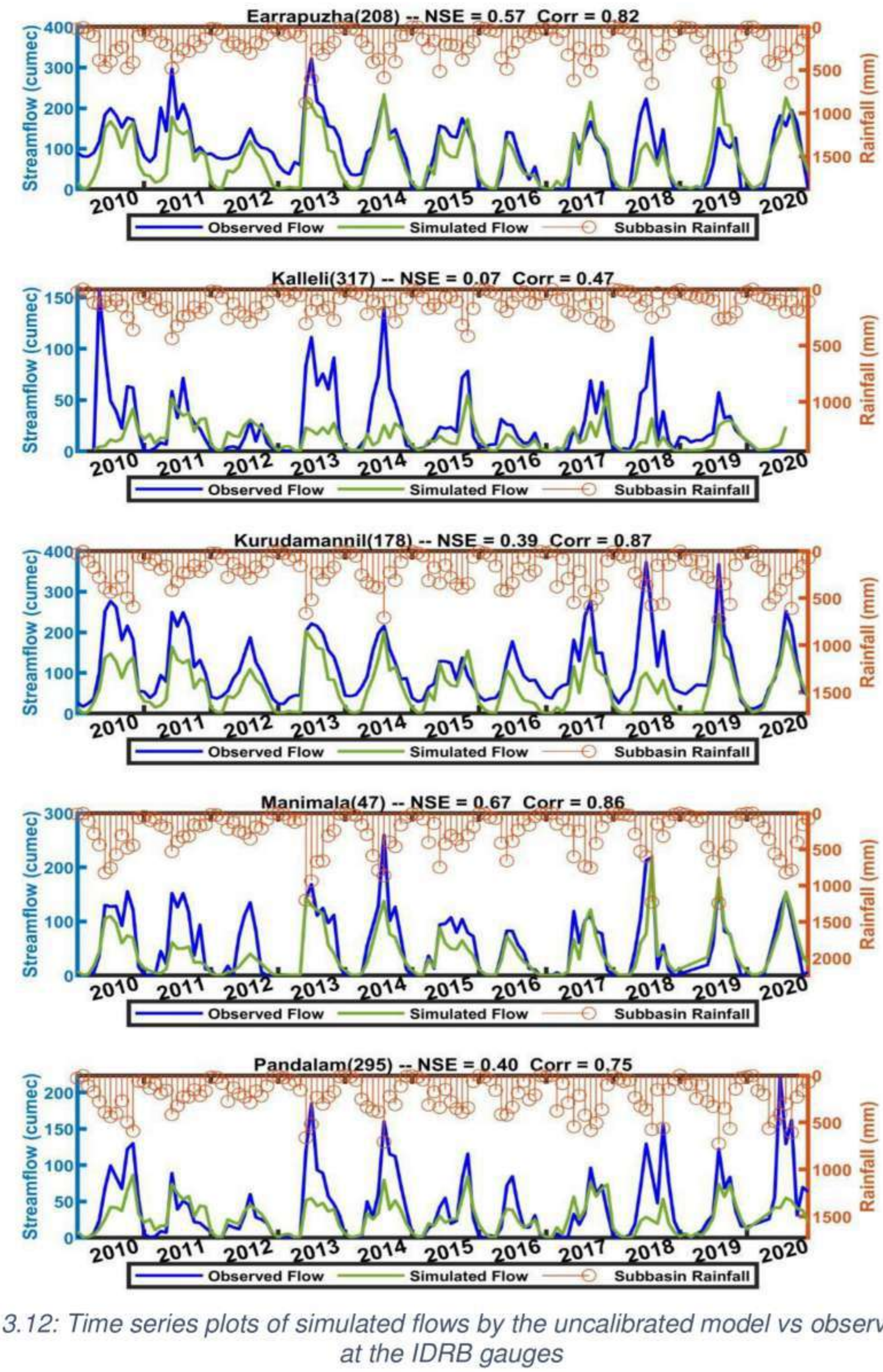


Figure 3.12: Time series plots of simulated flows by the uncalibrated model vs observed flows at the IDRB gauges

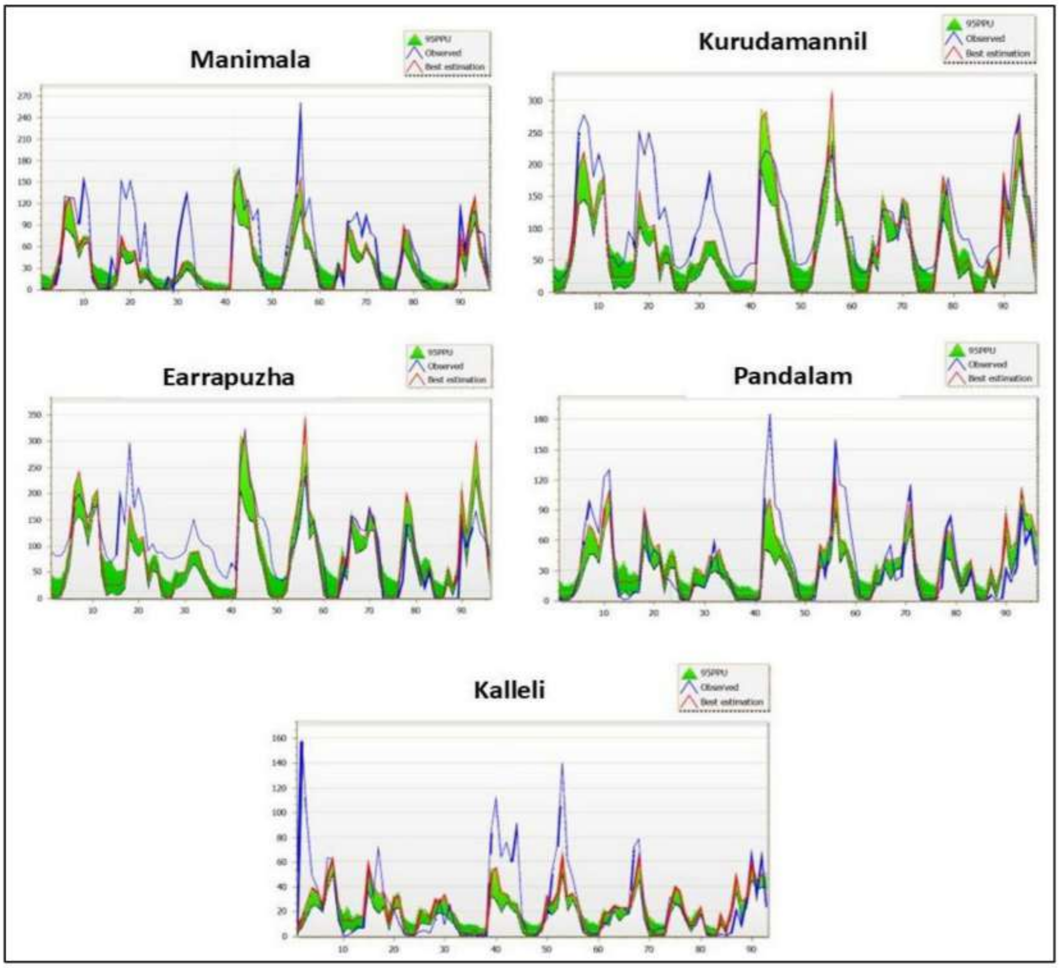


Figure 3.13: Comparison of flows simulated by calibrated model at the IDRB gauging stations

Table 3.2: Performance of the model after calibration

Variable	R^2	NSE	bR^2	MSE	SSQR	PBIAS	KGE	RSR	MNS
Manimala	0.76	0.66	0.49	1100	650	23.90	0.59	0.58	0.59
Kurudamannil	0.75	0.54	0.70	2200	930	26.20	0.70	0.68	0.35
Earrapuzha	0.63	0.39	0.61	280	840	14.10	0.66	0.78	0.22
Pandalam	0.76	0.75	0.50	420	160	-2.20	0.72	0.50	0.55
Kalleli	0.46	0.43	0.17	600	310	14.30	0.42	0.76	0.43

The statistical performance of the calibrated model was evaluated using standard metrics. The results highlight the model's varying performance across subbasins:

1. Manimala (R^2 = 0.76, NSE = 0.66, PBIAS = 29.3): The model shows good performance, with high R^2 and NSE values indicating its ability to capture the variance and dynamics of observed stream flows. However, the high positive PBIAS suggests a consistent overestimation of streamflow. The MNS (0.59) and KGE (0.59) support acceptable model performance.
2. Kurudamannil (R^2 = 0.75, NSE = 0.54, PBIAS = 26.2): The performance is moderate, with a slightly lower NSE indicating a less accurate simulation of observed flows compared to Manimala. The high bR^2 (0.7037) suggests strong predictive capabilities, but the positive PBIAS shows overprediction. The KGE value of 0.70 highlights improved performance over other subbasins.
3. Earrapuzha (R^2 = 0.63, NSE = 0.39, PBIAS = 14.1): This subbasin exhibits the weakest performance among upstream locations, with low NSE and R^2 values suggesting poor simulation of observed flow variability. However, the lower PBIAS indicates a reduced bias in streamflow predictions.
4. Pandalam (R^2 = 0.76, NSE = 0.75, PBIAS = -2.2): Pandalam exhibits the best overall calibration, with high R^2 and NSE values indicating good simulation of observed flows. The PBIAS confirms minimal bias, and a KGE of 0.72 supports its reliability.
5. Kalleli (R^2 = 0.46, NSE = 0.43, PBIAS = 14.3): The model performs poorly for Kalleli, with low R^2 and NSE values reflecting limited ability to replicate observed flows. The moderate PBIAS indicates some bias in flow predictions.

The calibration process revealed that hydrological parameters such as GWQMN and ALPHA_BF played a critical role in controlling baseflow dynamics, while CN2 strongly influenced surface runoff, particularly during storm events. Despite these observations in results, challenges such as limited observed data, and difficulties in capturing the spatial variability in rainfall because of the sparsely distributed rain gauge stations were noted. Nevertheless, the calibrated model provides a reliable foundation for scenario analysis, such as assessing the impacts of land use changes or climate variability on water resources in the Pamba River Basin. These results demonstrate the model's robustness and its applicability in designing sustainable water management strategies, including flood mitigation and drought preparedness.

3.6.7. Challenges and limitations

The calibration and modelling of the Pamba River Basin using SWAT faced several challenges and limitations that may have influenced the results. These challenges are rooted in data quality, model resolution, and the inherent complexity of the river basin's hydrology and management practices:

Sparse Distribution of Rainfall Stations - The limited number of rainfall stations across the basin restricts the spatial resolution of precipitation input, leading to potential inaccuracies in capturing localised rainfall events. This limitation is particularly significant for a basin like Pamba, where orographic effects and microclimatic variations can lead to highly variable rainfall patterns, especially in the upstream mountainous regions.

Poor Representation of Upstream Catchment's rainfall - The upstream regions of the Pamba Basin, particularly those above reservoirs, are poorly represented in the available rainfall data. These areas often serve as critical contributors to streamflow and groundwater recharge. The lack of detailed representation leads to challenges in accurately simulating inflows to reservoirs and downstream hydrological processes.

Missing Values in Rainfall Data - The available rainfall datasets contain significant gaps and missing values. Interpolation methods or surrogate data sources may introduce additional uncertainty, affecting the reliability of simulated streamflows and other hydrological components.

Lack of Temperature Data – The resolution of temperature data is too coarse, resulting in uncertainties towards the windward side of the Western Ghat mountain ranges. The influence of temperature gauges from the drier and hotter leeward side of the mountain range is visible in the gridded temperature data used, which may induce significant uncertainties in the modelled water balance components.

Complex River Network in Downstream Areas - The downstream portion of the Pamba River Basin is characterized by a highly complex river network, with multiple interconnected channels, backwater flows, and tidal influences. This complexity poses challenges for accurately routing water through the system towards the downstream.

Management Practices Represented to the Best Possible Extent - While efforts were made to include management practices (agricultural practices, reservoir operations), the representation is often based on limited data. This can lead to discrepancies between simulated and observed flows, especially in areas with significant anthropogenic impacts.

Uncertainty in Hydrological Representation - The Pamba Basin exhibits complex hydrological behaviour, with interactions between surface water and groundwater, seasonal variations in flow regimes, and the influence of reservoirs and irrigation practices. The simplifications inherent in the SWAT model may not fully capture these interactions, leading to limitations in simulating baseflows and peak flows accurately.

These challenges highlight the importance of improving data availability and quality, particularly for rainfall and upstream hydrology, to enhance the model's reliability. Addressing these limitations may involve integrating higher-resolution DEMs, expanding the spatial coverage of rainfall stations, and incorporating more detailed management practices. Additionally, using complementary hydrodynamic models for the downstream network and exploring ensemble modelling approaches could improve the overall representation of the Pamba Basin's complex hydrology.

3.7. Current and Future Water Availability for the Greater Pamba Basin

3.7.1. Current water availability

The historical water availability in the catchment is presented in Figure 3.14 and reflects the spatial variability of rainfall, runoff, soil moisture, and ET in the GPB for the period 1983 to 2005. These components collectively influence the hydrological balance and determine the overall water resources in the region. The rainfall patterns indicate significant spatial variability across the catchment. Western and central regions experience high annual rainfall (up to 3000 mm), while the eastern most areas receive comparatively lower rainfall (below 1500 mm). This uneven distribution of rainfall is the primary driver of differences in water balance components across the catchment. The downstream regions of GPB, with higher rainfall are likely to have better water availability, and are also thus more vulnerable to flood events.

The runoff in the GPB is highest in subbasins where the streams are present. The subbasins with streams are visible particularly in the downstream region. Streamflow is highest in the Pamba river compared to the Manimala and Achankovil streams. Low runoff in the majority of the catchment indicates poor surface water availability, which may cause challenges in irrigation and drinking water supply. The spatial variability is soil moisture shows clear pattern, with values ranging between 300 mm and 2000 mm. Western central regions show higher soil moisture levels, likely due to higher rainfall and favourable soil characteristics. Eastern areas, with lower rainfall, exhibit reduced soil moisture. Higher soil moisture in the western central subbasins suggests better agricultural potential in the region, while the southern and south-eastern subbasins may experience water stress for crop production. ET is consistently high across the catchment, with values ranging between 400 mm and 1700 mm. Higher ET rates are concentrated in the eastern subbasins, driven by higher temperatures and lower soil moisture retention. High ET rates indicate a significant loss of water to the atmosphere, reducing water availability for runoff and soil storage. South-eastern regions are particularly vulnerable due to the combined effects of high ET and low rainfall.

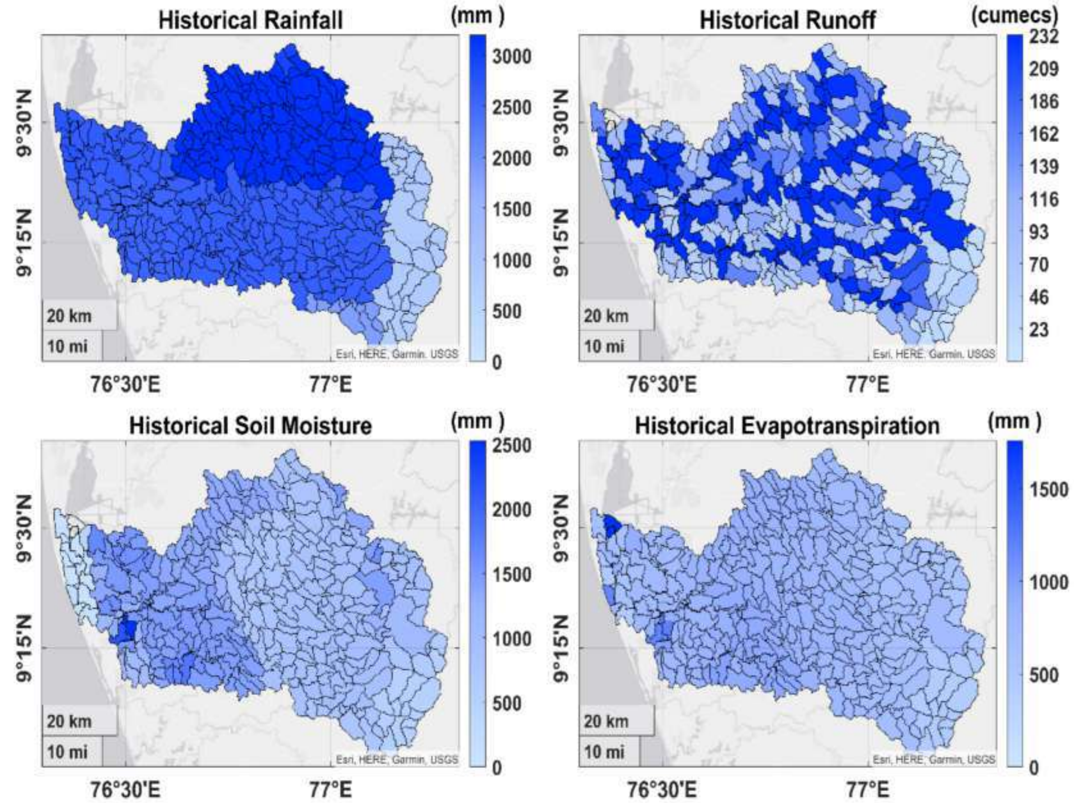


Figure 3.14: Historical water availability in the GPB. Spatial variation in Rainfall, Runoff, Soil Moisture and Evapotranspiration

In conclusion, the historical water availability in the GPB highlights the complex interplay between rainfall, runoff, soil moisture, and ET, which collectively determine the hydrological balance and water resources in the region. The spatial variability observed emphasizes the need for a region-specific approach to water management. While the northern and central regions exhibit relatively higher water security due to favourable rainfall and soil moisture conditions, the southern and south-eastern regions face significant challenges stemming from low rainfall, limited runoff, and high ET. These disparities underscore the importance of sustainable water resource management practices, including enhancing water storage, improving irrigation efficiency, and adopting climate-resilient agricultural practices. Addressing these challenges will be critical for mitigating water stress, ensuring equitable water distribution, and supporting livelihoods in vulnerable areas of the GPB.

3.7.2. Future water availability

This section analyses the projected changes in rainfall over the GBP and the associated changes in three key hydrological components: runoff, ET, and soil moisture, under two SSPs (SSP245 and SSP585) for the total period 2025 – 2099, and separately for near future period (2025 – 2047), mid future period (2048 – 2073) and far future periods (2074 – 2099). The projections are provided for the total period, near future, mid-future, and far future. The findings illustrate spatial variability and temporal trends in the water balance components of GPB in response to climate change.

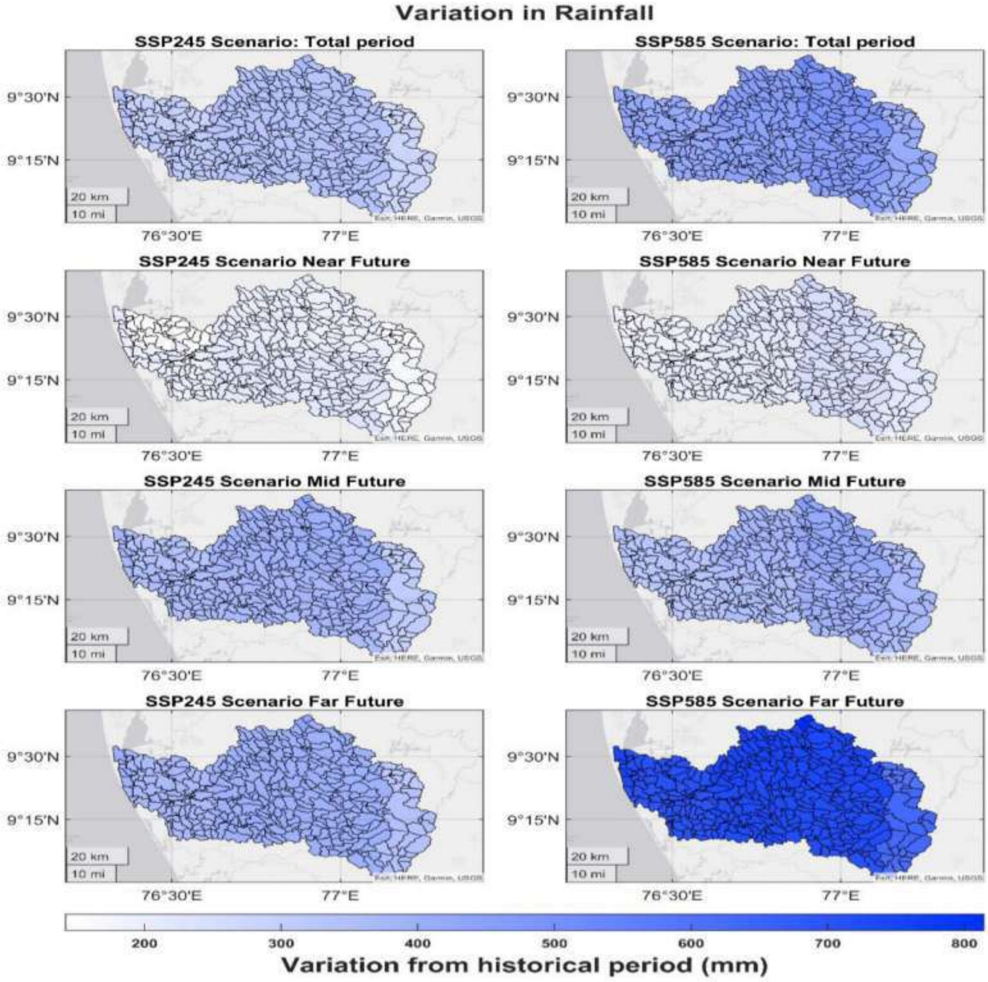


Figure 3.15: Projected average variations in rainfall over the GPB across different climate

Figure 3.15 shows that both emission scenarios point toward increased rainfall in the GPB, with SSP585 displaying markedly higher increases across all time-periods. The magnitude of change grows with time, especially under SSP585, highlighting the potential for substantial intensification of wet-season rainfall in the latter half of the century. Under SSP 245, the projected increases in rainfall are comparatively modest in the near-future, where most sub-basins exhibit only a slight rise (200–300 mm) above the historical baseline. By the mid-future, the change shifts to about 300–500 mm above baseline, suggesting more pronounced precipitation gains, particularly in the basin's central and eastern regions. In the far-future, these increases remain in the moderate-to-high range (generally 400–600 mm above historical levels), although no sub-basin shows the consistently high increments seen in the SSP585 scenario. In contrast, the SSP 585 scenario yields higher and more spatially uniform rainfall increases over the GPB. Even in the near-future, many areas already exceed 300 mm above the historical average, and the mid-future intensifies to widespread gains of 400–600 mm. In the far-future, large portions of the basin shift toward the darker blue range, indicating rainfall increases surpassing 600 mm—and in some sub-basins, approaching 800 mm—above the historical period.

The rainfall in GPB show an increasing trend, as is seen in Figure 3.16.The rainfall is increasing by about 28 to 48% from the historical period across the catchment. The increase in rainfall is higher in the SSP245 scenario compared to the SSP585 scenario. The south-eastern region of the GPB, where the historical rainfall is observed to be the lowest shows the most relative change in the future. The least change is seen in the northern part of the catchment. The spatial pattern of change in rainfall across the GPB is similar across the scenarios, and across the different future time periods considered, indicating a wet future in the catchment. The percentage change is higher in the near future period and reduces in the far future. These changes suggest potential shifts in water availability, with implications for hydrological processes, agricultural practices, and flood risk management in the catchment. The increasing trend in rainfall across the GPB, particularly in south-eastern regions, can be attributed to climate change-induced intensification of the hydrological cycle. Higher temperatures increase atmospheric moisture-holding capacity, leading to more intense and frequent precipitation events. The larger relative increases in historically drier areas may result from local topographic and atmospheric feedback, as well as shifts in monsoonal circulation patterns.

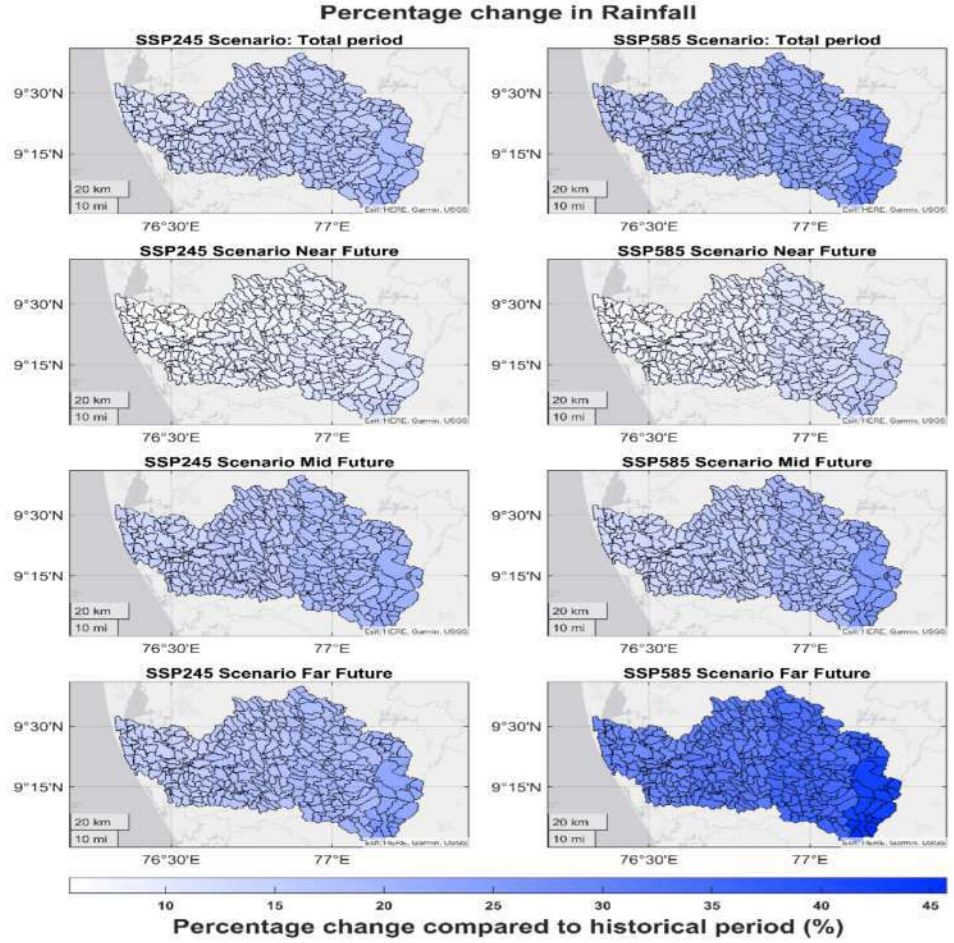


Figure 3.16: Projected percentage change in rainfall over the GPB across different climate scenarios

Figure 3.17 reveals that both emission scenarios suggest an overall rise in runoff across the GPB, with SSP585 exhibiting noticeably larger increases throughout all future time-frames. The intensity of this change grows over time, particularly under SSP585, underscoring the potential for more significant streamflow responses in the latter half of the century. Under SSP245, the projected increases in runoff are relatively modest in the near-future, with most sub-basins experiencing only slight gains (around 5–10 cumecs above the historical average). By the mid-future, these increments generally lie in the 10–20 cumecs range, indicating more pronounced runoff changes, especially in central and eastern parts of the basin. In the far-future, runoff tends to remain in the moderate range (20–30 cumecs above baseline), but none of the sub-basins approaches the higher levels seen under SSP585. In contrast, SSP585 yields higher and more spatially consistent runoff increases throughout the GPB. Even in the near-future, certain sub-basins already exceed 10–15 cumecs above the historical reference, and the mid-future shows broad gains of 20–30 cumecs. In the far-future, many sub-basins shift toward the darker blue shades, indicating runoff increases beyond 30 cumecs (and in some areas approaching 50 to 100 cumecs) above the historical period.

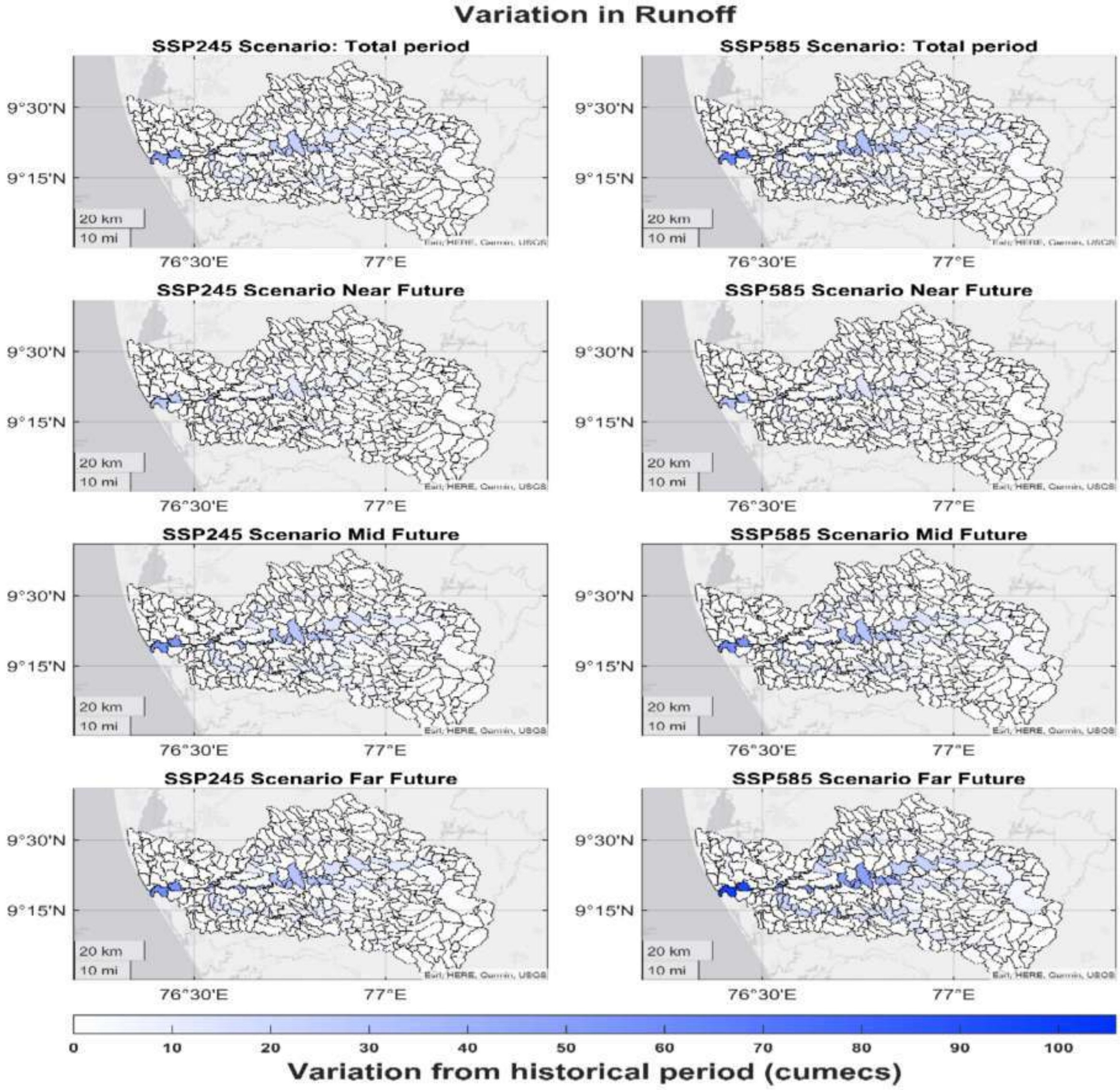


Figure 3.17: Projected average variations in runoff over the GPB across different climate scenarios

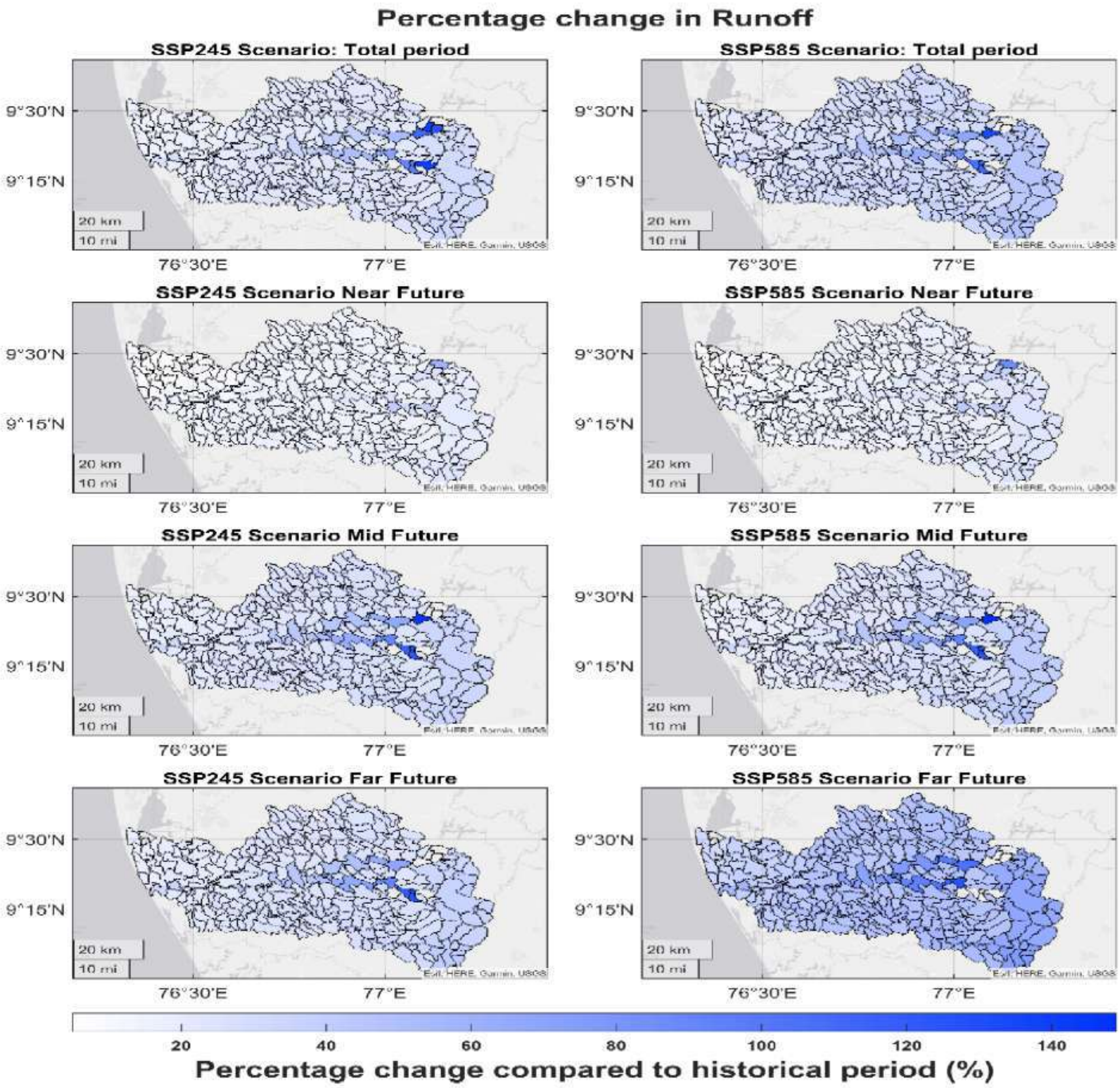


Figure 3.18: Projected percentage changes in the runoff in GPB across different climate scenarios

The projections of runoff show significant increases across all the subbasins in GPB (Figure 3.18). Historical runoff in the catchment is highest along the three major streams in the catchment, but when analysing the future data, a sharp increase is observed only in the Pamba stream. Significant increase (100 – 130%) is observed in the upstream subbasins along the Pamba stream. A moderate increase in runoff is seen in Achankovil stream (50-70%) along with the sharp increase in the Pamba stream in the SSP585 scenario. When considering the overall future period, most of the subbasins along the stream show moderate increases (40–

80%), with some central subbasins showing a change exceeding 100%. The significant increase in runoff, especially under SSP585, matches the significant increase in rainfall projected over the GPB and indicates potential risks of flooding. Central and southern regions may face challenges in water management due to extreme variability in the future. The significant increase in runoff, especially along the Pamba stream, corresponds closely to the projected rise in rainfall. The variability in runoff patterns reflects differences in land cover, slope, soil infiltration capacity, and rainfall intensity. Areas with steeper slopes or lower infiltration rates are likely to generate higher runoff. In the Pamba stream, higher rainfall combined with terrain effects amplifies runoff, increasing flood risks.

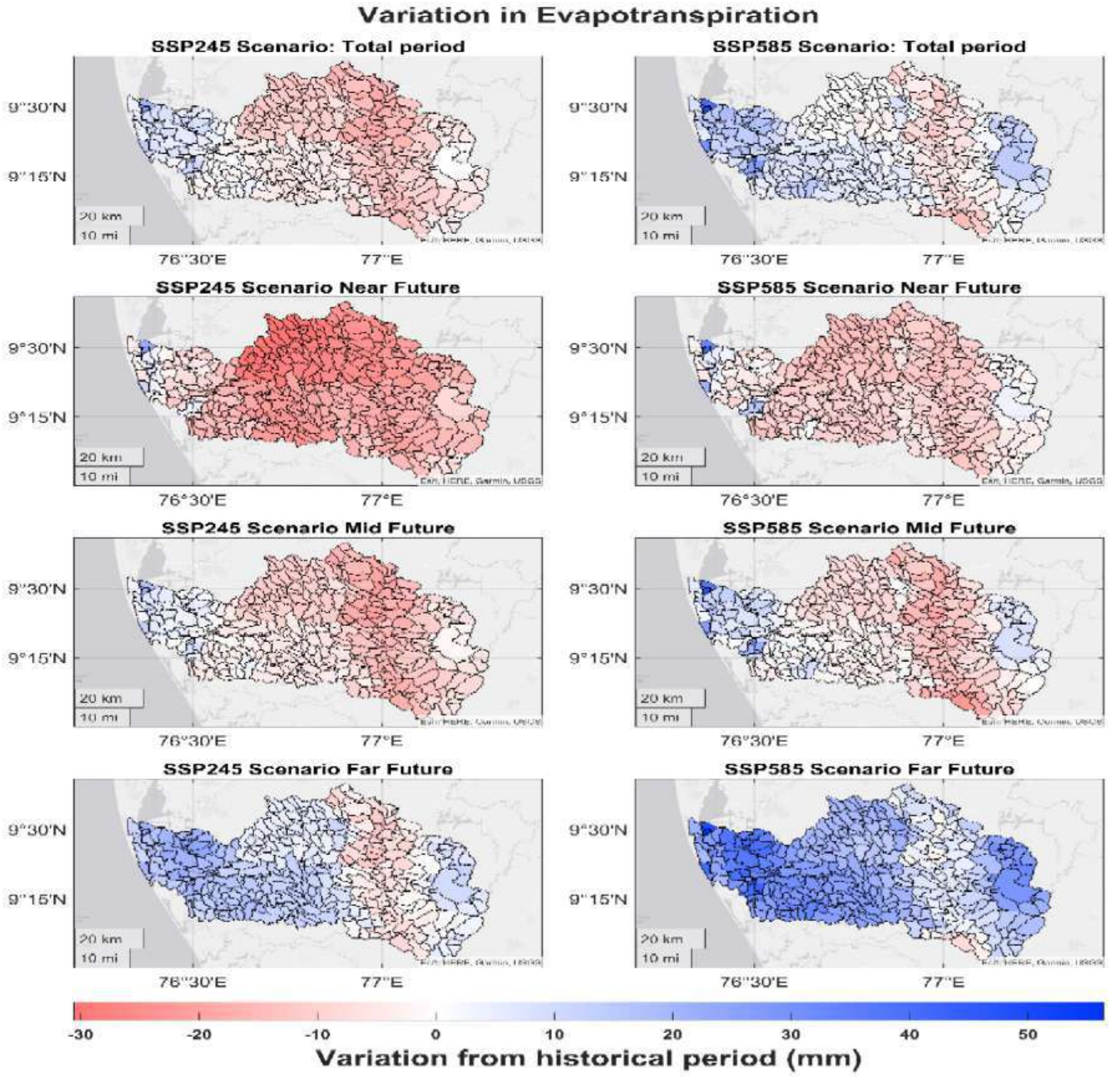


Figure 3.19: Projected average variations in evapotranspiration in the GPB across different climate scenarios

Figure 3.19 shows the change in average annual ET across the GPB for both SSP245 and SSP585, compared against a historical average. Under SSP245, much of the basin exhibits moderate reduction in ET through the near-future, with many sub-basins shifting roughly 10–30 mm below the historical levels. The largest reduction is seen in the northern part of the catchment, areas coming under the Kottayam district. By the mid-future, these reductions weaken (generally 0–20 mm above baseline) and contract spatially, towards the central and eastern regions. In the far-future, a more mixed pattern emerges, as the western sub-basins show increase in ET, whereas a minor portion of the central maintain a reduction of about 0–10 mm.

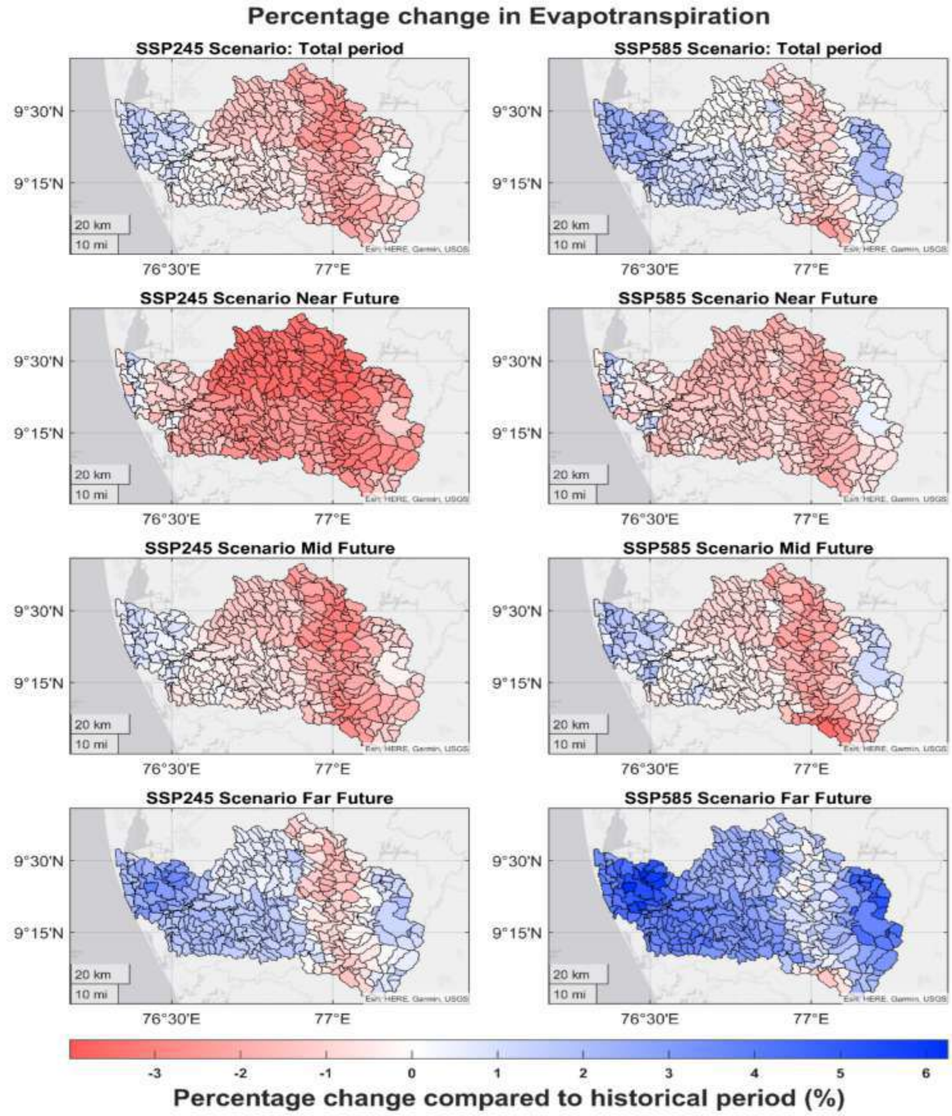


Figure 3.20: Projected percentage changes in evapotranspiration in GPB across different climate scenarios

In contrast, SSP585 scenario produces more pronounced and spatially varied changes in ET across the basin. In the near-future, a small number of sub-basins along the western boundary show modest increases (up to 10 mm), but most areas see slight reduction of up to 10 mm. By the mid-future, these increases become more widespread (often 15–25 mm), with the reductions contracting to subbasins in the central region. In the far-future, large portions of the basin experience robust ET rises exceeding 30 mm above the historical period. This outcome highlights a potential for significantly heightened evapotranspiration demand under higher-emission pathways.

ET is projected to show significant spatial variability across the GPB (Figure 3.20). Across the total future period analysed, moderate increase is observed towards the western part of the catchment. The relative change in ET decreases towards the eastern part of the catchment, with reduction in ET observed in the upstream subbasins. The variation in ET is similar across both the scenarios, when considering the entire future period. The projected change in ET is prominent in the near future period. The higher increases under SSP585 reflect the stronger warming associated with this scenario. The spatial variability in ET trends is driven by interactions between increasing temperature and changing soil moisture availability. Increases in ET in western regions are linked to higher rainfall, which supply more water for evaporation and plant transpiration. Conversely, south-eastern areas show reduced ET despite rising rainfall, which may be due to the rising temperatures, particularly under the SSP585 scenario.

Figure 3.21 indicates projected increase in soil moisture over the central and eastern regions of GPB and reduction over the western parts of the catchment. Under SSP 245, soil moisture changes are initially mixed much of the north and center are slightly negative (10 to 20 mm), while the east and southeast exhibit moderate increases of up to 30 mm. In the near-future period, large portions of the northern basin turn more strongly negative (around 20 to 30 mm), while the southwest and southeast hover near zero. In the mid-future period, the southern and eastern sub-basins transition to positive anomalies (20 to 30 mm), with the northwest remaining near or below zero. Over the far-future period, nearly the entire basin shifts to positive anomalies, especially the eastern half, where soil moisture can increase by 30 to 60 mm. Only parts of the western margin remain near zero or slightly negative.

By contrast, SSP 585 yields more pronounced spatial contrasts. Over the total period the northwest exhibits modest negative anomalies (10 to 20 mm), whereas eastern sub-basins show mild gains of up to 20 mm. In the near-future period, many central and northern areas dip by around 20 mm, with southwestern parts near zero or slightly positive. In the mid-future period, the west remains drier (up to 20 mm), while eastern sections experience moderate increases (10 to 30 mm). Over the far-future, most of the basin turns decisively wetter, especially in the east, where anomalies can exceed 50 mm. The southwestern corner, however, remains slightly negative. Overall, the SSP 585 scenario projects stronger and more extensive soil moisture increase, although some localized drying persists in the western portion of the basin. Under SSP 245, negative anomalies are more pronounced in the near-term but ultimately shift to widespread positive changes by the far-future, indicating a more gradual transition to wetter soil conditions.

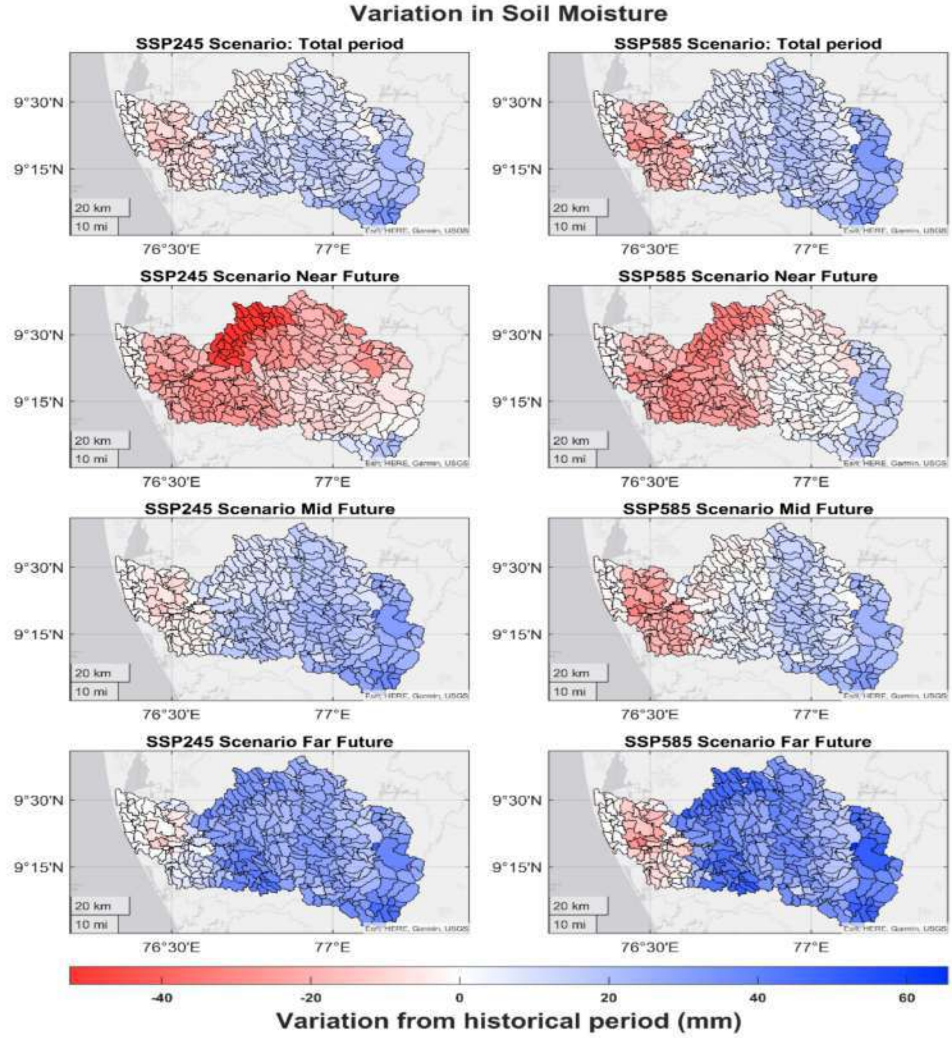


Figure 3.21: Projected average variations in soil moisture in the GPB across different climate scenarios

Soil moisture projections show contrasting patterns, with some regions experiencing increases and others decreases (Figure 3.22). Across the total future period considered, modest changes are observed, with decreases in the western areas (up to 2%) and increases in southern parts (up to 7%). The decrease in soil moisture over the western subbasins is higher in the SSP585 scenario, while the increase in soil moisture over the south-eastern regions is more prominent in the SSP245 scenario. The spatial variability in soil moisture change is uniform across both the scenarios, but in the mid future scenario, the decrease in soil moisture is less in the SSP245 scenario compared to the SSP585 scenario. Soil moisture trends highlight potential challenges for agriculture and ecosystem health, particularly in downstream areas. Adaptive strategies are needed to address moisture deficits. The contrasting trends in soil moisture are influenced by changes in rainfall, ET, and runoff dynamics. Reductions in soil moisture in western areas reflect higher ET rates and increased surface runoff, which depletes soil water. In south-eastern subbasins, increased rainfall and reduced ET contribute to modest increases in soil moisture.

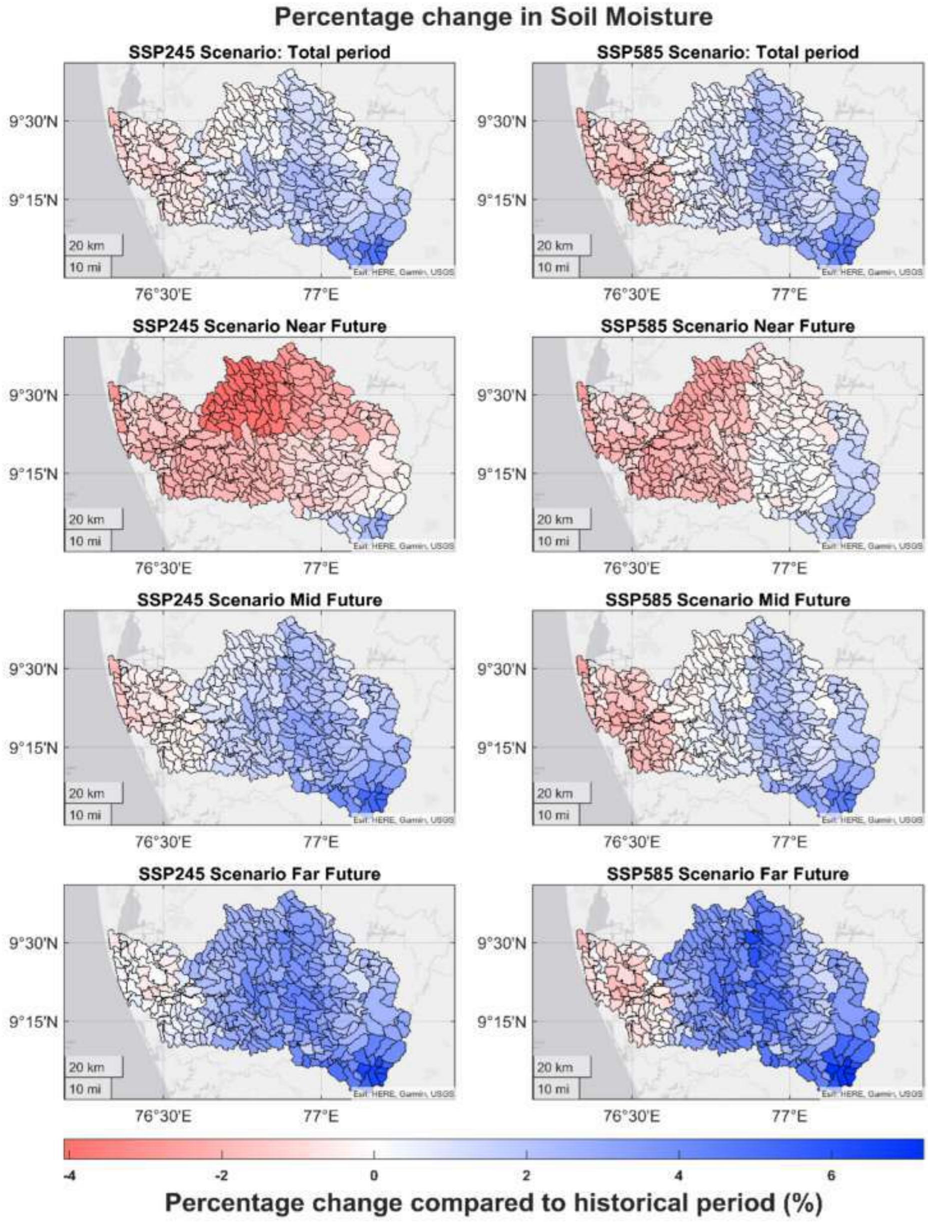


Figure 3.22: Projected percentage changes in soil moisture in GPB across different climate scenarios

The projected changes in water availability in the GPB under climate change scenarios have profound implications for the region's water balance, agriculture, and water resource management. The significant increase in rainfall, particularly in historically drier south-eastern areas, suggests enhanced water inputs, but this comes with increased risks of flooding, especially in central and southern regions. The sharp rise in runoff, particularly along the Pamba stream, indicates potential challenges in managing water flow and mitigating flood risks, necessitating improved drainage infrastructure and flood control measures. The spatial variability in ET, with increases in the western subbasins and reductions in south-eastern regions, reflects changing energy and water flux dynamics, likely impacting crop water requirements and ecosystem functioning. Contrasting soil moisture trends, with decreases in western areas and increases in south-eastern subbasins, underscore the complex interactions between rainfall, runoff, and ET. These changes could exacerbate water stress in traditionally water-secure regions while improving moisture conditions in historically drier areas. Collectively, these shifts demand adaptive strategies, such as enhancing water storage, promoting sustainable agricultural practices, and improving flood and drought resilience, to address the emerging challenges and ensure equitable water availability across the GPB.

3.7.3. Projected variation in Flow Duration Curve

Figure 3.23 illustrates Flow Duration Curves (FDCs) for the five key stations: Earrapuzha, Kalleli, Kurudamanil, Manimala, and Pandalam, located in the GPB. Each curve represents the relationship between runoff magnitude and the percentage of time that specific runoff values are equalled or exceeded. The FDCs are depicted for both historical and future scenarios under two climate pathways, SSP245 and SSP585. Historical curves include both observed and modelled values, allowing for a comparison between baseline and projected runoff conditions. Across all stations, the historical modelled FDCs closely follow the observed data in terms of shape and magnitude, though slight discrepancies may exist, especially at higher flow probabilities. These variations indicate reasonable model performance, with limitations likely stemming from localized hydrological complexities or uncertainties in the input data used for calibrating the model. Thus, for further analysis, the future model projections are compared with the historical model simulated data.

When considering the modelled runoff, the runoff magnitude during high-flow periods (lower exceedance probabilities) is notably increased in the future scenarios compared to historical conditions across all stations. The sharp increase in the high-flow values indicate high sensitivity to increasing rainfall in the GPB. This indicates significant increase in the extreme flow events in the catchment and point to an increased risk of flood events in GPB. The low-flow values (higher exceedance probabilities) remain same in the future scenarios considered, indicating stable baseflow conditions in the GPB. Stations such as Earrapuzha and Kurudamannil on the Pamba river show higher runoff magnitudes compared to the others, indicating spatial heterogeneity in catchment responses.

The FDCs of the GPB provide critical insights into future hydrological behaviour under changing climatic conditions, with significant implications for water management in the region. The projected increase in high-flow highlights an elevated flood risk across all stations. This necessitates immediate attention to disaster preparedness and mitigation measures, including the strengthening of flood early warning systems and upgrading existing infrastructure, such as dams and drainage networks, to handle higher runoff volumes. Moreover, the design of new flood control structures must account for these projections to enhance resilience against extreme rainfall events.

Interestingly, the low-flow values remain consistent across future scenarios, suggesting stable baseflow conditions. This stability offers opportunities for effective water allocation during dry seasons, ensuring adequate water supply for agricultural, domestic, and industrial uses while maintaining ecological flow requirements. However, balancing these demands will require careful regulation and monitoring. The spatial heterogeneity in runoff behaviour, with stations like Earrapuzha and Kurudamanil exhibiting higher runoff magnitudes, underscores the need for sub-basin-specific management strategies. Areas with higher flood risks may require enhanced flood control measures, while regions with lower flows might benefit from initiatives like groundwater recharge and wetland conservation to maintain hydrological balance.

The anticipated increase in extreme flows also poses challenges to aquatic ecosystems, potentially disrupting habitats, particularly during monsoon seasons. However, the stable baseflows provide an opportunity to maintain ecological integrity, supporting biodiversity conservation. Wetland restoration and protection in the GPB could serve as natural flood buffers, improving water quality and mitigating flooding impacts. Furthermore, the sharp increase in high-flow events emphasizes the importance of adopting adaptive water management practices, including rainwater harvesting, check dam construction, and soil water retention strategies, to mitigate excess runoff and ensure sustainable water availability.

Long-term planning for water resources in the GPB must integrate climate change projections, such as those under SSP245 and SSP585 scenarios, to address future uncertainties. Policies should be periodically updated to reflect emerging hydrological challenges, ensuring their continued relevance. Community engagement is vital in this context, as raising awareness about changing water regimes and involving stakeholders in decision-making will enhance the effectiveness of water management strategies. Additionally, the implications for agriculture are critical, as increased flood events may lead to widespread crop damage, threatening food security in the region. Promoting resilient agricultural practices, such as climate-smart farming and flood-resistant crop varieties, will be essential to mitigate these risks. In summary, the projected changes in flow regimes in the GPB demand an integrated and adaptive approach to water management. While the increased high flows necessitate robust flood mitigation efforts, the stable low flows present opportunities for reliable water supply and ecosystem conservation. Sub-basin-specific strategies, climate adaptation measures, and community involvement will be key to ensuring sustainable water resources and resilience to future hydrological challenges in the GPB.

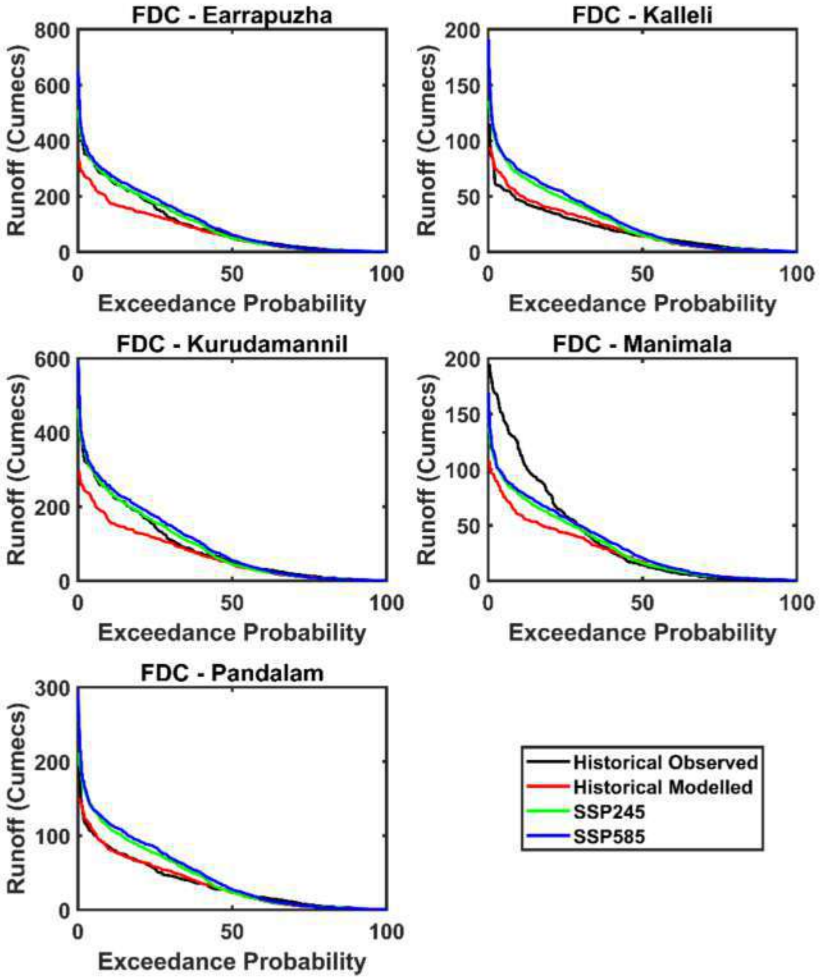


Figure 3.23: Historical and projected Flow - Duration curves at IDRB gauge locations in the GPB

3.7.4. Comparison of current and future water availability

This section evaluates the trends in runoff, ET, and soil moisture for the GPB based on the statistically significant slopes derived from historical data and future projections under SSP245 and SSP585 scenarios. The slopes are calculated using Sen's slope method (Sen, 1968) and the statistical significance of the trends are studied using the Mann-Kendall trend test (Gilbert, 1987). These trends provide insights into changes in the water balance components of the basin and potential future impacts on water resources and ecosystem sustainability.

Over the historical period, the annual runoff in the catchment shows a statistically significant increasing trend (Figure 3.24). The slope of the trend is highest along the three major streams, indicating increasing runoff in the streams. The increasing trend is visible for the future period in both the scenarios, but the slope along the streams is seen to reduce from the historical values. When considering the different periods of the future, statistically significant trends are visible only along the streams in the SSP245 scenario for the near future period. No statistically significant trends are present in the SSP245 scenario in the mid and far future periods. The presence of statistically significant trends in the long-term period, while absent in short term periods indicate that the variation in the runoff is primarily driven by climate change. The slopes along the three major streams are higher in the SSP585 scenario compared to the SSP245 scenario. Statistically significant trends are present in the mid and far future periods in SSP585 scenario, with significant slope in the entire catchment in the far future period, which may be due to the intensification of rainfall in this scenario. The positive trends in runoff under both scenarios suggest potential benefits for surface water availability.

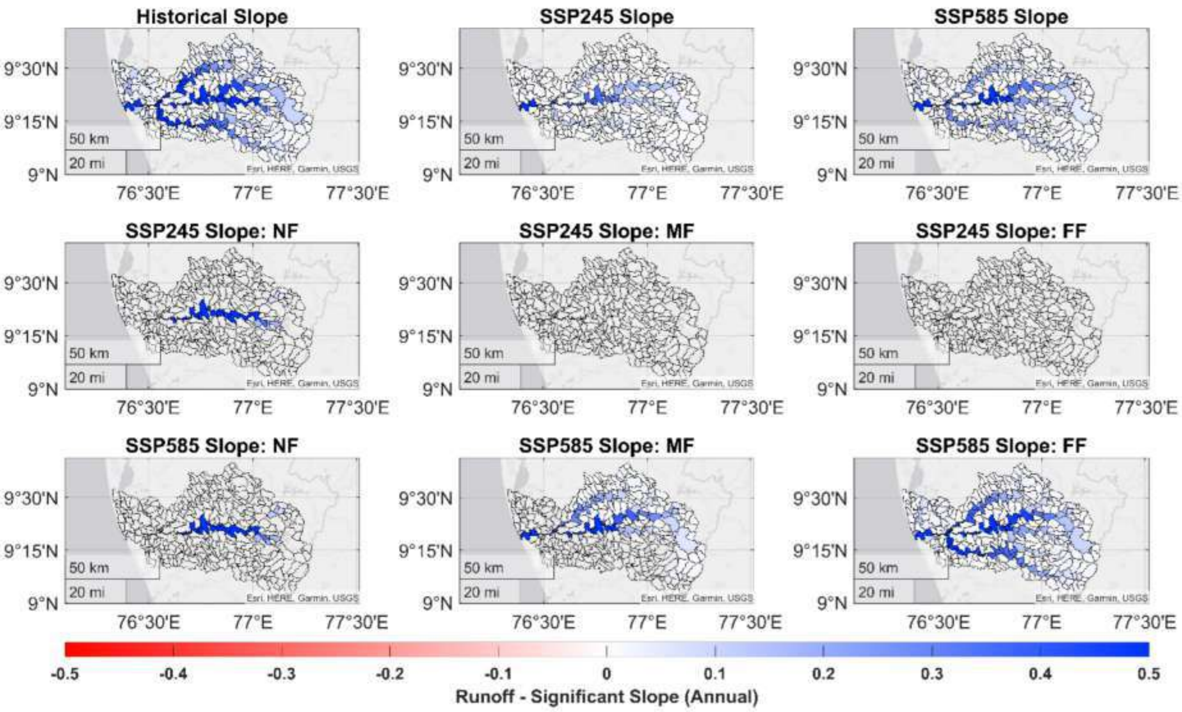


Figure 3.24: Spatial distribution of long-term trends in runoff in the GPB

The projected ET in the GPB exhibits significant increasing trends, reflecting increased atmospheric demand for water (Figure 3.25). Over the historical period, very few subbasins exhibit any statistically significant trends in ET. In the future period, most of the subbasins in GPB exhibit significant trends over the long-term. Over short-term period, none of the subbasins exhibit any significant trends in the future indicating long term variation in ET, driven by climate change. Increasing ET trends suggest rising water demand and greater pressure on water resources, particularly in the eastern regions. This may exacerbate water stress in areas already facing moisture deficits.

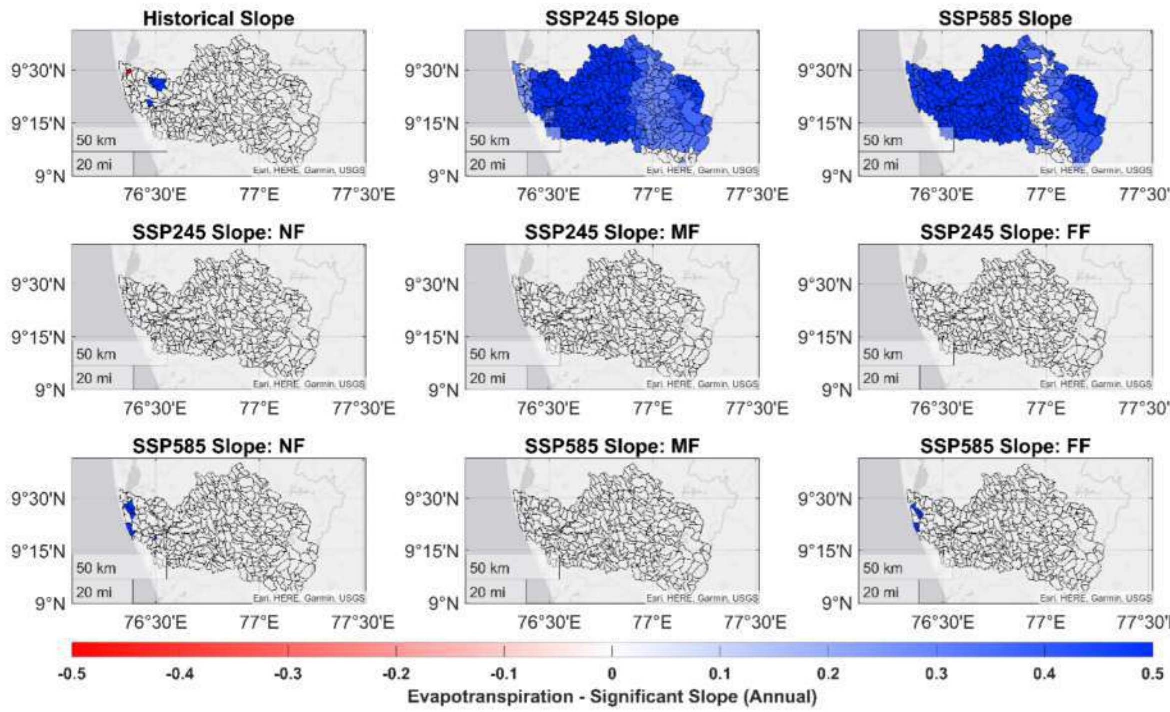


Figure 3.25: Spatial distribution of long-term trends in evapotranspiration in the GPB

Statistically significant increasing slope is seen in the soil moisture for central and eastern subbasins in both historical and future periods (Figure 3.26). The downstream regions of the catchment show no statistically significant slopes in any of the periods considered. Absence of trend in these subbasins does not mean that the soil moisture does not change in the future, just that the variation is not monotonous. The short-term future periods considered show little to no subbasins with statistically significant trends, indicating only long-term variations in the soil moisture in GPB. The spatial variability in slope indicates that the changes in soil moisture is driven by complex interactions of multiple factors and cannot be attributed to climate change alone.

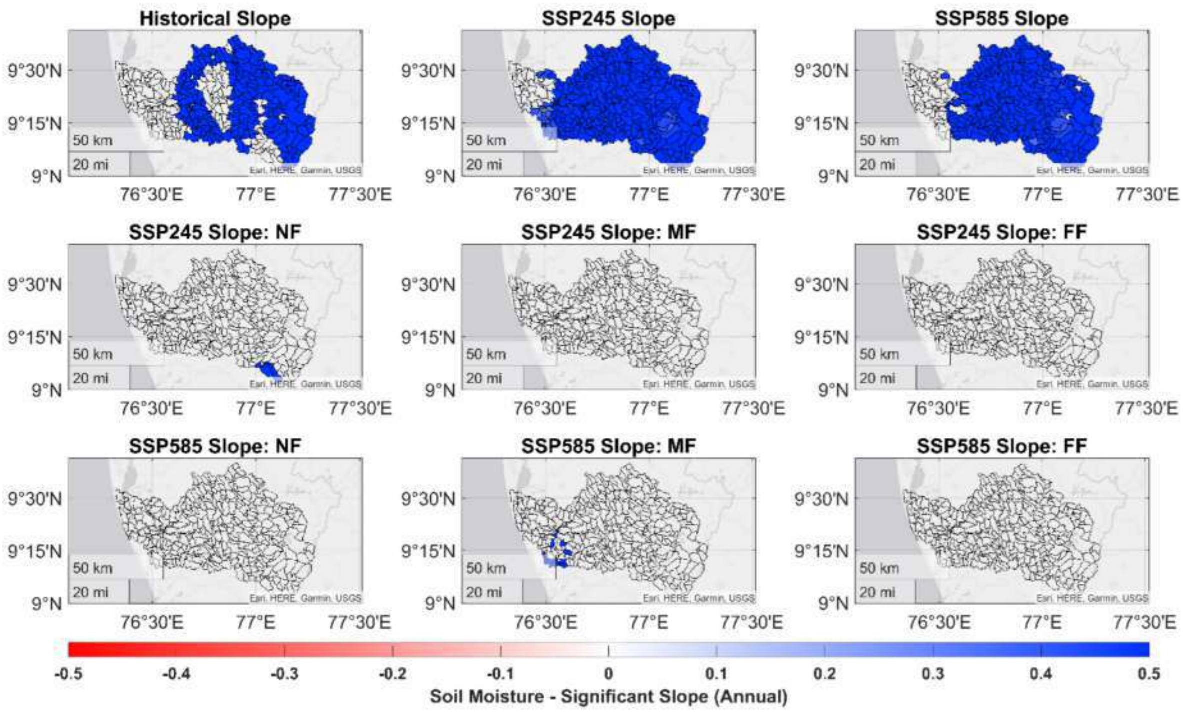


Figure 3.26: Spatial distribution of long-term trends in soil moisture over the GPB

Runoff trends indicate moderate increases in certain subbasins due to increased precipitation. Some regions may benefit from the enhanced runoff, but the overall increase is tempered by rising ET. Runoff is likely to become more variable, with potential increases in flood risks in certain regions and drought risks in others. Increases in ET are projected to intensify in eastern regions, reducing water availability in soils and rivers. ET trends are steep, reflecting stronger warming and heightened water losses across all subbasins. The increasing trend can also be attributed to increased water availability due to increased rainfall. The upstream subbasins are particularly vulnerable, where ET may exceed any potential gains in rainfall. The variability in runoff, ET and soil moisture in the GPB will likely exacerbate agricultural challenges, with some regions facing drought-like conditions and others experiencing excess moisture. Variability in the water availability will lead to challenges in water resource management, with implications for drinking water supply, hydroelectric power generation, and industrial use.

3.7.5. Critical regions of Greater Pamba Basin

Within the GPB, different regions are projected to suffer varied risks from impacts of climate change. The south-eastern subbasins, historically known for low rainfall and high ET, are projected to experience significant increases in rainfall under both climate scenarios. While this might reduce the water scarcity concerns in the region, the projected sharp increase in runoff intensifies the flood risks, particularly in low-lying areas. These regions may struggle with infrastructure inadequacies for flood management, leading to potential crop losses, soil erosion, and damage to local livelihoods.

Conversely, the western subbasins are at risk of reduced soil moisture levels due to rising ET and runoff rates, even though the rainfall is high in the region. This trend could significantly impact agricultural productivity in the region. These areas may face challenges in maintaining agricultural sustainability, which may lead to significant economic instability in the regional agricultural community.

The central subbasins of GPB, particularly those areas near the Pamba stream, are expected to witness substantial increases in runoff. This poses the risk of increased frequency and intensity of floods, which endangers the high-density human settlements present along the river banks. Flood risks in these regions are further worsened by poorly designed and maintained drainage infrastructures and encroachments into the natural waterways, necessitating urgent floodplain management actions in the GPB.

Overall, the GPB faces a complex mixture of water availability risks, where some regions may experience water surpluses leading to flooding, while others grapple with water stress due to declining soil moisture and increasing ET. Effective water resource management strategies, tailored to address the specific needs and vulnerabilities of each subbasin, are critical to ensuring sustainable water security in the face of these challenges.

3.7.6. Impact of climate change on water availability at major control locations of Greater Pamba basin

This section evaluates the basin's response to changing climatic conditions by analysing streamflow variations using hydrological simulations. To account for the inherent uncertainties in climate projections, the analysis incorporates outputs from multiple climate models under different emission scenarios. The focus is on assessing the variability and range of monthly streamflows by considering both the minimum and maximum flows reported across each model and finally arriving at the min and max reported across the models. The analysis was done for both emission scenarios. This comprehensive approach ensures that the analysis captures the entire spectrum of possible future hydrological conditions, providing insights into the basin's water availability, flood potential, and drought risks.

By evaluating the basin's hydrological behaviour at 75% dependability, this study emphasizes the likely conditions under which water resources will be available during most years. The findings aim to support evidence-based decision-making for water allocation, flood mitigation, and climate adaptation strategies in the Pamba Basin. The hydrologic response of the basin and water availability under future climatic conditions with respect to the baseline is presented in the form of 75% dependable flows, maximum monthly flows, and FDCs at control points selected within the basin. FDCs are graphical representation of the probability that a given magnitude of flow is equalled or exceeded during the specified period and quantifies the hydrologic sensitivity of the basin under projected climate change scenarios. The control points selected include the following locations- Manimala, Kurudamannil, Earrapuzha, Pandalam and Kalleli (Figure 3.27).

The following section presents the temporal variability in the 75 % dependable monthly flows, temporal variability in maximum monthly flows and FDCs based on annual flow volume along with the respective analysis.

The Figure 3.27 illustrate the projected variations in 75% dependable monthly streamflows for different locations (Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli) in the Pamba River Basin under historical conditions and future climate scenarios (Early 4.5 and Early 8.5) for the period 2025 - 2047.

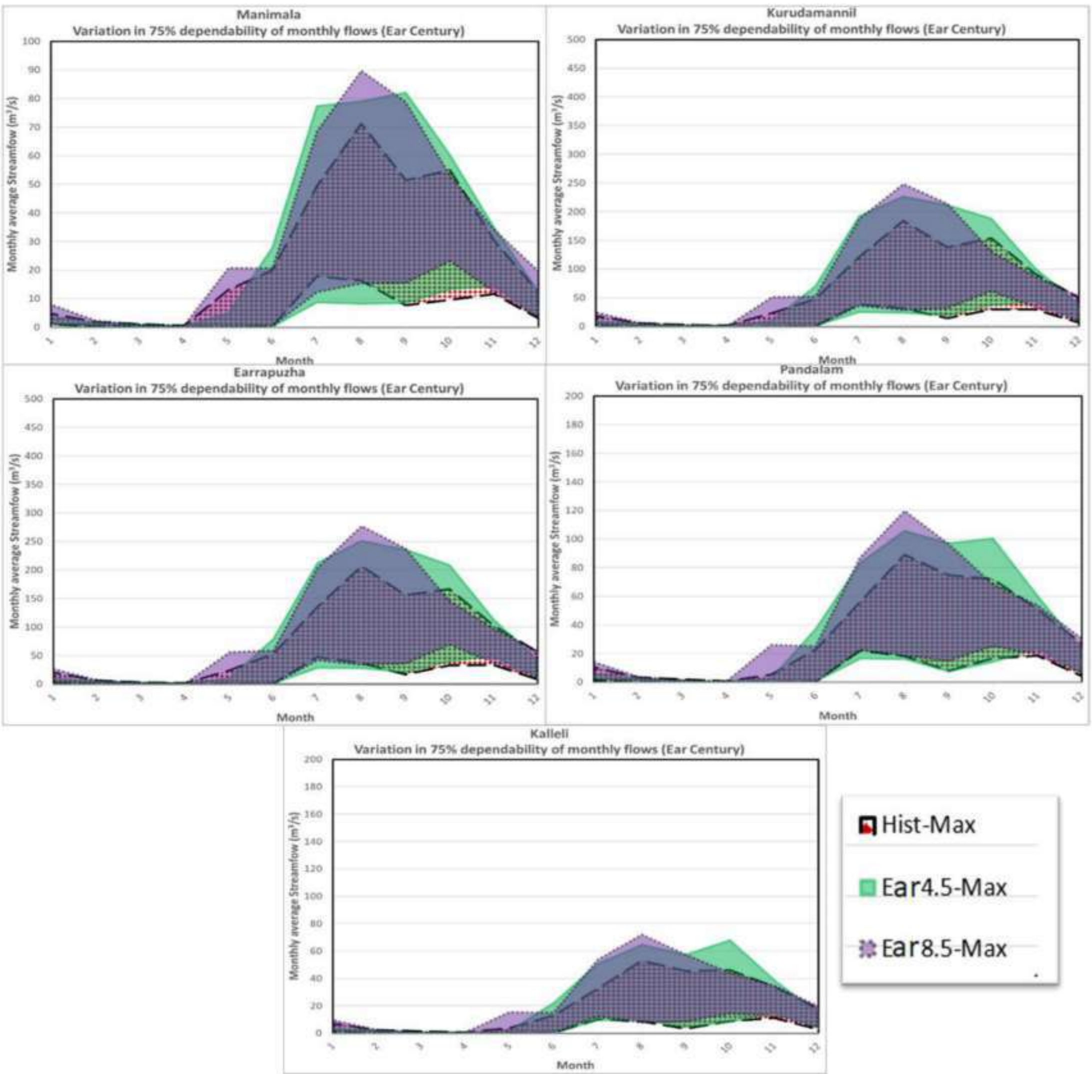


Figure 3.27: Variation of 75% dependable monthly streamflows (early-century)

1. General Trends Across Locations:

- Future Scenarios Show Increased Monsoon Flows: Both RCP 4.5 (moderate emissions) and RCP 8.5 (high emissions) scenarios indicate an increase in monsoon streamflows (June to September) compared to historical data, reflecting potential intensification of monsoon rainfall.
- Higher Variability Under RCP 8.5: The RCP 8.5 scenario displays higher variability in monthly flows, especially during monsoon months, suggesting greater hydrological uncertainty under a high-emission pathway.
- Minimal Changes in Dry-Season Flows: Across all scenarios, the dry season (January to May) shows persistently low flows, indicating limited climate change impact on baseflow conditions during this period.

2. Location-Specific Observations:

Manimala and Kurudamannil:

- These upstream locations exhibit marked increases in monsoon flow peaks under both scenarios.
- RCP 8.5 projections indicate the highest flows and variability, posing potential challenges for flood management.
- Dry-season flows remain negligible, consistent with historical trends.

Earrapuzha:

- Demonstrates the highest peak monsoon flows among all locations, especially under RCP 8.5, indicating significant flood risks.
- The variability of flows during monsoon months is pronounced, particularly in the RCP 8.5 scenario.

Pandalam:

- Being a downstream station, the monsoon peaks appear slightly attenuated compared to upstream stations.
- Similar to other locations, dry-season flows remain critically low, emphasizing potential water scarcity.

Kalleli:

- Shows the lowest streamflows among the stations overall, reflecting its downstream location with limited runoff contributions.
- Monsoon flow increases are modest under future scenarios, with relatively consistent flow variability compared to upstream locations.

3. Impact of Climate Change Scenarios:

RCP 4.5 (Moderate Emissions):

- Shows moderate increases in monsoon streamflows with less variability, suggesting more manageable hydrological impacts under this scenario.

RCP 8.5 (High Emissions):

- Projects higher monsoon flows with substantial variability, highlighting the risks of extreme weather events, such as floods.
- Increased hydrological uncertainty under this scenario calls for adaptive planning and resource management.

4. Hydrological Implications:

- Flood Risk: Increased monsoon flows, especially under RCP 8.5, highlight a heightened flood risk in regions like Earrapuzha and Kurudamannil.
- Water Scarcity: Persistent low flows during dry seasons across all scenarios emphasize the critical need for enhanced water storage and conservation strategies.
- Management Strategies: Adaptive water resource management will be essential, especially under the RCP 8.5 scenario, to address challenges posed by increased variability and extreme events. Flood mitigation infrastructure and water conservation practices will be vital for sustainable resource management in the basin.

Figure 3.28 depict variations in the 75% dependability of monthly streamflows across five different locations in the GPB: Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli. These analyses consider historical data (Hist-Max) and mid-century projections under two climate change scenarios, RCP 4.5 (Mid4.5-Max) and RCP 8.5 (Mid8.5-Max). The analysis highlights the temporal and spatial variability in stream flows under changing climatic conditions.

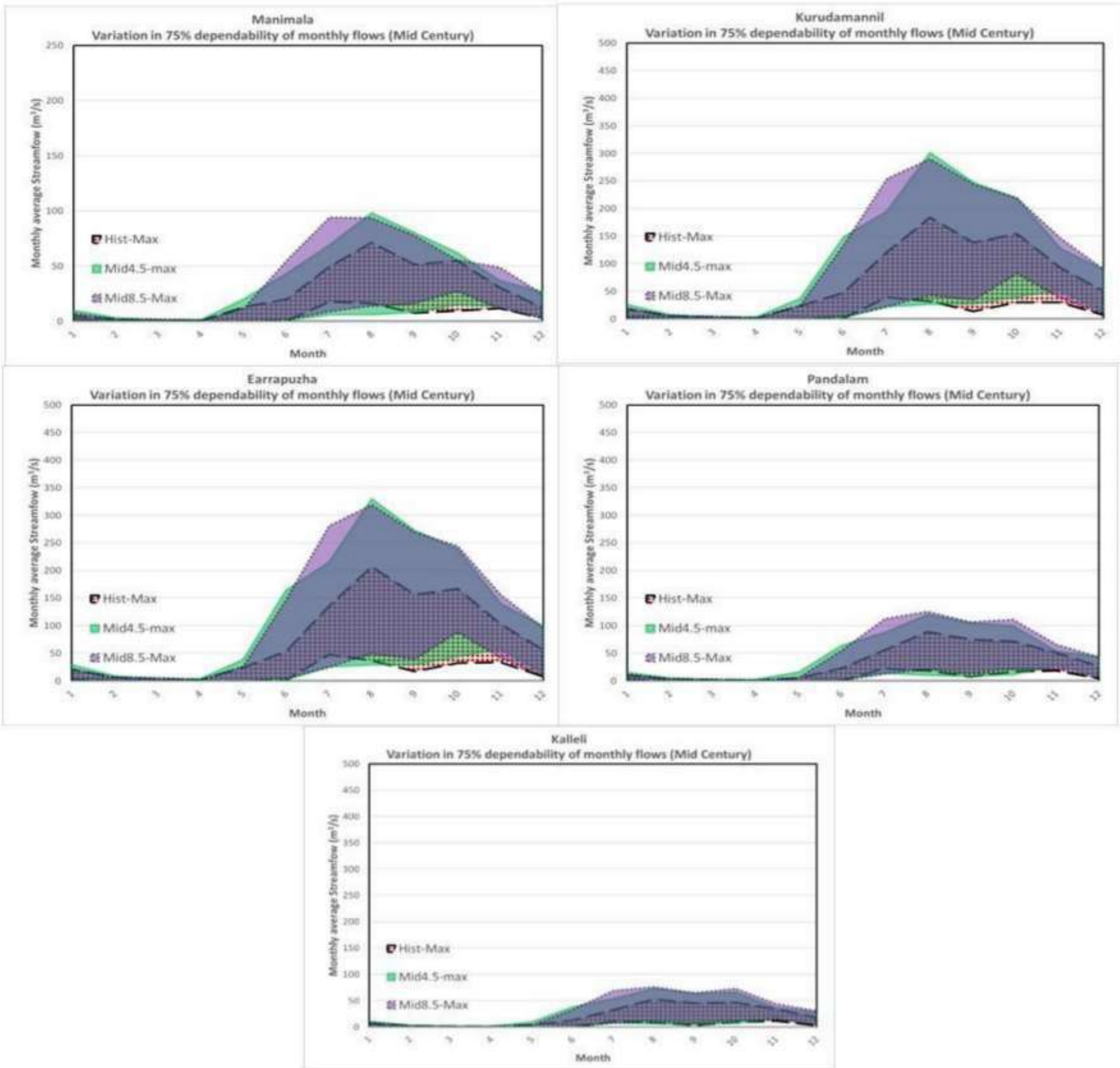


Figure 3.28: Variation of 75% dependable monthly streamflows (mid-century)

1. Seasonal Streamflow Patterns

- Across all locations, the historical flows (Hist-Max) exhibit a distinct seasonal pattern, with higher stream flows during the monsoon months (June to September) and significantly reduced flows during the dry season (October to May).
- Both climate change scenarios (Mid4.5-Max and Mid8.5-Max) show an increase in peak flows during the monsoon months, indicating an intensification of rainfall and higher runoff generation in the basin.

- Dry-season flows remain low across all scenarios, with some locations (Pandalam and Kalleli) showing minimal changes, highlighting persistent water scarcity in non-monsoon months.

2. Comparative Analysis of Climate Change Scenarios

RCP 4.5 (Mid4.5-Max):

- This moderate emission scenario projects a noticeable increase in peak flows during the monsoon across all locations.
- The increases are less pronounced compared to RCP 8.5, suggesting more manageable flow variability and potential benefits of moderate emission control measures.

RCP 8.5 (Mid8.5-Max):

- This high emission scenario projects substantially higher peak flows during the monsoon, particularly in locations like Kurudamannil and Earrapuzha, reflecting increased monsoon intensity.
- The broader range of maximum flows across the months suggests higher variability and greater uncertainty under RCP 8.5.
- Post-monsoon flows decline more sharply under this scenario compared to RCP 4.5, indicating dry-season water scarcity.

3. Spatial Variability in Streamflow Response

Manimala and Kurudamannil:

- These locations exhibit significant increases in peak flows during the monsoon under both scenarios, with RCP 8.5 showing wider variability.
- The sharp contrast between monsoon and non-monsoon flows highlights potential risks of flooding during the wet season and water shortages during the dry season.
- Peak flow is higher at Kurudamannil, almost three times as the peak at Manimala. This indicates higher flows in the Pamba stream compared to the Manimala stream.

Earrapuzha:

- This location shows the highest peak flows among all stations under both climate scenarios, particularly under RCP 8.5, indicating it may experience extreme hydrological events.

Pandalam and Kalleli:

- These downstream locations show comparatively lower flows than the upstream stations.
- While monsoon peaks increase under RCP 4.5 and 8.5, the range of variation remains narrower.

4. Implications for Basin Hydrology

- Flood Risk: Increased monsoon flows, particularly under RCP 8.5, indicate a higher likelihood of flooding.
- Dry-Season Scarcity: Persistently low dry-season flows across all scenarios emphasise the need for improved water storage and conservation strategies.
- Regional Planning: Spatial differences in flow responses highlight the need for localised water management plans tailored to upstream and downstream conditions.

Figure 3.29 illustrate the projected variations in 75% dependable monthly streamflows for different locations (Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli) in the Pamba River Basin under historical conditions (Hist-Max) and future climate scenarios (End4.5-Max and End8.5-Max) towards the end of the century.

1. General Trends Across Locations:

- Both future scenarios (RCP 4.5 and RCP 8.5) show an increase in peak monsoon flows (June to September) compared to historical conditions, reflecting intensified monsoon rainfall.
- The RCP 8.5 scenario exhibits higher variability and a wider range of streamflows compared to RCP 4.5, indicating greater hydrological uncertainty under high-emission pathways.
- Flows during the dry season (January to May) remain minimal, showing limited impact of climate change on low-flow conditions.

2. Location-Specific Observations:

- Manimala and Kurudamannil: These upstream locations show significant increases in monsoon peaks under both scenarios, with RCP 8.5 projecting the highest flows and variability. Dry-season flows remain negligible.
- Earrapuzha: This station shows the highest peak flows among all locations, particularly under RCP 8.5, indicating a heightened risk of flooding.

- Pandalam: As a downstream station, monsoon peaks are slightly attenuated compared to upstream locations, but dry-season flows remain critically low, similar to other stations.
- Kalleli: This station exhibits the lowest flows overall, with modest increases during the monsoon under future scenarios, reflecting its downstream location and limited runoff contribution.

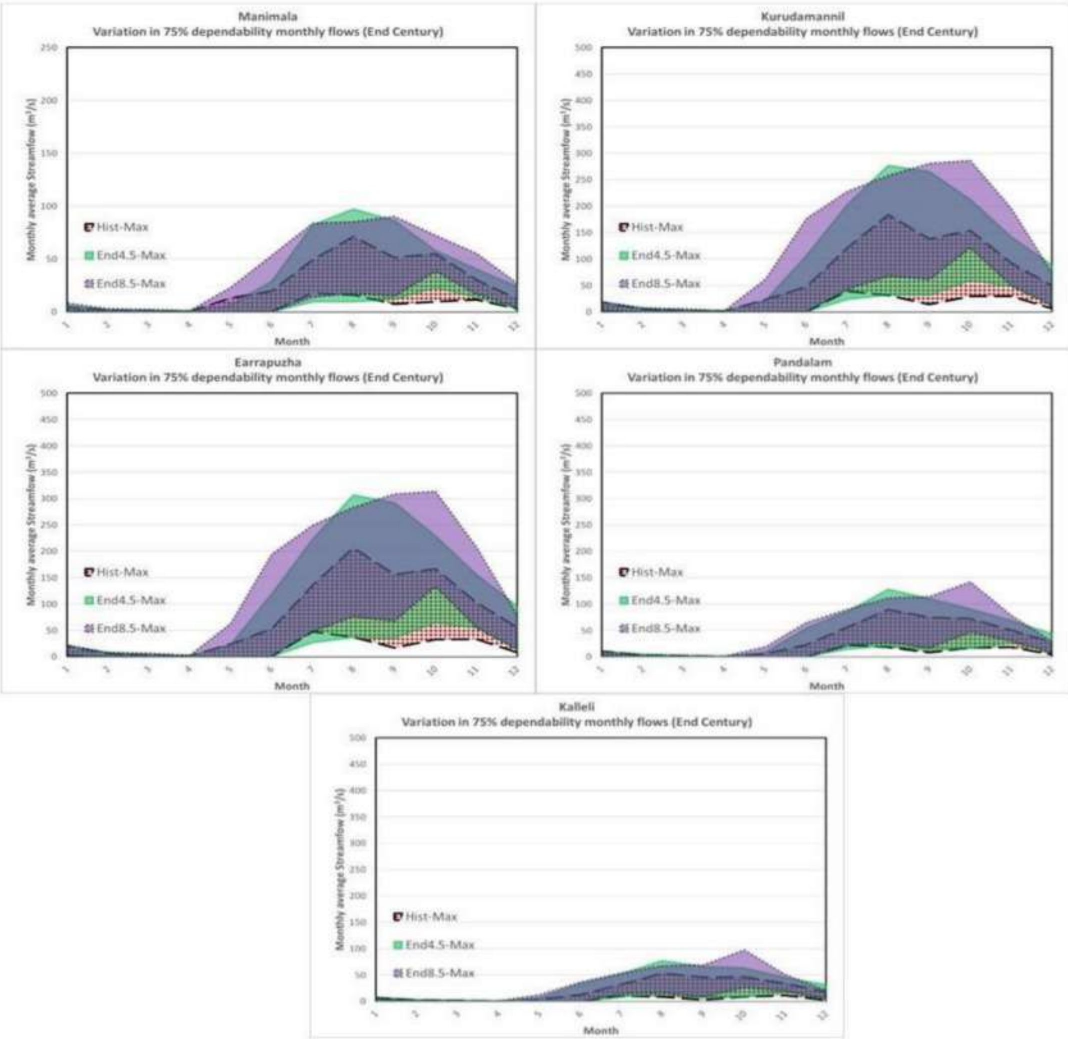


Figure 3.29: Variation of 75% dependable monthly streamflows (end century)

3. Impact of Climate Change Scenarios:

- RCP 4.5 (Moderate Emissions): Presents moderate increases in monsoon flows with less variability, indicating more manageable hydrological impacts.
- RCP 8.5 (High Emissions): Projects substantially higher and more variable monsoon flows, highlighting the risks of extreme hydrological events and increased flooding.

4. Hydrological Implications:

- Flood Risk: Increased monsoon flows, particularly under RCP 8.5, point to a higher likelihood of flood events in upstream regions such as Earrapuzha and Kurudamannil.
- Water Scarcity: Persistent low flows during the dry season emphasize the need for water storage and conservation measures to address potential shortages.
- Management Strategies: The significant variability under RCP 8.5 calls for adaptive and resilient water management practices to mitigate risks.

Figure 3.30 depict the variations in maximum monthly streamflows for various locations (Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli) in the Pamba River Basin under historical conditions (Hist-Max) and two future climate scenarios (Ear4.5-Max and Ear8.5-Max). These projections demonstrate the influence of different climate change pathways (RCP 4.5 and RCP 8.5) on hydrological extremes by the beginning of the century.

1. General Trends Across Locations:

- Increased Peak Flows in Future Scenarios: Both RCP 4.5 and RCP 8.5 scenarios project significant increases in peak monsoon flows (June to September) compared to historical conditions. The RCP 8.5 scenario consistently shows higher maximum flows and greater variability compared to RCP 4.5, reflecting the amplified effects of high-emission scenarios.
- Dry-Season Stability: Maximum flows during the dry season (January to May) remain low across all locations and scenarios, with little visible impact from climate change during these months.
- Interannual Variability: Shaded regions indicating variability are more pronounced under RCP 8.5, especially for peak flows, highlighting increased uncertainty under high-emission conditions.

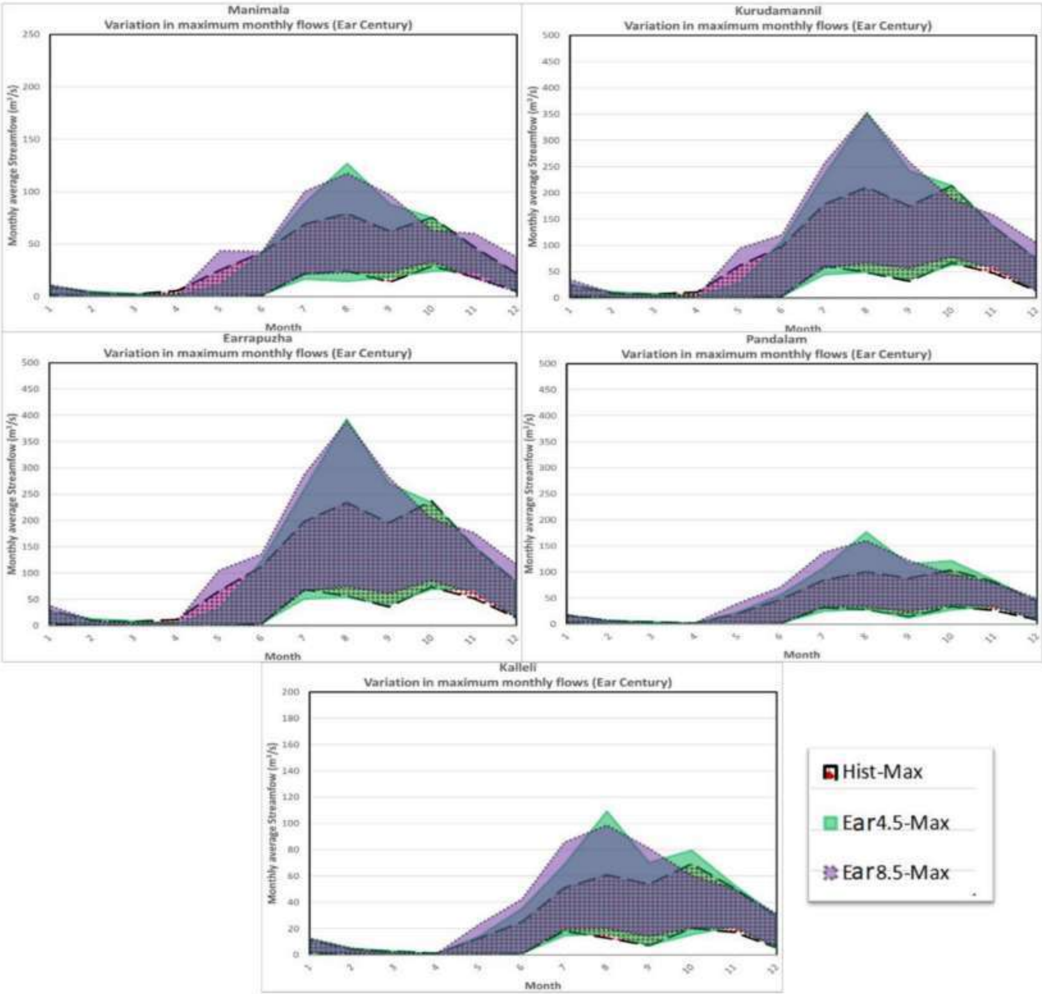


Figure 3.30: Variation of maximum monthly stream flows (early-century)

2. Location-Specific Observations:

Manimala:

- Moderate increases in monsoon peak flows under future scenarios.
- Variability under RCP 8.5 is wider compared to historical or RCP 4.5 projections, indicating heightened hydrological uncertainty.

Kurudamannil:

- Among the highest projected peak flows, particularly under RCP 8.5.
- Greater variability during monsoon months suggests challenges in predicting and managing extreme hydrological events.

Earrapuzha:

- Consistently records the highest maximum flows across all locations.
- The station seems to be sensitive to changes in climate, emphasizing the need for flood management strategies in this region.

Pandalam:

- Downstream results in relatively lower peaks compared to upstream locations like Earrapuzha and Kurudamannil.
- Maximum flows remain highly seasonal, with minimal impact observed during dry months.

Kalleli:

- Exhibits the lowest maximum flows overall, with modest increases under future scenarios.
- Monsoon variability is more muted compared to other locations, reflecting limited hydrological response to extreme rainfall events.

3. Impact of Climate Change Scenarios:

RCP 4.5 (Moderate Emissions):

- Projects moderate increases in monsoon flows with relatively lower variability, making hydrological changes more manageable.
- Presents a more sustainable pathway for water resource planning.

RCP 8.5 (High Emissions):

- Substantially higher maximum flows during the monsoon season, coupled with pronounced variability, indicate a heightened risk of extreme hydrological events such as floods.
- Represents significant challenges for adaptive water management and infrastructure resilience.

4. Hydrological Implications:

- Flood Management: Increased maximum flows, particularly in Earrapuzha and Kurudamannil, highlight an elevated flood risk under future scenarios, especially RCP

8.5. Proactive measures, including improved forecasting and flood defenses, are essential to mitigate risks.

- Water Resource Planning: Persistent low flows during the dry season underscore the importance of storage and water conservation measures. Diversified water sources and enhanced storage capacity can address seasonal water demands.
- Infrastructure Resilience: Enhanced variability and extreme peaks necessitate the design of adaptive infrastructure to withstand hydrological extremes under high-emission scenarios.

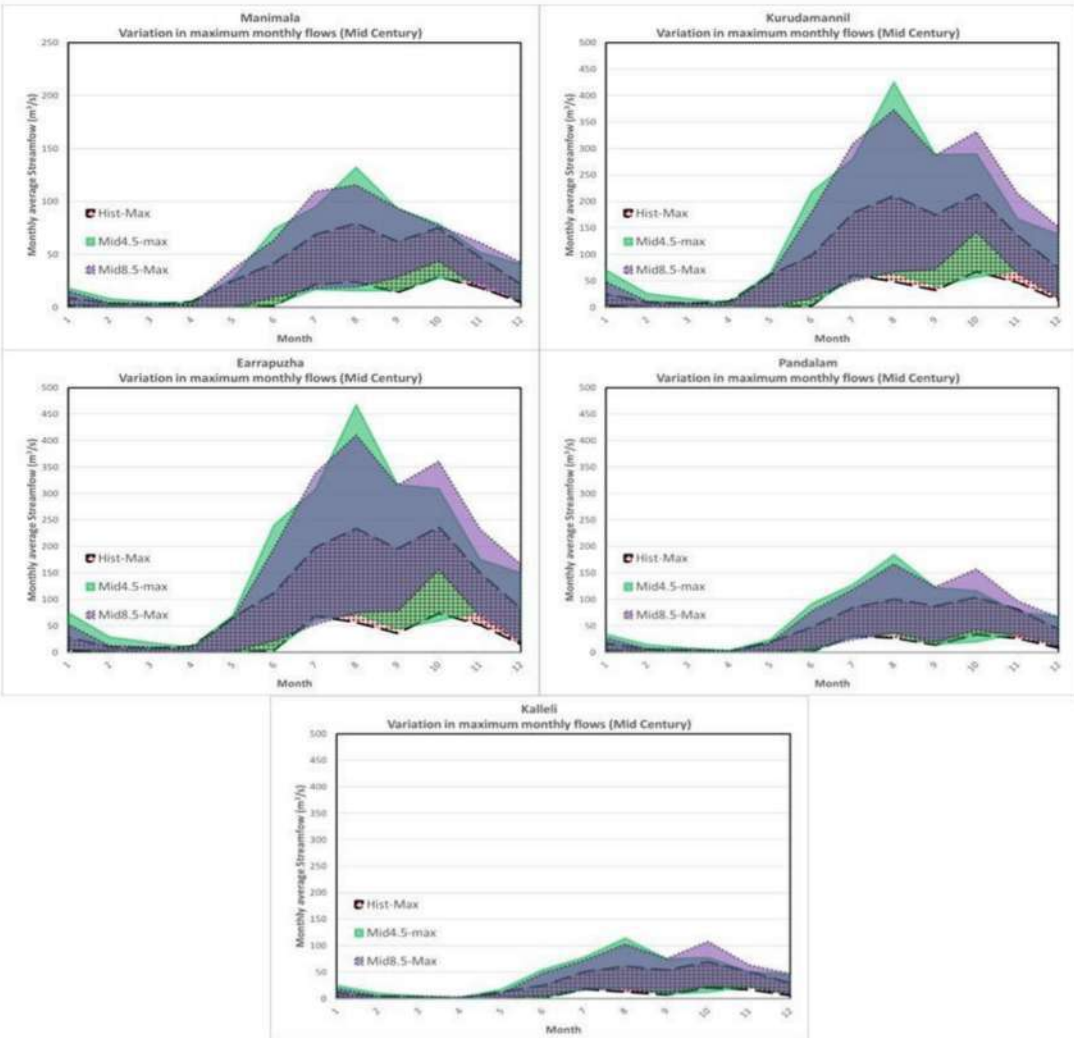


Figure 3.31: Variation of maximum monthly stream flows (mid-century)

Figure 3.31 depict the variation in maximum monthly streamflows for the mid-century period across five locations in the Pamba River Basin (Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli) under historical (Hist-Max) and future climate scenarios (Mid4.5-Max and Mid8.5-Max). The analysis highlights key trends in flow magnitudes and variability:

1. Seasonal and Peak Flow Patterns

- Across all locations, the historical flows (Hist-Max) show a clear monsoon-driven pattern, with peak flows concentrated in the June to September period and low flows during the dry months (October to May).
- Future scenarios (Mid4.5-Max and Mid8.5-Max) reveal higher peak flows during the monsoon season, indicating intensified rainfall and runoff during this period.
- Non-monsoon flows (January to May) remain low across all scenarios, with minimal increases projected, emphasizing limited changes in baseflow conditions during the dry months.

2. Climate Scenario Impacts

RCP 4.5 (Mid4.5-Max):

- Moderate increases in peak flows during the monsoon months are observed across all locations compared to historical conditions.
- The variability and magnitude of maximum flows are more controlled compared to the RCP 8.5 scenario, indicating that emission mitigation efforts could reduce the intensity of extreme flow events.
- NE Monsoon peaks are reduced compared to the historical period, indicating reduced flow post the SW Monsoon season.

RCP 8.5 (Mid8.5-Max):

- Substantial increases in monsoon peak flows are observed across all locations, with a wider range of variability, indicating a higher likelihood of extreme hydrological events.
- The significant increase in maximum flows under RCP 8.5 suggests increased flood risks, particularly in upstream locations such as Kurudamannil and Earrapuzha.

3. Location-Specific Observations

Manimala and Kurudamannil:

- These upstream stations show pronounced increases in peak flows under both scenarios, with RCP 8.5 projecting much higher variability and extreme flows compared to RCP 4.5.
- This highlights a possibility of greater flood risk in these regions, necessitating effective upstream flood control measures.

Earrapuzha:

- Exhibits the highest peak flows among all locations, especially under RCP 8.5. The substantial increase in flow magnitude and variability under this scenario indicates a critical need for flood preparedness in this region.
- Higher flows in the Pamba streams indicate the importance of climate change impact analysis in the region.

Pandalam:

- As a downstream station, Pandalam experiences somewhat attenuated peak flows compared to upstream stations. However, the increased variability under RCP 8.5 suggests downstream flood risks could still be significant.

Kalleli:

- This station shows the lowest flow magnitudes overall, reflecting its downstream position and lower runoff contributions. Monsoon peaks increase modestly under RCP 4.5 but show a broader variability under RCP 8.5.

4. Implications for Basin Management

- Flood Risks: The amplified peak flows during the monsoon season under RCP 8.5, particularly at upstream locations, underscore the need for enhanced flood management strategies, including reservoir operation and land-use planning.
- Climate Adaptation: The variability in flows under RCP 8.5 highlights the importance of integrating climate-resilient infrastructure and adaptive water management practices.
- Emission Mitigation: The moderate increases under RCP 4.5 reinforce the benefits of emission reduction efforts in managing extreme hydrological impacts.

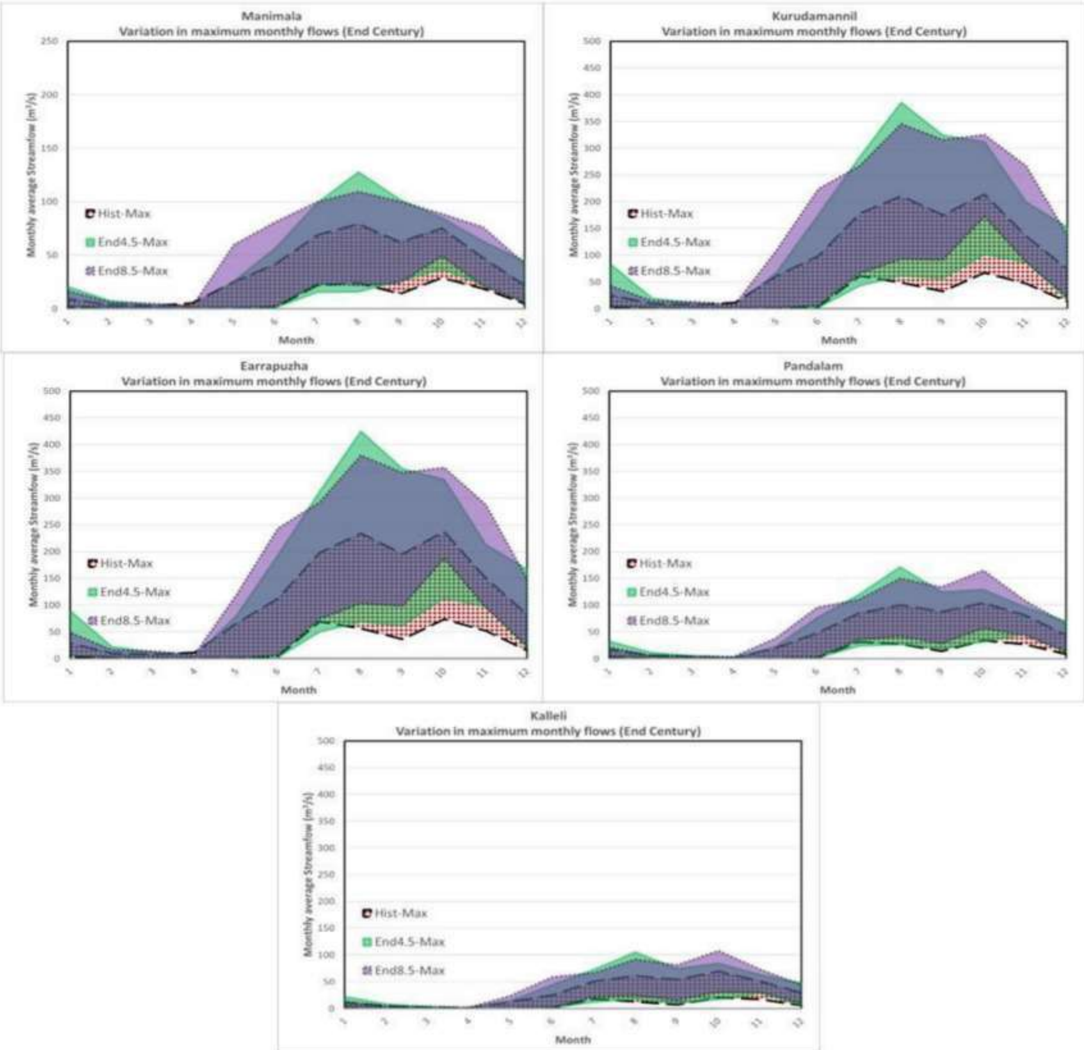


Figure 3.32: Variation of maximum monthly streamflows (end century)

Figure 3.32 illustrate the variation in maximum monthly flows across five locations in the Pamba River Basin (Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli) under historical conditions (Hist-Max) and future projections (End4.5-Max and End8.5-Max) for the end of the century.

1. Seasonal Peaks:

- Monsoon-driven peak flows (June–September) significantly increase under both climate scenarios compared to historical conditions.

- Dry-season flows (January–May) remain minimal across all scenarios, highlighting persistent water scarcity during non-monsoon months.

2. RCP 4.5 vs. RCP 8.5:

- RCP 4.5: Exhibits moderate increases in peak flows with less variability.
- RCP 8.5: Projects substantial increases in peak flows with greater variability, especially during the monsoon, indicating a higher risk of extreme hydrological events such as floods.

3. Location-Specific Observations:

- Manimala and Kurudamannil: Significant increases in monsoon peaks, with RCP 8.5 showing pronounced variability, reflecting high flood risk.
- Earrapuzha: Displays the highest peak flows among all locations, particularly under RCP 8.5, highlighting extreme flood vulnerability.
- Pandalam: Experiences attenuated peaks due to downstream location but still shows increased variability under RCP 8.5.
- Kalleli: Lowest peak flows overall, with modest increases under RCP 4.5 and higher variability under RCP 8.5.

4. Implications:

- Increased monsoon flows demand improved flood control measures.
- Persistent low dry-season flows necessitate enhanced water conservation and storage strategies.
- High variability under scenarios underscores the urgency of climate adaptation and emission mitigation measures.

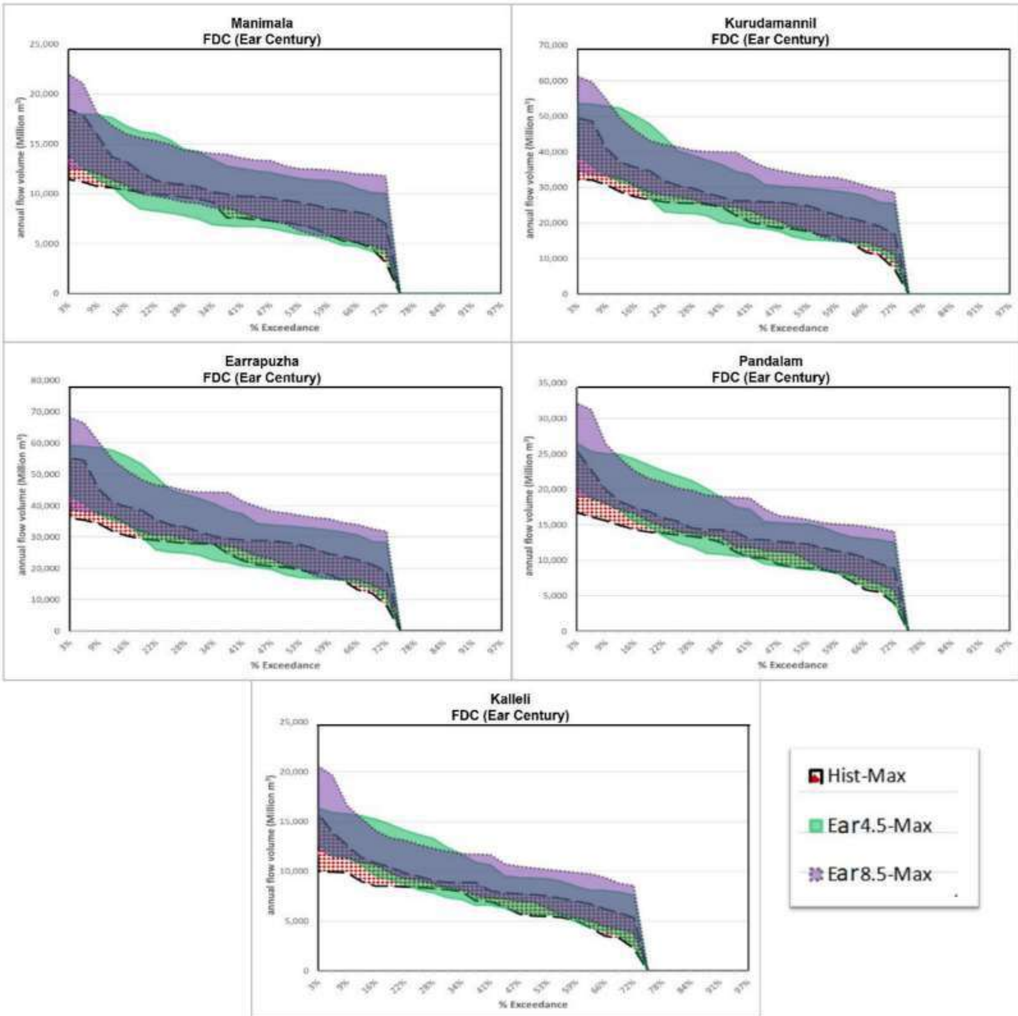


Figure 3.33: Flow duration curves at control locations (early-century)

Figure 3.33 represents the FDCs for various locations in the Pamba River Basin (Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli) under historical (Hist-Max) and future climate scenarios (Ear4.5-Max and Ear8.5-Max). These curves provide insights into the variability and reliability of streamflows at different exceedance probabilities.

1. General Observations:

- Higher Flows in Future Scenarios: Both RCP 4.5 and RCP 8.5 scenarios indicate increased high-flow volumes compared to historical conditions, particularly at lower exceedance levels (3%-20%). RCP 8.5 generally shows the highest flow volumes, reflecting more extreme hydrological events under a high-emission pathway.

- Wider Variability in RCP 8.5: The shaded regions for RCP 8.5 are generally broader, indicating greater interannual variability and higher uncertainty in projected flows.

2. Location-Specific Analysis:

Manimala:

- Moderate increases in flow volumes under RCP 4.5 and RCP 8.5, especially at lower exceedance probabilities (high flows).
- Flow reductions are less pronounced at higher exceedance levels, indicating relatively stable low-flow conditions.

Kurudamannil:

- Substantial increases in flow volumes under RCP 8.5, particularly for high flows (3%-20% exceedance).
- Greater variability in high-flow conditions compared to historical scenarios.
- Low-flow conditions remain consistent across scenarios.

Earrapuzha:

- Displays the highest flow volumes overall, particularly under RCP 8.5.
- High flows (3%-10% exceedance) are significantly elevated, indicating increased flood risks.
- Dry-season flows (70%-90% exceedance) show minimal differences across scenarios.

Pandalam:

- Lower flow volumes compared to upstream locations like Kurudamannil and Earrapuzha.
- High-flow increases under RCP 8.5 are noticeable but more subdued than in upstream stations.
- Low-flow conditions remain similar to historical patterns, with limited variability.

Kalleli:

- Lowest flow volumes among all locations.
- Modest increases in high-flow volumes under future scenarios.
- Relatively stable low-flow conditions, with minimal impact from climate change scenarios.

3. Implications of Climate Scenarios:

RCP 4.5 (Moderate Emissions):

- Moderate increases in high flows, with relatively stable low-flow reliability.
- Reduced variability makes this scenario more manageable for water resource planning.

RCP 8.5 (High Emissions):

- Significant increases in high-flow volumes, especially for low exceedance probabilities.
- Higher variability and lower reliability at higher exceedance levels highlight the risks of extreme hydrological events and potential droughts during the dry season.

4. Hydrological Implications:

- Flood Risk: Substantial increases in high flows under RCP 8.5, particularly in Earrapuzha and Kurudamannil, highlight the need for robust flood management strategies.
- Dry-Season Reliability: Persistent low flows across all scenarios emphasize the importance of water storage and conservation measures to mitigate potential water shortages.
- Water Resource Management: The increased variability in RCP 8.5 calls for adaptive water management strategies to address the dual challenges of floods and droughts.

The FDCs for five locations in the Pamba River Basin (Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli) show the variability of flow volumes at different exceedance probabilities under historical (Hist-Max) and future climate scenarios (Mid4.5-Max and Mid8.5-Max) (Figure 3.34). Key observations include:

1. General Trends

- The FDCs display a clear reduction in low flows (high exceedance probabilities) and an increase in high flows (low exceedance probabilities) under future climate scenarios compared to historical conditions.
- Greater variability is observed under RCP 8.5 (Mid8.5-Max) compared to RCP 4.5 (Mid4.5-Max), especially in the higher flow regime (low exceedance).

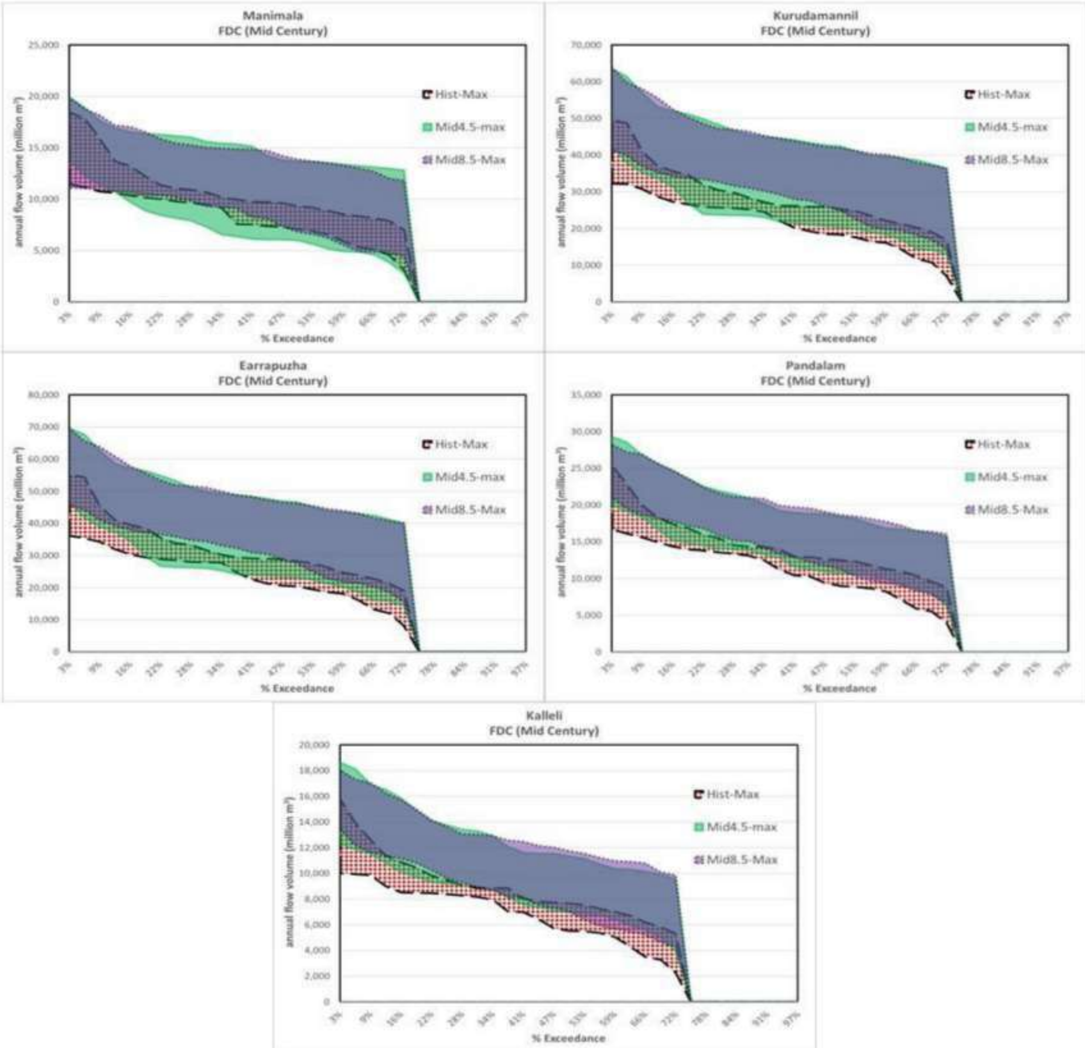


Figure 3.34: Flow duration curves at control locations (mid-century)

2. Scenario Comparisons

RCP 4.5:

- Higher exceedance probabilities (low flows) show slight reductions in flow, indicating minor changes in baseflows.

RCP 8.5:

- Significant increases in high flows (low exceedance probabilities), reflecting an elevated risk of extreme hydrological events.

- Low flows (high exceedance probabilities) are further reduced, suggesting increased periods of water scarcity during dry months.

3. Location-Specific Observations

Manimala and Kurudamannil:

- Both stations exhibit substantial increases in high flows under RCP 8.5, indicating higher flood risks.
- Low flow reductions are moderate, but overall variability is more pronounced under RCP 8.5.

Earrapuzha:

- This station shows the largest increases in high flows, especially under RCP 8.5, highlighting its susceptibility to extreme hydrological events.

Pandalam:

- As a downstream location, high flows are less pronounced than upstream stations, but reductions in low flows under both scenarios emphasize challenges in maintaining baseflows.

Kalleli:

- Exhibits the least variability in flow volumes compared to other locations, with moderate increases in high flows under both scenarios.

4. Implications for Water Management

- Flood Risks: Increased high flows, particularly under RCP 8.5, necessitate enhanced flood control infrastructure and policies.
- Dry-Season Scarcity: Reduced low flows across all scenarios emphasize the need for effective water storage and conservation strategies.
- Climate Resilience: The heightened variability under RCP 4.5 and 8.5 underscores the importance of adaptive management to mitigate extreme hydrological impacts.

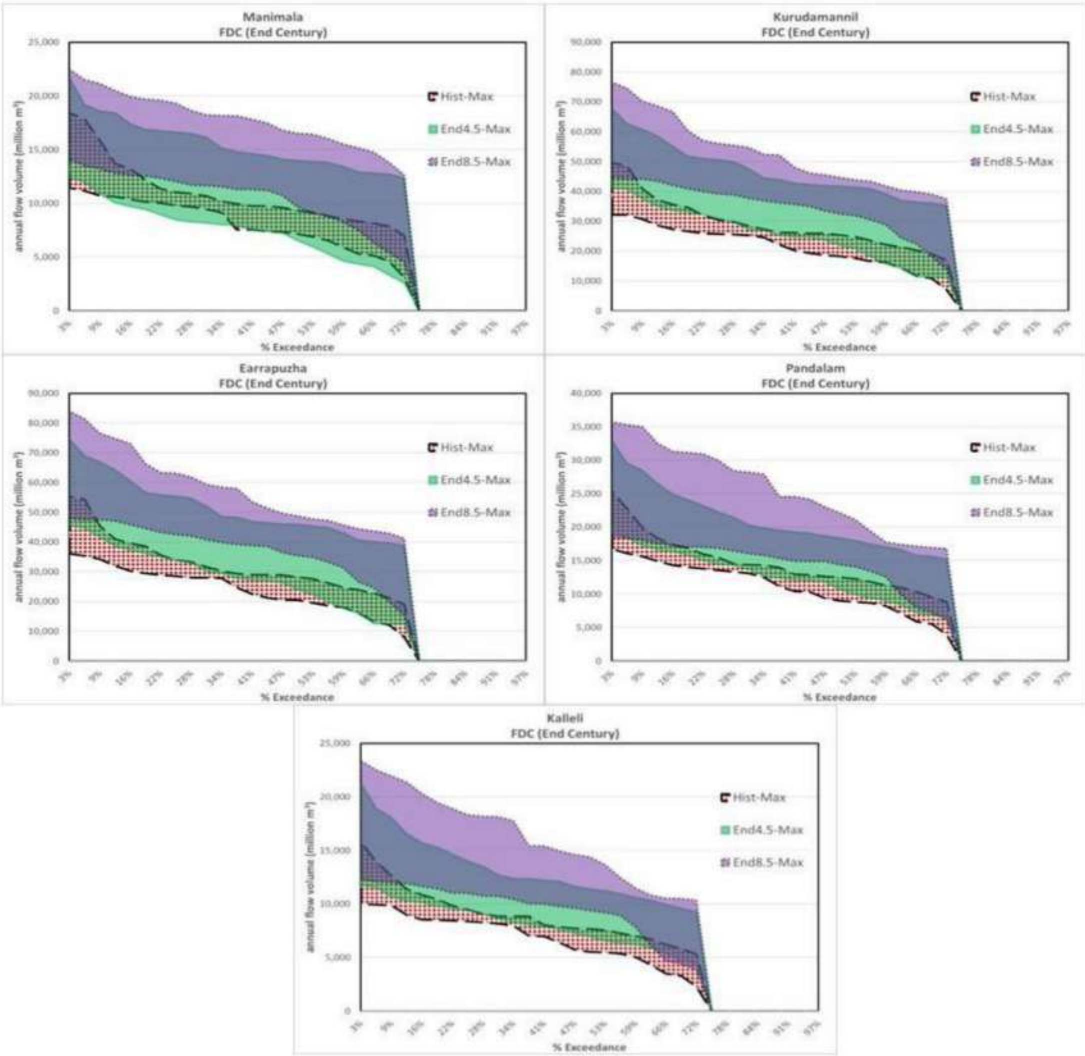


Figure 3.35: Flow-duration curves at control locations (end century)

The FDCs for Manimala, Kurudamannil, Earrapuzha, Pandalam, and Kalleli illustrate changes in flow volumes under historical (Hist-Max) and future climate scenarios (End 4.5-Max and End 8.5-Max) for the end of the century (Figure 3.35).

1. General Flow Trends

High Flows (Low Exceedance Probabilities):

- Both RCP 4.5 and RCP 8.5 show significant increases in high flows compared to historical conditions, with larger variations under RCP 8.5.

Low Flows (High Exceedance Probabilities):

- Future scenarios predict a reduction in low flows, highlighting potential challenges in maintaining baseflows during dry periods.

2. Scenario Comparisons

RCP 4.5 (End4.5-Max):

- Shows moderate increases in high flows and less reduction in low flows compared to RCP 8.5, reflecting controlled hydrological impacts under emission mitigation.

RCP 8.5 (End8.5-Max):

- Projects substantial increases in high flows and significant reductions in low flows, indicating higher variability and extreme hydrological conditions.

3. Location-Specific Observations

Manimala and Kurudamannil:

- High flows increase prominently under both scenarios, with RCP 8.5 showing greater variability. Low flows experience minor reductions, particularly under RCP 8.5.

Earrapuzha:

- Exhibits the largest flow volumes overall. High flows are significantly amplified under RCP 8.5, posing risks of extreme flood events.

Pandalam:

- Moderate increases in high flows are observed, but reductions in low flows are more pronounced, highlighting downstream impacts.

Kalleli:

- Displays smaller flow volumes compared to other locations, with high flow increases under both scenarios and noticeable low flow reductions under RCP 8.5.

4. Implications for Water Resource Management

- Flood Management: Enhanced infrastructure is needed to address increased high flows.
- Baseflow Preservation: Strategies to maintain dry-season flows are essential, given the reductions projected under both scenarios.

- Climate Adaptation: The scenarios results highlight the need of emission mitigation and adaptive water management to handle extreme hydrological changes.

Thus, the hydrological analysis for the GPB, derived from monthly maximum flows, FDC, and dependable flow variations under historical and future climate scenarios, reveals significant impacts of climate change on the basin's water resources. Both RCP 4.5 and RCP 8.5 scenarios project pronounced increases in peak monsoon flows, reflecting the intensification of extreme rainfall events. These increases are more severe under RCP 8.5, indicating heightened flood risks in upstream regions such as Earrapuzha and Kurudamannil. The dependable flow analysis at 75% exceedance highlights a seasonal shift, with peak flows becoming more pronounced during the monsoon and reduced flow availability in the dry months (January–May). This reduction in baseflows across most scenarios signals a potential challenge in sustaining water resources during non-monsoon periods, particularly for downstream locations.

The FDC analysis reinforces these trends, showing significant variability in flow regimes. High flows (low exceedance probabilities) are projected to increase dramatically under RCP 8.5, while low flows (high exceedance probabilities) decline, emphasizing the dual challenges of flood management and dry-season water scarcity. Spatial variability across the basin reveals that upstream regions are more sensitive to high flow changes, while downstream regions face exacerbated low-flow reductions. The comparison between RCP 4.5 and RCP 8.5 underscores the critical role of emission mitigation in moderating extreme hydrological changes. These findings highlight the urgency of integrating adaptive water management strategies, including enhanced flood control measures, water storage infrastructure, and policies promoting sustainable land and water use, to address the complex impacts of climate change on the GPB.

3.8. Groundwater Resource Scenario

Groundwater occurs under phreatic conditions in the weathered and fractured hard crystalline rocks, laterites and unconsolidated coastal sediments. The quality of ground water from the shallow zone in hard rocks, residual laterite and coastal alluvium is suitable for drinking and agricultural purposes. The Annual Extractable Ground Water Recharge of the basin is 736.11 MCM and existing Gross Ground Water Extraction is of the order of 283.37 MCM. The Stage of Ground Water Extraction is 40.21%. All the 24 blocks in the basin are Safe from the point of view of ground water extraction. (GEC Report, CGWB 2023).

The Groundwater Resource assessment has been carried out for all the 24 blocks that falls within the basin. Based on the annual groundwater recharge takes place within the basin and also by considering the annual groundwater extraction for various purposes the annual groundwater extraction was computed as on March 2023 (Figure 3.36). The graph presents a comprehensive overview of groundwater availability and utilization across 24 blocks in the basin. It includes total annual groundwater recharge and annual groundwater extraction, which are crucial for assessing the sustainability of groundwater resources in each region.

3.8.1. Groundwater Availability and Usage

The total annual groundwater recharge varies across different blocks, ranging from 1705.63 ha.m (Elanthoor) to 5997.97 ha.m (Pallom). This variation is influenced by factors such as rainfall, geological formations, and land use patterns. On the other hand, annual groundwater extraction varies from as low as 546.73 ha.m (Veliyanad) to as high as 1987.83 ha.m (Pallom). The availability of groundwater is estimated as per the GEC norms 2017 which was based on the annual groundwater recharge in the area and also based on the total draft for various purposes. From the analysis it is found that some blocks falls within the basin experience significant groundwater usage, likely due to irrigation, industrial and domestic demands. The total available groundwater and annual groundwater extraction is given in the Figure 3.36 below.

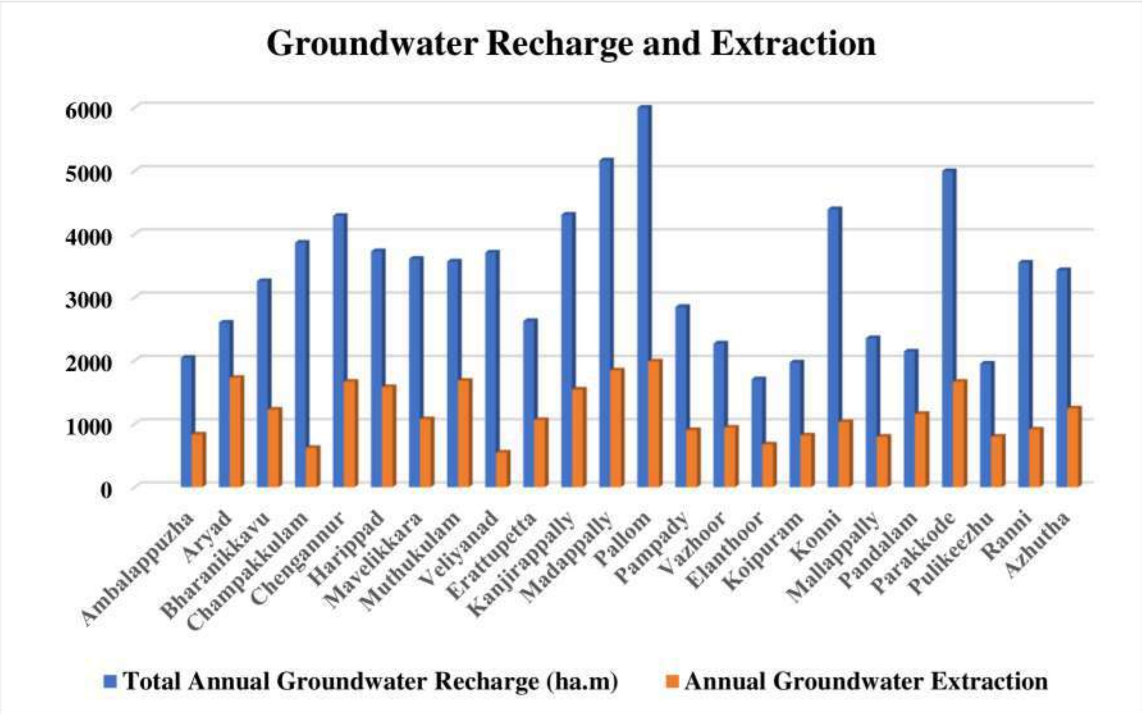


Figure 3.36: Graph representing Groundwater recharge and extraction (in ha.m)

- **Blocks with High Groundwater Extraction**

Even though certain blocks show high levels of groundwater extraction as comparted to their recharge rates, all the blocks coming under the basin belongs to safe category.

Aryad has an annual groundwater extraction of 1728.01 ha.m, which is a significant portion of its total recharge of 2601.24 ha.m.

Muthukulam extracts 1681.5 ha.m, which is nearly half of its total recharge (3567.24 ha.m).

Chengannur and Parakkode both extract more than 1600 ha.m, making them among the highly utilized groundwater regions.

Pallom, the block with the highest groundwater recharge (5997.97 ha.m), also has the highest extraction (1987.83 ha.m), showing a substantial dependency on groundwater resources.

- **Blocks with Low Groundwater Extraction**

Several blocks demonstrate relatively low groundwater extraction compared to their recharge rates, suggesting a sustainable utilization pattern or lower water demand.

Veliyanad, with a recharge of 3707.95 ha.m, only extracts 546.73 ha.m, showing a highly conservative water usage trend.

Champakkulam also has a low extraction rate of 620.82 ha.m against a recharge of 3865.5 ha.m, ensuring better sustainability.

Elanthoor, Koipuram, and Pulikeezhu show extractions below 900 ha.m, indicating they are not heavily dependent on groundwater.

3.8.2. Average Groundwater Fluctuation

The behaviour of groundwater levels within the basin in each block area was assessed based on the long term (decadal) water level analysis. The analysis of data indicates, the fluctuation of groundwater level within the basin ranges from 0.02 m at Muthukulam of Alleppey district to 2.12 m at Mallappaly in Pathanamthitta district. The average groundwater level fluctuation is given in the chart as below (Figure 3.37). The annual fluctuation of groundwater is an indication on the extent to which the groundwater is subjected to change/or the aquifer is able to replenish annually.

Table 3.3: Blockwise average groundwater level fluctuation

Sl No	Block	District	Average Fluctuation (m)
1	Ambalappuzha	Alappuzha	0.27
2	Aryad	Alappuzha	1.29
3	Bharanikkavu	Alappuzha	0.15
4	Champakkulam	Alappuzha	0.49
5	Chengannur	Alappuzha	1.79
6	Harippad	Alappuzha	1.46
7	Mavelikkara	Alappuzha	1.27
8	Muthukulam	Alappuzha	0.02
9	Veliyanad	Alappuzha	0.64
10	Erattupetta	Kottayam	0.17

11	Kanjirappally	Kottayam	0.99
12	Madappally	Kottayam	2.05
13	Pallom	Kottayam	1.89
14	Pampady	Kottayam	0.4
15	Vazhoor	Kottayam	1.2
16	Elanthoor	Pathanamthitta	0.38
17	Koipuram	Pathanamthitta	0.88
18	Konni	Pathanamthitta	0.96
19	Mallappally	Pathanamthitta	2.12
20	Pandalam	Pathanamthitta	1.55
21	Parakkode	Pathanamthitta	1.65
22	Pulikeezhu	Pathanamthitta	0.8
23	Ranni	Pathanamthitta	1.37
24	Azhutha	Idukki	1.79

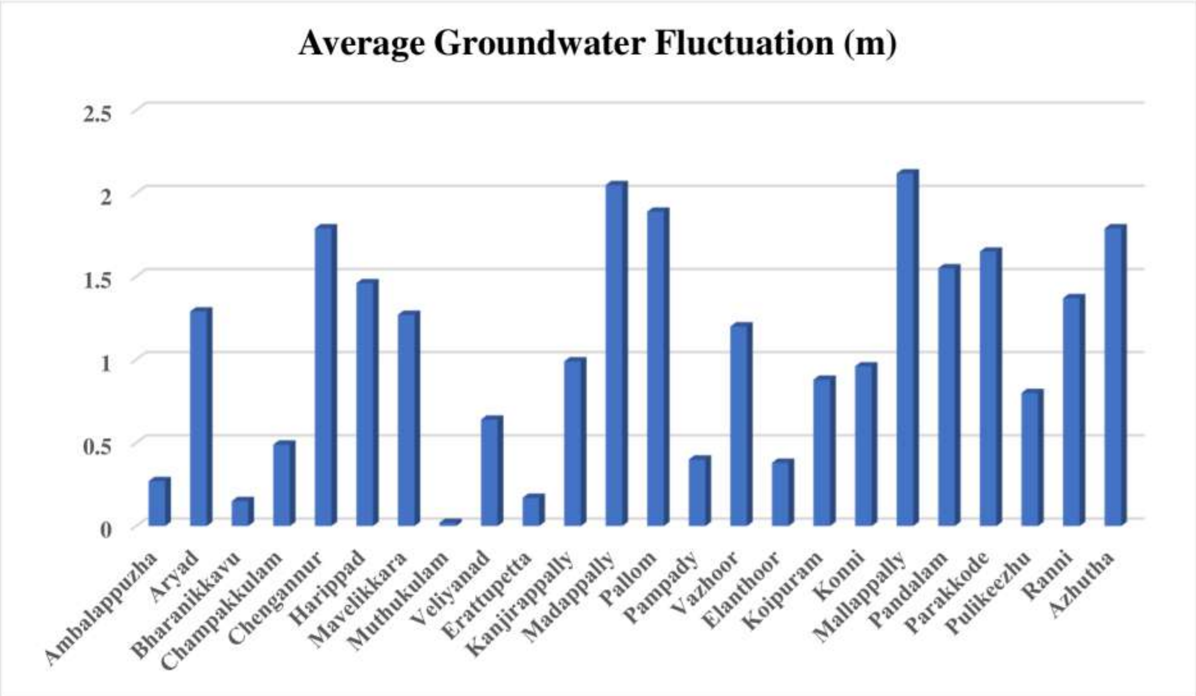


Figure 3.37: Average groundwater level fluctuation

Groundwater levels fluctuate due to seasonal variations, rainfall patterns, extraction rates, and geological conditions. The dataset (Table 3.3) presents the average groundwater level fluctuation (in meters) across 24 blocks in the basin.

- **Blocks with Minimal Fluctuation (Below 0.5 meters)**

Blocks with minimal groundwater fluctuations indicate a stable water table where groundwater recharge and discharge are nearly balanced or might be due to shallow groundwater conditions. These areas experience little seasonal variation in groundwater levels, suggesting discharge area having high groundwater potential

Muthukulam (0.02 m) records the lowest fluctuation, indicating an almost static water table. This could be due to low groundwater extraction, high recharge from rainfall or surface water, or proximity to water bodies.

Bharanikkavu (0.15 m), Erattupetta (0.17 m), Ambalappuzha (0.27 m), Elanthoor (0.38 m), Pampady (0.4 m), and Champakkulam (0.49 m) also fall under this category, indicating relatively stable groundwater conditions.

- **Blocks with Moderate Fluctuation (0.5 meters - 1.5 meters)**

Moderate groundwater fluctuation suggests seasonal variations in water availability. These areas fall in the intermediate zone bridging the recharge and the discharge area. The fluctuations in these area could be caused by irrigation, extraction for domestic and industrial use, and variations in rainfall recharge.

Blocks such as Veliyanad (0.64 m), Pulikeezhu (0.8 m), Koipuram (0.88 m), Konni (0.96 m), Kanjirappally (0.99 m), and Vazhoor (1.2 m) exhibit moderate fluctuation.

Other notable blocks include Aryad (1.29 m), Ranni (1.37 m), Harippad (1.46 m), and Pandalam (1.55 m), which show fluctuations indicating groundwater dependence and varying recharge rates.

- **Blocks with High Fluctuation (Above 1.5 meters)**

High groundwater fluctuation indicates recharging zone where significant seasonal variations in water levels often encountered. The high fluctuation in water level might be due to natural recharging of aquifers and fast movement of groundwater in to other areas. The extraction of groundwater for agriculture, urbanization, deforestation etc. also plays a major role in the groundwater fluctuvation.

Chengannur (1.79 m) and Azhutha (1.79 m) exhibit high fluctuations, indicating substantial seasonal variation in groundwater levels.

Pallom (1.89 m), Parakkode (1.65 m), and Mallappally (2.12 m) experience the highest groundwater fluctuations, suggesting excessive reliance on groundwater resources.

Madappally (2.05 m) also falls into this category, indicating potential groundwater stress due to high demand and limited recharge opportunities.

3.8.3. Categorization of Assessment Unit

As emphasized in the National Water Policy, 2012, a convergence of Quantity and Quality of ground water resources is required while assessing the ground water status in an assessment unit. Therefore, it is recommended to separate estimation of resources where water quality is beyond permissible limits for the parameter salinity.

3.8.4. Categorization of Assessment Unit Based on Quantity

The categorization based on status of ground water quantity is defined by Stage of Ground Water Extraction as given below:

Stage of Ground Water Extraction	Category
≤ 70%	Safe
> 70% and ≤90%	Semi-critical
> 90% and ≤100%	Critical
> 100%	Over Exploited

3.8.5. Categorization of Assessment Unit Based on Quality

As it is not possible to categorize the assessment units in terms of the extent of quality hazard, based on the available water quality monitoring mechanism and database on groundwater quality, the Committee recommends that each assessment unit, in addition to the Quantity based categorization (safe, semi-critical, critical and over-exploited) should bear a quality hazard identifier. If any of the three quality hazards in terms of Arsenic, Fluoride and Salinity are encountered in the assessment sub unit in mappable units, the assessment sub unit may be tagged with the particular Quality hazard. The report details with only quantification of resources and the quality component is not touched upon.

3.8.6. Annual Extractable Groundwater

The annual extractable groundwater refers to the amount of groundwater that can be sustainably withdrawn from underground reserves. This includes the amount of groundwater recharged in to the aquifer against the groundwater that can be safely withdrawn after accounting the natural losses. The values for different blocks show significant variations, indicating differences in natural recharge capacity, geographic conditions, and water demand. Among the blocks analysed (table 4), Pallom has the highest extractable groundwater availability at 5,698.07 ha.m, followed by Madappally (4,648.38 ha.m), Parakkode (4,496.45 ha.m), Kanjirappally (3,877.04 ha.m), and Chengannur (3,860.24 ha.m). These blocks have a higher capacity to sustain groundwater extraction due to favorable recharge conditions or lower existing extraction pressure. On the other hand, blocks with the lowest annual extractable groundwater include Elanthoor (1,535.07 ha.m), Pulikeezhu (1,757.8 ha.m), Koipuram (1,774.85 ha.m), Vazhoor (2,044.25 ha.m), and Pandalam (2,038.22 ha.m). These regions might have limitations in groundwater recharge, making them more vulnerable to water scarcity, especially during dry periods.

3.8.7. Stage of Groundwater Extraction

Among the blocks, Aryad has the highest stage of extraction at 69.93%, followed by Pandalam (56.81%), indicating significant reliance on groundwater resources. These areas require careful water management strategies to prevent excessive depletion and ensure future water security. In most of the blocks the stage of groundwater extraction is in the range of 30-40%. This is categorised as safe. Conversely, Veliyanad (16.38%) and Champakkulam (16.91%) have the lowest stage of extraction, suggesting that these blocks have ample groundwater resources that are currently underutilized. This could be due to lower population density, less industrial or agricultural demand, or better surface water availability.

There is no thread to the depletion of groundwater resources, but the groundwater in the basin is subjected to high degree of contamination and also prone to salinity in the coastal tracts. The urban flooding and stagnant groundwater conditions due to infrastructure development in the area contributes to the rise in water level in many parts of the basin.

3.9. Summary

The SWAT has been used to evaluate the water availability in the basin. The historical water availability in the GPB highlights the complex interplay between rainfall, runoff, soil moisture, and ET, which collectively determine the hydrological balance and water resources in the region. The rainfall patterns indicate significant spatial variability across the catchment. Western and central regions experience high annual rainfall (up to 3000 mm), while the eastern most areas receive comparatively lower rainfall (below 1500 mm). This uneven distribution of rainfall is the primary driver of differences in water balance components across the catchment. The downstream regions of GPB, with higher rainfall are likely to have better water availability, and are also thus more vulnerable to flood events.

Considering the modelled runoff, the runoff magnitude during high-flow periods (lower exceedance probabilities) is notably increased in the future scenarios compared to historical conditions across all stations. The sharp increase in the high-flow values indicate high sensitivity to increasing rainfall in the GPB. This indicates significant increase in the extreme flow events in the catchment and point to an increased risk of flood events in GPB. The low-flow values (higher exceedance probabilities) remain same in the future scenarios considered, indicating stable baseflow conditions in the GPB. Over the historical period, the annual runoff in the catchment shows a statistically significant increasing trend. On climate change projections, High flows (low exceedance probabilities) are projected to increase dramatically under RCP 8.5, while low flows (high exceedance probabilities) decline, emphasizing the dual challenges of flood management and dry-season water scarcity.

Various levels of stakeholder meetings were conducted across the basin to identify and understand the prevailing challenges. These meetings facilitated the recognition of key issues affecting the basin, providing valuable insights from diverse perspectives. The next chapter presents a comprehensive analysis of the identified problems, incorporating detailed stakeholder consultations and a review of existing legislation governing basin management. This assessment aims to offer a clear understanding of the regulatory framework and stakeholder concerns to inform effective management strategies.

4. Stakeholder Engagements and Legislation

4.1. Introduction

The legal acts and policies form a crucial foundation for the effective planning and management of the Pamba River Basin. This framework, coupled with the governing structure, establishes the rules and requirements adhered to by national, state, district, and municipal stakeholders. Its purpose is to facilitate the strategic planning, control, and maintenance of surface waters and groundwaters within the Pamba River Basin. The roles and collaborations among stakeholders in River Basin Management (RBM) in the Pamba River Basin are partially determined by this framework.

Effective water management in the Pamba Basin requires a collaborative and multi-dimensional approach, involving various stakeholders with specific interests in different aspects of water-related challenges. Table 4.1 provides an overview of key interest categories, the relevant stakeholders, and their specific interests in the sustainable management of water resources in the Pamba Basin. From governmental bodies and environmental agencies to local governance institutions, religious organizations, and the media, each stakeholder plays a crucial role in addressing specific challenges and promoting sustainable practices in the region.

Table 4.1: Stakeholder Interest Analysis in the Pamba Basin

Interest Category	Stakeholders	Specific Interest
Water Management and Agricultural Practices	Department of Agriculture & Farmers Welfare, Directorate of Agriculture, Agriculture University, Farmers Associations, Soil Survey & Soil Conservation Department	- **Department of Agriculture Development and Farmers Welfare:** Formulating and implementing policies for agriculture. - **Directorate of Agriculture:** Optimizing irrigation practices, managing water resources for crops, implementing sustainable agricultural practices in the Pamba Basin. - **Agriculture University:** Research and education for sustainable agricultural practices. - **Farmers Associations:** Advocating for the welfare of farmers and promoting sustainable agriculture. - **Soil Survey & Soil Conservation Department:** Implementing soil conservation measures for sustainable agriculture.

Water Resources and Sustainability	Water Resources Department, Irrigation Department, Groundwater Department, Kerala Water Authority (KWA), State Water Transport Department	- **Water Resources Department:** Formulating state water policies and ensuring sustainable water use. - **Irrigation Department:** Managing water resources, addressing water scarcity, and promoting sustainability. - **Groundwater Department:** Regulating and managing groundwater resources. - **Kerala Water Authority (KWA):** Ensuring reliable and sustainable water supply. - **State Water Transport Department:** Managing and regulating water transport sustainably in the basin.
Environmental Conservation and Climate Change	Department of Environment & Climate Change, Forests Department, Kerala Coastal Zone Management Authority, Kerala State Coastal Area Development Corporation Limited, Kerala Land Use Board, Kerala State Pollution Control Board	- **Department of Environment & Climate Change:** Formulating and implementing policies for environmental conservation and climate change mitigation. - **Forests Department:** Managing and conserving forest resources. - **Kerala Coastal Zone Management Authority:** Regulating activities in coastal zones to prevent environmental impacts. - **Kerala State Coastal Area Development Corporation Limited:** Implementing coastal conservation projects. - **Kerala Land Use Board:** Regulating land use to balance development with environmental conservation. - **Kerala State Pollution Control Boards:** Preventing pollution and ensuring water quality.
Local Governance and Community-Specific Issues	Kerala State Planning Board, Local Self Government Department, Local Self Government Institutions, LSGD Planning, Kudumbashree, Co-ops, NGOs, Asha workers, etc.	- **Kerala State Planning Board:** Integrating water management into state-level development plans. - **Local Self Government Department:** Formulating policies for local self-government and addressing community-specific water issues.

		- **Local Self Government Institutions:** Implementing water management plans at the local level. - **LSGD Planning:** Planning for local self-government development. - **Kudumbashree:** Community development initiatives. - **Co-ops:** Cooperative organizations participating in sustainable practices. - **NGOs and Asha workers:** Community engagement and awareness.
Disaster Response and Safety	Kerala State Disaster Management Authority, Police Department, Fire & Rescue Department, Emergency Response Teams	- **Kerala State Disaster Management Authority:** Formulating and implementing disaster response plans. - **Police Department:** Ensuring law and order during water-related emergencies. - **Fire & Rescue Department:** Providing swift disaster response, including floods and landslides. - **Emergency Response Teams:** Rapid response teams for water-related disasters.
Cultural and Religious Preservation	Travancore Devaswom Board, Major Religious Institutions	- **Travancore Devaswom Board:** Managing and preserving cultural and religious sites from water-related impacts. - **Major Religious Institutions:** Participating in the preservation of water resources during religious events and pilgrimages.
Tourism and Hospitality	Tourism Department, Hotels	- **Tourism Department:** Managing water resources sustainably to support tourism. - **Hotels:** Adhering to sustainable water practices and addressing associated environmental impacts.
Fisheries and Aquatic Ecosystems	Fisheries Department	- **Fisheries Department:** Preserving aquatic ecosystems, preventing overfishing, and addressing the impacts of climate change in aquatic environments.
Health and Healthcare Services	Department of Health and Family Welfare, Hospitals	- **Department of Health and Family Welfare:** Addressing water-borne diseases, ensuring access to clean

		drinking water, and promoting public health.
Industries and Industrial Water Use	Industries	- **Industries:** Balancing industrial water use with environmental conservation, preventing water pollution.
Media and Awareness	Media	- **Media:** Communicating water-related issues, creating awareness, and influencing public opinion.
Financial Support for Development	External Funding Agencies	- **External Funding Agencies:** Supporting projects aimed at addressing water-related challenges in the basin.
General Interests	Pilgrims (Visitor to religious and cultural sites)	- **Pilgrims:** Ensuring the sustainable use of water resources during religious events and pilgrimages.

4.2. Indicative list of Stakeholder Engagements

The Greater Pamba River Basin encompasses a diverse set of stakeholders, each with a crucial role in its management and development. These stakeholders can be broadly classified into primary and secondary groups. The primary stakeholders include the populace residing in the basin, spread across hilly, midland, and coastal regions, and further categorized by gender, age groups, and economic backgrounds. These residents are the main beneficiaries of the water resources, relying on the basin for their livelihoods, access to water, protection of life and property, and the improvement of socio-economic conditions.

4.2.1. Primary Stakeholders

The local communities play a critical role in the utilization of the basin's resources. The residents across the hilly, midland, and coastal regions have different needs based on topography, economic activities, and access to resources. These communities are directly impacted by water availability, flood risks, and environmental changes, making them central to the success of the basin's management. Their interests lie in ensuring equitable access to water, safeguarding their livelihoods, and fostering socio-economic growth. Key issues they face include flooding, landslides, soil erosion, water scarcity, water pollution, waterborne diseases, ecology degradation, coastal erosion, and climate change. They also face challenges related to improper sewerage disposal and encroachment on natural areas.

4.2.2. Secondary Stakeholders

1. **Ministry of Agriculture & Farmers Welfare** plays a pivotal role in formulating policies related to agriculture, focusing on irrigation and water availability in India. This ministry's key interest lies in addressing challenges related to sustainable agricultural practices

and irrigation efficiency, which are often impacted by water scarcity, salinity intrusion, and changing rainfall patterns.

2. **Ministry of Jal Shakti**, as the overarching body for water resources in India. Their primary interest is to manage water scarcity, facilitate irrigation, and oversee equitable distribution of water resources.
3. **Ministry of Environment, Forest and Climate Change** formulates policies for environmental conservation and climate change mitigation. Their interest focuses on preserving ecosystems, maintaining biodiversity, and mitigating the impacts of climate change.
4. **Kerala State Planning Board** coordinates state-level development plans, integrating water management practices into broader developmental goals. Their interest is in ensuring that sustainable water use is a part of the state's growth trajectory.
5. **Water Resources Department:** Formulates state water policies and ensures the sustainable management and distribution of water across the basin.
6. **Local Self Government Department** addresses governance and urban planning issues at the local level. The department plays an essential role in managing urban water demands and addressing local water-related challenges such as infrastructure development, disaster management, and sanitation.
7. **Irrigation Department** is responsible for managing the irrigation infrastructure, including canal systems and minor irrigation schemes. Their role is to ensure efficient water distribution for agriculture and manage the risks of flooding in the basin.
8. **Groundwater Department** manages and monitors groundwater extraction across the basin. Their work is critical in ensuring that groundwater is sustainably used, and over-extraction is prevented, particularly in areas affected by water scarcity.
9. **Local Self Government Institutions** are responsible for governance at the grassroots level. They address community-specific water issues and ensure local participation in the water management process, particularly in flood-prone and underdeveloped regions.
10. **Kerala State Electricity Board (KSEB)** manages the generation and distribution of electricity in Kerala, balancing hydropower generation needs with other water demands in the basin. They must carefully manage the use of water for electricity production to prevent over-extraction and ensure sufficient water for agricultural and domestic use.
11. **Kerala State Disaster Management Authority** handles disaster response, focusing on mitigating the impacts of floods, landslides, and other water-related emergencies on communities within the basin.

12. **Kerala Forest Department** is responsible for conserving forest resources and protecting wildlife habitats. They ensure the preservation of river ecosystems and biodiversity, which are vital for maintaining the ecological balance of the basin.
13. **Department of Environment & Climate Change** formulates and implements policies that address environmental degradation and climate change. Their interest lies in reducing the impacts of climate change on water resources and ecosystems in the basin.
14. **LSGD Planning** coordinates local self-government activities, integrating water management into local development plans and addressing community-specific needs, including disaster preparedness and infrastructure improvements.
15. **Department of Mining and Geology** monitors and regulates mining activities that may cause water pollution or soil erosion, ensuring that mining does not degrade the water quality or riverbed of the Pamba River.
16. **Kerala Coastal Zone Management Authority** manages the preservation of coastal ecosystems, focusing on addressing issues like coastal erosion, flooding, and maintaining water quality.
17. **Kerala State Coastal Area Development Corporation Limited** implements projects for the development of coastal areas, balancing development and environmental conservation in coastal regions, particularly around river mouths.
18. **Fisheries Department** is tasked with regulating fisheries activities, ensuring that aquatic ecosystems remain healthy and fish populations are sustainable. Their interest lies in preserving biodiversity and preventing overfishing.
19. **Department of Agriculture Development and Farmers Welfare** promotes sustainable agricultural practices, to enhance agricultural productivity of agricultural commodities so as to make agriculture a sustainable and viable vocation providing livelihood support.
20. **Agriculture University** provides research and education in agricultural sciences, offering expertise to improve agricultural productivity and sustainability in the basin.
21. **Department of Health and Family Welfare** focuses on addressing waterborne diseases and ensuring access to clean drinking water, safeguarding public health in the basin.
22. **Tourism Department** manages tourism activities, ensuring that water resources are used sustainably and addressing environmental impacts caused by tourism-related activities.

23. **Animal Husbandry Department** is responsible for regulating animal husbandry practices and ensuring access to water for livestock, preventing pollution, and addressing water-related challenges.
24. **Police Department** ensures law and order during emergencies, particularly in flood situations. They are essential for managing disaster responses and ensuring public safety during water-related incidents.
25. **Fire & Rescue Department** participates in emergency responses to natural disasters, including floods, and helps with rescue operations during water-related emergencies.
26. **Emergency Response Teams** are specialized units trained to respond swiftly and effectively to water-related emergencies, ensuring that communities are safeguarded during floods or other water crises.
27. **Travancore Devaswom Board** manages Hindu temples and related religious activities, ensuring that water-related impacts do not affect cultural and religious sites.
28. **Kerala Water Authority (KWA)** is responsible for managing and regulating water supply in the state. Their interest lies in ensuring a reliable and safe water supply for domestic and industrial use while addressing water scarcity issues.
29. **State Water Transport Department** regulates water transport, ensuring sustainable navigation on the rivers and addressing issues related to waterway sustainability.
30. **Kerala Land Use Board** is responsible for planning and regulating land use in the basin, ensuring that land use policies are integrated with water management strategies to prevent environmental degradation.
31. **Kerala State/Central Pollution Control Boards** monitor and regulate pollution, particularly water pollution, ensuring water quality is maintained for human consumption and ecosystem health.
32. **Kudumbashree, Co-ops, NGOs, Asha workers, etc.** are community-based organizations and NGOs that play an important role in addressing water-related issues at the grassroots level. They promote sustainable practices and raise awareness about water conservation.
33. **Major Religious Institutions** play a key role in the basin, managing religious sites and activities while ensuring that water resources are used sustainably during religious events.
34. **Farmers Associations** represent the interests of farmers in the basin, advocating for sustainable agricultural practices, efficient water management, and addressing irrigation challenges.

35. **Pilgrims** visit religious sites in the basin, particularly during the Sabarimala pilgrimage season. Their interest lies in ensuring the sustainable use of water resources during peak pilgrimage periods to avoid water shortages.
36. **Media** plays a critical role in reporting and creating awareness about water-related issues, influencing public opinion, and promoting water conservation through outreach campaigns.
37. **Hospitals** provide healthcare services and address health issues related to water quality, including waterborne diseases and contamination.
38. **Industries** in the basin use water for industrial processes. Their interest is balancing water use with environmental conservation, preventing water pollution, and ensuring that industries contribute to sustainable development.
39. **Hotels** in the region, particularly in areas with tourism, manage water resources for hospitality services. Their focus is on ensuring the sustainable use of water to support tourism while mitigating the impacts on local water supplies.

4.3. Stakeholder Engagements

4.3.1. Kuttanad Flood Management Consultation (January 10, 2023)

On January 10, 2023, a stakeholder consultation was conducted for the Kuttanad Package Flood Management Programme. The session involved representatives from the Kerala Irrigation Department, technical experts from IIT Madras, local authorities, and community leaders, aiming to address flood risks in the flood-prone Kuttanad region while minimizing disruption to livelihoods and ecosystems.

During the meeting, stakeholders raised significant concerns about the initial proposal to install multiple flood regulators, such as those at Karumadi, Thakazhy, and Cheruthana. Challenges highlighted included potential habitat disruption, land acquisition difficulties, and the logistical complexity of constructing flood walls (bunds) along densely populated or encroached river stretches. These concerns underscored the need for alternatives that prioritized efficiency and feasibility without compromising flood resilience.

In response, participants proposed non-structural measures centered on improving channel capacity. Key suggestions included Increasing the carrying capacity the Thottappally Leading Channel by 50–200 meters and creating new parallel channels, such as alongside Korankuzhy Thodu or between the Pampa River and Thottappally Spillway, to divert floodwater more effectively. The study team integrated these proposals into revised simulations, testing scenarios that combined partial channel modifications with fewer regulators. Technical validation revealed that Increasing the carrying capacity of the Thottappally channel by 200 meters or constructing parallel channels could lower water levels by 0.5–1.5 meters during moderate floods (e.g., 25-year events), significantly reducing overtopping risks in vulnerable areas like Kidangara and Mankombu. However, stakeholders acknowledged that extreme events, such as 100-year floods, would still require complementary strategies, including temporary gate operations during flood recession.

Final recommendations prioritized channel modifications over extensive structural interventions. Increasing the carrying capacity critical channels and constructing strategic parallel pathways were endorsed as primary solutions, supplemented by minimal regulator placement at critical junctions like Kuthiyathodu. This approach balanced hydrological efficacy with socio-environmental feasibility, ensuring minimal disruption to agricultural livelihoods and ecosystems.

4.3.2. Pathanamthitta Workshop on Integrated River Basin Management (February 17, 2024)

On February 17, 2024, a stakeholder engagement workshop was held in Pathanamthitta to address the integrated management of the Pamba, Manimala, and Achankovil river basins. The workshop brought together diverse stakeholders, including local communities, government departments, environmental groups, industry representatives, and technical experts, to collaboratively address water-related challenges such as flooding, water scarcity, pollution, and ecosystem degradation. The primary goal was to formulate strategies for equitable and climate-resilient governance while balancing ecological sustainability and socio-economic needs.

Discussions focused on five key themes. First, participants highlighted the urgent need to address river health issues, particularly siltation, sand mining, and encroachments in the Manimala and Pamba rivers. Proposals included systematic desilting, check dam construction, and rehabilitation of degraded stretches.

Second, pollution control emerged as a critical concern, with stakeholders advocating for stricter enforcement of bio-toilet systems, sewage treatment plants (STPs), and real-time monitoring of industrial discharge and coliform bacteria levels. Third, ecosystem conservation priorities centered on reforestation of riverbanks, removal of invasive species, and soil conservation measures to mitigate fertilizer overuse and landslides.

Fourth, flood management dominated the dialogue, with unanimous consensus on conducting a comprehensive flood analysis to map vulnerabilities, identify high-risk zones, and design targeted mitigation measures such as embankment reinforcement and early warning systems.

Fifth, climate resilience strategies emphasized flood forecasting systems, rainwater harvesting, and climate-resilient agricultural practices. Local representatives stressed the importance of ward-level participation in decision-making, improved drainage networks, and collaboration with the Kerala State Disaster Management Authority (KSDMA) for disaster preparedness.

Key outcomes included immediate actions such as desilting critical river stretches, installing flood forecasting systems, and establishing STPs. Policy reforms focused on developing a Drainage Master Plan to align urban infrastructure with natural watercourses and revising the RKI Master Plan to integrate climate resilience and coastal salinity mitigation. Community-driven initiatives prioritized rainwater harvesting, check dams for water scarcity, and awareness campaigns for sustainable farming practices.

4.3.3. Outcomes

The consultations in Pathanamthitta (2024) and Kuttanad (2023) collectively underscored the importance of aligning technical solutions with community needs and ecological realities. The Pathanamthitta workshop established a holistic framework for integrated basin management, emphasizing pollution control, and ecosystem restoration. In contrast, the Kuttanad consultation focused on localized flood mitigation through channel modifications, ensuring minimal disruption to livelihoods in one of Kerala's most agriculturally sensitive regions.

Common priorities emerged across both initiatives, including community-centric governance, adaptive infrastructure, and risk-informed planning. Enhanced stakeholder participation at the ward level, combined with structural measures like check dams and nature-based solutions such as reforestation, formed the backbone of proposed strategies. Flood forecasting systems and master plans were identified as critical tools for addressing both immediate and long-term challenges.

The workshop successfully synthesized diverse stakeholder inputs into a cohesive roadmap for IRBM, balancing ecological sustainability, climate resilience, and socio-economic equity. By aligning interventions with the Risk Matrix priorities, the framework aims to address urgent challenges while fostering long-term water security.

4.4. Issues Faced by Stakeholders

Communities in the region face numerous water-related challenges, necessitating a coordinated effort from various stakeholders. Table 4.2 outlines key issues, the communities affected, and the roles and interests of relevant stakeholders in addressing these challenges.

Table 4.2: Water Management Stakeholder Roles and Interests for Various Issues

Issue	Communities Affected	Roles and Interests of Stakeholders
Flooding	Residents/Local Communities, Agricultural Communities, Industries	**- Kerala State Disaster Management:** Mitigating impacts of floods, including reallocation of affected people **-Agriculture Department:** Promoting sustainable agricultural practices to prevent soil erosion and enhance water retention.

		- Irrigation Department: Managing water resources, including dams, to prevent flooding through effective water release and regulation. **- Revenue Department:** Addressing land use planning and flood-prone area management, including people reallocation. **- Kerala State Electricity Board (KSEB):** Managing dam operations to control water release and mitigate flooding risks. **- Local Self Government:** Participating in local-level disaster response and recovery efforts, coordinating with communities.
Landslides	Residents/Local Communities	- **Agriculture Department:** Implementing measures to address water availability and agricultural practices to prevent landslides. - **Kerala State Land Use Board:** Addressing soil stability, land-use planning, and implementing measures to prevent landslides. - **Revenue Department:** Addressing land use planning and slope stability to prevent landslides, including people reallocation. - **Kerala State Disaster Management Authority (KSDMA):** Involved in disaster risk reduction and management, implementing measures to prevent and respond to landslides, including people reallocation. - **Local Self Government:** Participating in local-level disaster response and recovery efforts, coordinating with communities.
Soil Erosion	Residents/Local Communities, Environmental and Conservation Groups	- **Agriculture Department:** Implementing measures to address water availability and agricultural practices, reducing soil erosion. - **Department of Forests & Wildlife:** Managing and conserving forest resources to prevent soil erosion. - **Soil Survey & Soil Conservation Department:** Implementing soil conservation measures, conducting

		surveys, and promoting sustainable soil management practices. - **Kerala State Land Use Board:** Addressing soil conservation and land-use planning. - **Local Self Government:** Participating in local-level environmental conservation and land-use planning, coordinating with communities.
Drought/Inadequate Flow	Residents/Local Communities	- **Agriculture Department:** Addressing water availability and agricultural practices. - **Irrigation Department:** Managing water resources, including dams, to ensure efficient water use for agriculture. - **Kerala State Electricity Board (KSEB):** Managing dam operations to address water scarcity and ensure sustainable water release. - **Local Self Government:** Participating in local-level water management and planning, coordinating with communities.
Drinking Water Scarcity	Residents/Local Communities, Livestocks	- **Agriculture Department:** Addressing water availability. - **Kerala Water Authority (KWA):** Ensuring reliable and safe water supply. - **Local Self Government:** Participating in local-level water supply planning, coordinating with communities.
Water Pollution & Water-borne Diseases	Residents/Local Communities, Livestocks, Industries, Tourism and Recreation	- **Department of Environment and Climate Change:** Protecting ecosystems and mitigating climate change impacts. - **Kerala State/Central Pollution Control Boards:** Preventing water pollution and ensuring water quality. - **Local Self Government:** Participating in local-level pollution control and environmental conservation, coordinating with communities. Participating in local-level public health planning and awareness, coordinating with communities. - **Health Department:** Addressing health issues related to water quality.

Ecology/Ecosystem Degradation	Residents/Local Communities, Environmental and Conservation Groups, Fishing and Aquatic Communities	- **Department of Environment and Climate Change:** Protecting ecosystems and biodiversity. - **Kerala State Land Use Board:** Addressing ecosystem conservation and land-use planning. - **Local Self Government:** Participating in local-level environmental conservation and planning, coordinating with communities. - **Fisheries Department:** Managing and regulating fisheries activities.
Coastal Erosion	Residents/Local Communities	- **Kerala State Disaster Management Authority (KSDMA):** Involved in disaster risk reduction and management, implementing measures to address coastal erosion and flooding. - **Irrigation Department:** Managing water resources to mitigate coastal erosion impacts. - **Harbor Engineering Department:** Implementing measures to address coastal erosion and safeguard coastal infrastructure. - **Revenue Department:** Addressing land use planning for coastal areas and mitigating erosion impacts, including people reallocation. - **Local Self Government:** Participating in local-level disaster response and recovery efforts, coordinating with communities.
Encroachment	Residents/Local Communities	- **Agriculture Department:** Addressing water availability and agricultural practices. - **Revenue Department:** Addressing land use planning, including preventing and mitigating encroachments. - **Local Self Government:** Participating in local-level land use planning and enforcement, coordinating with communities.
Lack of Proper Sewerage Disposal Mechanisms	Residents/Local Communities, Tourism and Recreation	- **Kerala State Pollution Control Boards:** Regulating and preventing water pollution.

		- **Local Self Government:** Addressing water-related challenges at the local level, including sewerage disposal planning, Implementing and managing local-level sewerage disposal systems, coordinating with communities.
Salinity Intrusion / Prevention of Saltwater Entry using Barrages	Agricultural Communities, Fishing and Aquatic Communities	- **Irrigation Department:** Managing water resources, including barrages, to manage salinity intrusion. - **Local Self Government:** Participating in local-level water management and planning, coordinating with communities. - **Agriculture Department:** Addressing water availability and agricultural practices. - **Fisheries Department:** Managing and regulating fisheries activities, collaborating with the Irrigation Department for water management.

A Risk Matrix analysis revealed stakeholder-specific priorities. Residents and local communities identified flooding, water scarcity, pollution, and inadequate sewerage disposal as high risks, while agricultural communities highlighted flooding, water scarcity, and climate change. Industries prioritized flooding and pollution, whereas environmental groups focused on pollution, ecosystem degradation, and climate change. Tourism sectors flagged pollution and sewerage disposal as critical issues, and livestock owners emphasized water scarcity. This matrix underscored cross-cutting challenges like flooding and pollution, while sector-specific risks, such as salinity intrusion for coastal agricultural communities, demanded targeted interventions. Table 4.3 shows Risk Matrix of Stakeholders Engagement.

Table 4.3:Table showing Risk Matrix of Stakeholders Engagement

Stakeholder	Flooding	Water Scarcity	Water Pollution	Ecosystem Degradation	Climate Change	Salinity Intrusion	Lack of Sewerage Disposal
Residents/Local Communities	High	High	High	Medium	Medium	Low	High
Livestock Owners	Low	High	Medium	Low	Medium	Low	Low
Agricultural Communities	High	High	Medium	Low	High	High	Low
Fishing and Aquatic Communities	Medium	Medium	High	Medium	Medium	Medium	Low

Industries	High	Medium	High	Low	Medium	Low	Medium
Tourism and Recreation	Low	Low	High	Low	Low	Low	High
Environmental and Conservation Groups	Medium	Low	High	High	High	Low	Low

4.5. Legislation

In addition to water-related acts, it is essential to consider legislation from other sectors to ensure a comprehensive and integrated approach to RBM. A list of pertinent Indian legal acts and policies relevant to the implementation of water resources and river basin management in the Pamba River Basin, encompassing both national and state legislations are given in Table 4.4 and Table 4.5 respectively.

Table 4.4: National-Level Legislations

Year	Type	Legislation	Key Features	Importance for IRBM in Pamba
1974	Act	Water (Prevention and Control of Pollution) Act, 1974	Establishes Pollution Control Boards for water pollution prevention and control.	Provides a framework for preventing and controlling water pollution, crucial for river health.
1986	Act	Environment (Protection) Act, 1986	Empowers central government for environmental protection and sustainable development.	Instrumental in shaping environmental policy, vital for addressing diverse environmental challenges.
2002	Policy	National Water Policy, 2002	Formulated by the Ministry of Water Resources to govern water resources planning and development.	Guides sustainable and equitable use of water resources, addressing complexities in water management.
2005	Act	National Disaster Management Act, 2005	Comprehensive legislation for effective disaster management at national, state, and district levels.	Addresses proactive disaster management, including response and recovery, relevant in water-related incidents.
2006	Act	The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006,	To correct the historical injustices faced by forest-dwelling communities, particularly Scheduled Tribes (STs) and Other Traditional Forest Dwellers (OTFDs), by	Ensuring the inclusion and rights of forest-dependent communities in conservation efforts.

			recognizing their rights to forest land and resources	
2013	Act	The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act, 2013	To ensure a fair and transparent process for land acquisition, provisions for their rehabilitation and resettlement.	Ensures fair and systematic approach to land acquisition for river conservation, flood management, and infrastructure development.
2017	Rule	Wetlands (Conservation and Management) Rules, 2017	Governs the conservation and management of wetlands to protect biodiversity.	Relevant for sustaining ecological balance and biodiversity in wetlands within the Pamba Basin.

Table 4.5: State-Level Legislations

Year	Type	Legislation	Key Features	Importance for IRBM in Pamba
1986	Act	Kerala Water Supply and Sewerage Act, 1986	Regulates water supply and sewerage services, sets standards, licenses, and penalties for violations.	Ensures proper management and distribution of water resources, critical for maintaining water quality.
2001	Act	Kerala Protection of River Banks and Regulation of Removal of Sand Act, 2001	Protects river banks, regulates sand mining to prevent environmental damage.	Addresses unregulated sand mining as a cause for reduced flow in Pamba river, crucial for IWRM.
2002	Act	Kerala Groundwater (Control and Regulation) Act, 2002	Regulates groundwater extraction, requires permission, and facilitates conservation efforts.	Relevant to controlling and managing groundwater in the Pamba Basin, offering regulatory tools.
2003	Act	Kerala Irrigation and Water Conservation Act 2003	Provides legal provisions for irrigation works, water conservation, and farmer involvement.	Encourages farmer participation and ensures water equity through balanced water allocation rights.
2003	Act	Kerala Forests (Vesting and Management of Ecologically Fragile Lands) Act, 2003	Controls exploitation of ecologically fragile lands for biodiversity conservation.	Addresses concerns like sand mining and deforestation impacting biodiversity in the Pamba Basin.
2008	Act	Kerala Conservation of Paddy and Wetland Act, 2008	Aims to conserve paddy land and wetlands, restricts conversion to sustain agriculture and ecology.	Significant for Kuttanad area in the Pamba Basin, where paddy decline is linked to inadequate water flow.

2008	Policy	Kerala State Water Policy, 2008 (Draft 2023)	Promotes integrated water management, transparent water entitlements, and river basin approach.	Lays the foundation for introducing IWRM in Kerala, aligning with the National Water Policy.
2009	Act	Pamba River Basin Authority Act 2009	Establishes the authority for water resource conservation in the Pamba Basin, institutionalizing IWRM.	Specific to IWRM in Pamba, managing river basin planning and operations for sustainable water use.
2019	Rule	Kerala Municipal Building Rules 2019	Regulates building construction and roof water harvesting, important for groundwater recharge.	Directly addresses groundwater reduction issues in small and medium-sized towns within the Pamba Basin.

4.6. Summary

This chapter emphasizes the collaborative and legislative frameworks essential for managing the Pamba River Basin. Central to the discussion are two stakeholder workshops that prioritized flooding as the most pressing issue impacting both upstream and downstream communities. While other challenges like water scarcity, pollution, and ecosystem degradation were acknowledged, they are slated for future interventions, with immediate focus directed toward flood mitigation strategies informed by detailed hydrodynamic analysis.

A Risk Matrix analysis revealed flooding as a cross-cutting high-priority issue for residents, agricultural communities, and industries. Sector-specific risks, such as salinity intrusion for coastal farmers, were noted but deferred for targeted future action. Proposed interventions combined structural measures (e.g., channel modifications), minor modifications (e.g., river rehabilitation), and non-structural measures (e.g., flood forecasting systems, revised master plans and awareness campaigns).

The upcoming chapter on flood analysis will detail the hydrodynamic studies underpinning the proposed interventions, including structural, and non-structural interventions such as flood forecasting systems. Future developments will address deferred issues like water scarcity and pollution, ensuring a holistic approach to basin management.

5. Flood Analysis

5.1. Introduction

The primary causes of flooding in the Pamba Basin and Kuttanad area are the total precipitation and its distribution across the drainage area. Key natural factors contributing to flood occurrences include rainfall type and intensity, surface features of the drainage basin, and subsurface soil and geological composition. Effective flood assessment requires interdisciplinary knowledge from meteorology, hydrology, and hydrogeology. Floods in this region occur as a result of river overflow, inundating adjacent lands, and can range from flash floods caused by localized thunderstorms to widespread flooding due to prolonged rainfall or rapid snowmelt. Flood behaviour is influenced by basin characteristics, with spatial and temporal flood scales determined by the nature of rainfall, weather, and climate conditions. Flood prediction models should incorporate discharge data and occurrence dates, along with the statistical properties of site-specific flood records for regional interpretations. However, data limitations often necessitate extrapolation from record-known sites, which may not fully capture the variability of the region. Models often lack the resolution required for the midland and lowland regions of the Pamba Basin, including Kuttanad, and tend to provide average parameter estimates. This approach overlooks the nonlinear behaviour of extreme events like floods, underscoring the need for careful consideration of deviations and uncertainties in future predictions. These factors are critical when planning major structural interventions in the basin to manage flooding effectively.

5.1.1. Flood and Hazard

Floods refer to extreme runoff volumes following intense storm rainfall events over a drainage basin. They occur when water from rivers, streams, or channels overflows onto adjacent land that is typically not inundated. A flood is also defined as a high flow event that surpasses natural or artificial streambanks. Managing floods is critical to ensuring that their impact remains within acceptable limits. Low-lying areas, such as the Kuttanad region, are particularly vulnerable to flooding and inundation hazards. These areas often host large populations due to the availability of groundwater and efficient transportation networks. In smaller basins like Kuttanad, flash floods are frequent as intense rainfall delivers more water than the basin can discharge as surface runoff within a short period, leading to higher runoff volumes and increased flood risks.

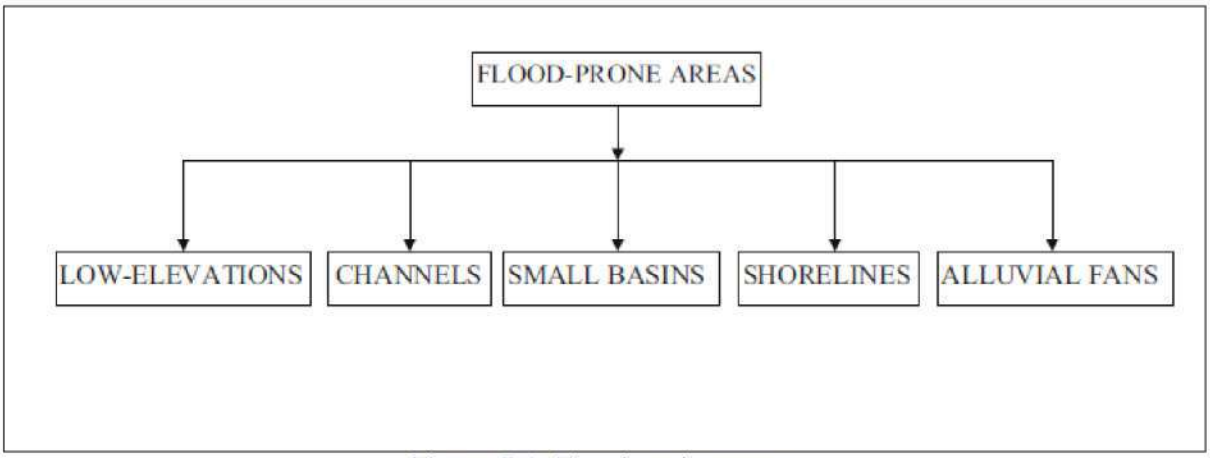


Figure 5.1: Flood environments

5.1.2. Ordinary Floods

In the Greater Pamba Basin, water divide storage distributes water among various catchments and sub-catchments. Geomorphological features significantly influence flood velocity, which amplifies damage, particularly in areas lacking sufficient vegetation cover. High-velocity flash floods pose severe risks to human life and property. In addition to natural causes, social factors like improper planning and mismanagement exacerbate flood risks, as evident in the settlement patterns of the Greater Pamba Basin. Flash floods are triggered by sudden, intense precipitation over short durations, while prolonged rainfall over weeks saturates soil, leading to surface flow that gradually escalates into floods. Although prolonged floods may be less destructive than flash floods, the latter, characterized by rapid onset and high intensity, can occur even in arid regions due to the inability of water to seep into the ground, resulting in immediate surface flow and severe flooding.

5.1.3. Flash Floods

A flash flood is a sudden and rapid flooding event that occurs with minimal warning, typically affecting small areas. It is primarily caused by heavy rainfall concentrated over a specific region within a short time frame. Even in areas with prolonged dry spells, intense rain over a few hours can result in flash flooding. However, if heavy rainfall persists across a wider area, it can lead to river or mainstream flooding, where major rivers overflow and inundate extensive regions, often continuing even after the rainfall has ceased.

5.1.4. Physical Causes of Flood

The primary trigger for natural hazardous events like floods is atmospheric conditions, particularly meteorological setups conducive to intense precipitation. Extreme precipitation events, often quantified as "probable maximum precipitation," are key contributors. However, rainfall alone is not sufficient to cause flooding; hydrological, geomorphological, and geological factors also play significant roles.

Primary Causes: These stem from meteorological and climatic conditions, including rainfall occurrence, type, intensity, direction, and excessive precipitation.

Secondary Causes: These involve surface features of the drainage basin, such as geomorphology, geology, vegetation, catchment area, slope, drainage density, main channel length, and time of concentration.

5.1.5. Flood Plains

Floodplains in the Pamba Basin and Kuttanad region are low-lying areas adjacent to the rivers and streams, which are prone to recurring inundation, particularly during monsoons. These flood-prone areas are dynamic and demand careful examination in the context of regional development and land use. The floodplain serves as a natural overflow area for the Pamba River and its tributaries, but human activities and settlement in these regions increase the risk to life and property.

Historically, early settlers in Kuttanad and the surrounding areas lacked an understanding of flood risks and suffered from inundations. Over time, they identified these areas and avoided human activities in the most vulnerable zones. However, with the pressure of modern urbanization and agricultural practices, particularly in Kuttanad, which is often referred to as the "Rice Bowl of Kerala," the need for floodplain management and protection has become critical.

Flooding in the Pamba and Kuttanad region is intricately tied to the hydrological cycle of the basin, showing the need for detailed analysis of the main river channels and their floodplains. If floodplains are already urbanized, as in parts of Kuttanad, there is increasing pressure from local communities for structural flood protection measures, despite the challenges of balancing environmental sustainability with urban demands. The Kuttanad region experienced the most severe flooding during the 2018 floods. Figure 5.2 shows the flooded area in the Pamba Basin.

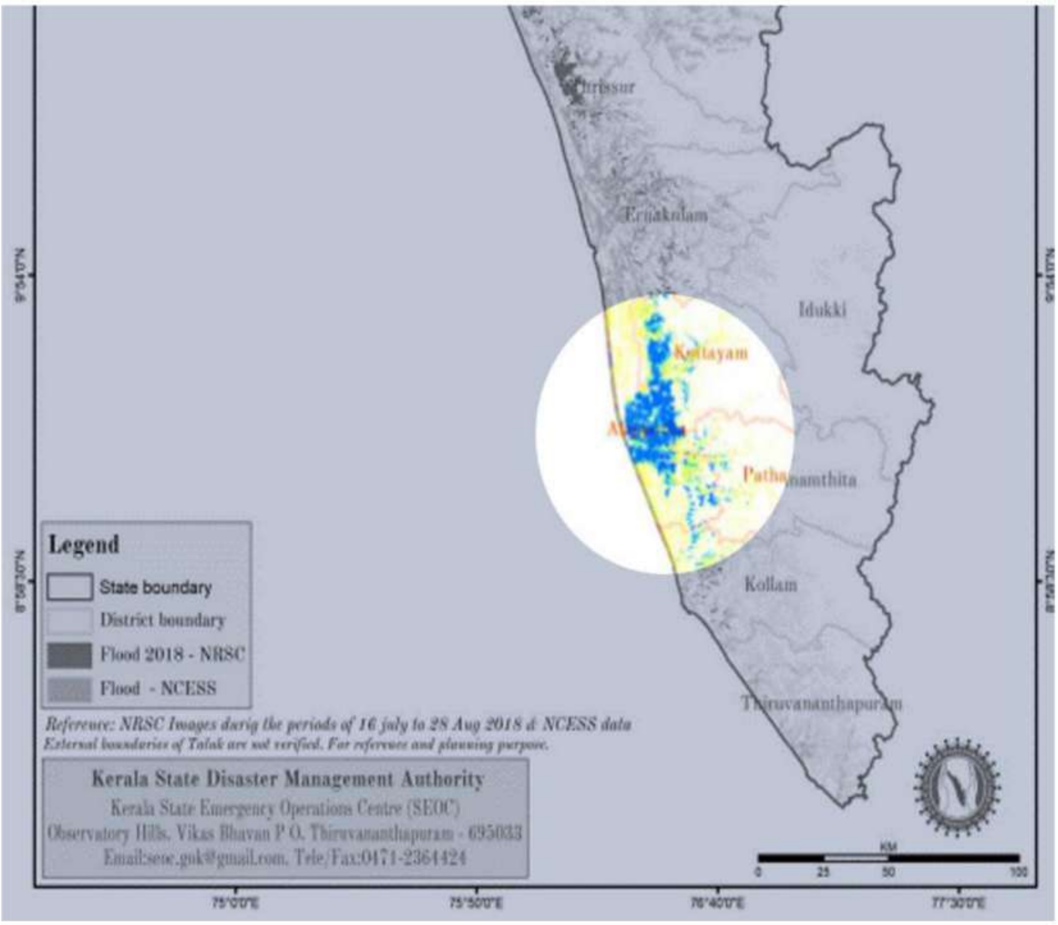


Figure 5.2: The most affected places in the Greater Pamba Basin is the Kuttanad Region during 2018 floods

Figure 5.3 presents satellite images of the Kuttanad region before and after the flood, highlighting the severe impact of the disaster. The flooding was extensive, with water having no clear path to recede.

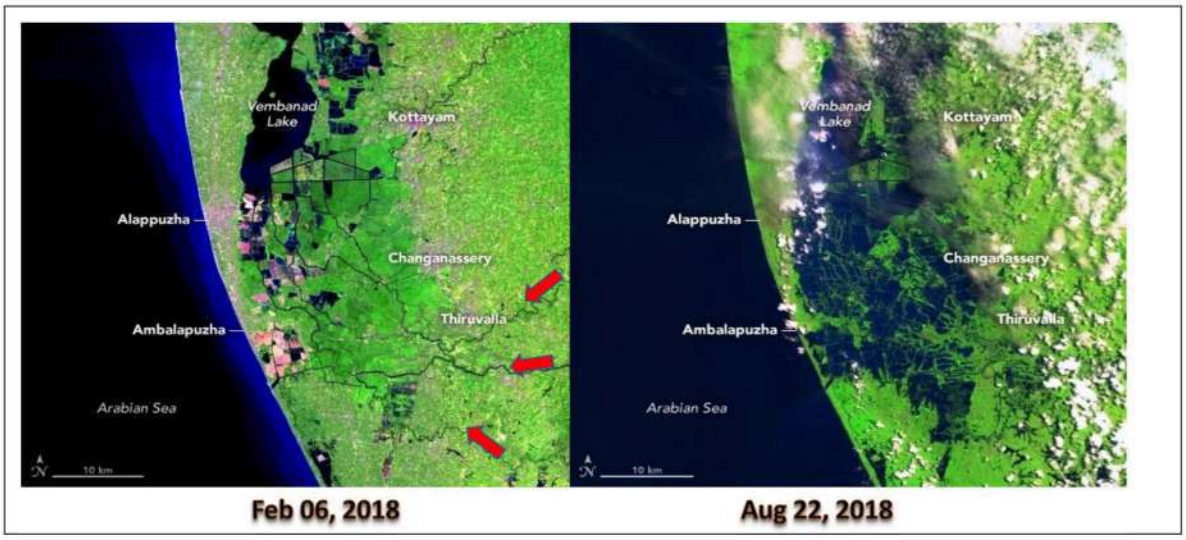


Figure 5.3: Satellite images showing before an after flood 2018 in the Kuttanad Region

Increase the carrying capacity of the cross-section

If the cross-sectional area of the river channel widens, the flow of water is spread over a larger area, resulting in a decrease in water depth. This can lead to less concentrated flooding, reducing the overall inundation risk in that section.

Deepening of cross-Section

A deeper cross-sectional area will allow for a greater volume of water to be accommodated, leading to an increase in the inundation area. This means that larger areas along the floodplain could be submerged, especially during high-flow conditions or heavy rainfall events.

Increase in Slope

If the slope of the riverbed increases in the vicinity of a cross-sectional area, the flow velocity will also increase. Faster-moving water reduces the water depth in that section, but can cause more erosion and increase the risk of flooding downstream due to the higher velocity.

Contraction of cross-Section

If the cross-sectional area narrows, the flow velocity increases and the water depth increases as well. This can lead to a higher risk of flooding in the immediate vicinity, as the water is forced to rise and spread across the floodplain more rapidly, covering a larger area. The hydraulic modelling done had taken direct cross sections through the field survey and integrated into the model.

Human Causes

Intensive land use should never be allowed on floodplains in the Pamba and Kuttanad regions to ensure flood hazard-free and sustainable human activities. However, this ideal guideline is often compromised due to increasing population pressure and the growing demand for land for development. By consulting flood inundation maps with varying risk levels, individuals can assess the potential risks associated with their property location and decide based on an acceptable risk threshold. In the Greater Pamba Basin, the flood inundation levels are categorized in different risk zones, as illustrated in Figure 5.4, to help visualize the varying flood risks.

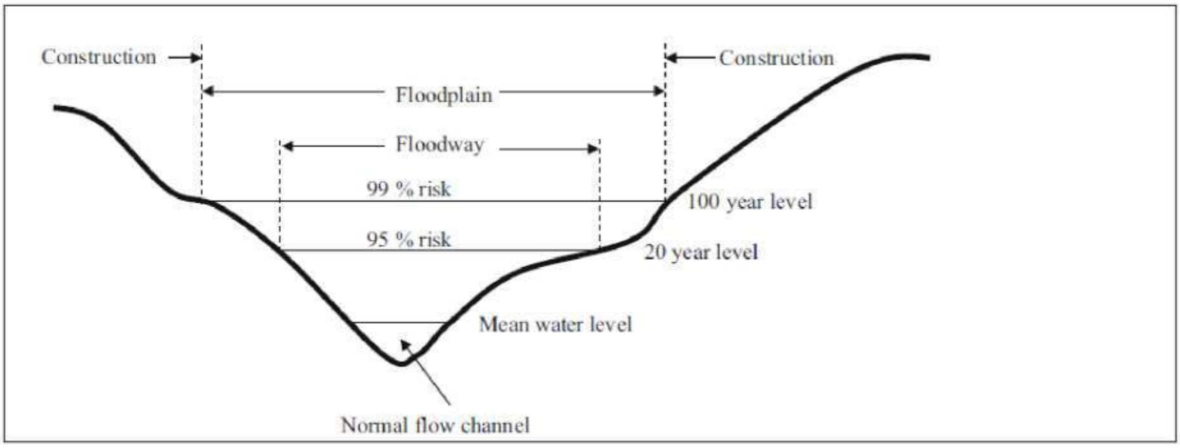


Figure 5.4: Schematic delimitation of hazard planning zones in Greater Pamba Basin

Absolute Protection Zone (90% risk)

This is the most hazardous zone, which is highly likely to experience flooding regardless of flood intensity. Local and central authorities must strictly prohibit any construction or human activity within this zone.

Significant Protection Zone (90–80% risk)

In this area, limited human activities can be permitted, such as the construction of small buildings. A general rule could allow up to 10% of the land for light building constructions, but these structures should not accommodate critical activities like schools, hospitals, or public services.

Moderate Protection Zone (80–70% risk)

Approximately 30% of the land in this zone may be used for activities like agriculture, irrigation, and the construction of storage buildings, considering the lower flood risk.

Weak Protection Zone (70–50% risk)

These areas can be utilized for public activities, with up to 50% of the land available for construction and development, subject to the level of risk involved.

The greater the extent of development on floodplains in the Pamba and Kuttanad regions, and the larger the existing investments in these areas, the more significant the economic benefits from flood control structures. Consequently, flood protection schemes in these areas are more likely to be implemented based on cost-benefit considerations. The cost-benefit ratio becomes more favorable for construction when land in flood-prone areas, such as those near the Pamba River or Kuttanad's low-lying areas, is protected from flood risks, allowing it to be utilized for development. The higher the land values in these "protected" areas, the more likely further encroachment on the floodplains will occur.

However, the actual costs of flood protection and the encroachment on flood-prone zones are often not fully borne by the local communities or developers most directly involved. This can lead to unsustainable development, exacerbating flood risks in the long term.

5.2. River systems in the Low-lying area of Greater Pamba Basin

The river system in the Kuttanad region is designed to channel water into the Arabian Sea through the Thottappally Pozhi mouth, after flowing over the Thottappally spillway located on the leading channel of the Pampa River. However, backflow was observed during the 2018 and 2019 floods, raising concerns about the effectiveness of further deepening the leading channel. Additionally, Increasing the carrying capacity of the leading channel across the area is not feasible due to encroachment and various cross structures, such as railway and road bridges. To prevent sand accumulation at the Thottappally Pozhi mouth, the possibility of constructing a training wall at the mouth should be explored, and a detailed hydraulic design should be developed.

The channel network in the study area consists of a series of cross-sections that describe the river and floodplain topography. Most of the river's thalweg points in lower Kuttanad fall below mean sea level. Since open-source Digital Elevation Models (DEMs) from satellites, such as the Shuttle Radar Topography Mission (SRTM), do not penetrate below water, using SRTM data to represent river cross-sections is not viable. As a result, a Differential Global Positioning System (DGPS) survey was used to collect channel bathymetry and bank details. DGPS enhances the accuracy of the Global Positioning System (GPS), providing location accuracy ranging from 15 meters with standard GPS to about 1-3 cm in ideal conditions. DGPS uses fixed ground-based reference stations (Base) to calculate the difference between an accurately known position and the position indicated by GPS satellites. This correction is broadcasted to receiver stations (Rover), which then provide accurate elevation and coordinate values.

Pressure sensors and level staff were employed to measure water depth at various locations. The Rover component of the DGPS system was used to precisely obtain the elevation and coordinates of points on the water surface, relative to the known base. The measured depths were subtracted from the water surface elevation to determine the channel bed levels. Elevation data for the floodplains were also collected 2-3 meters away from the banks. Since the main objective was to identify reaches that may overtop, further detailing of the floodplains was deemed unnecessary. During a field visit, key locations for river cross-sections were identified, and these locations were subsequently surveyed. More than 200 selected locations were surveyed using DGPS, with the survey points shown in the accompanying Figure 5.5.

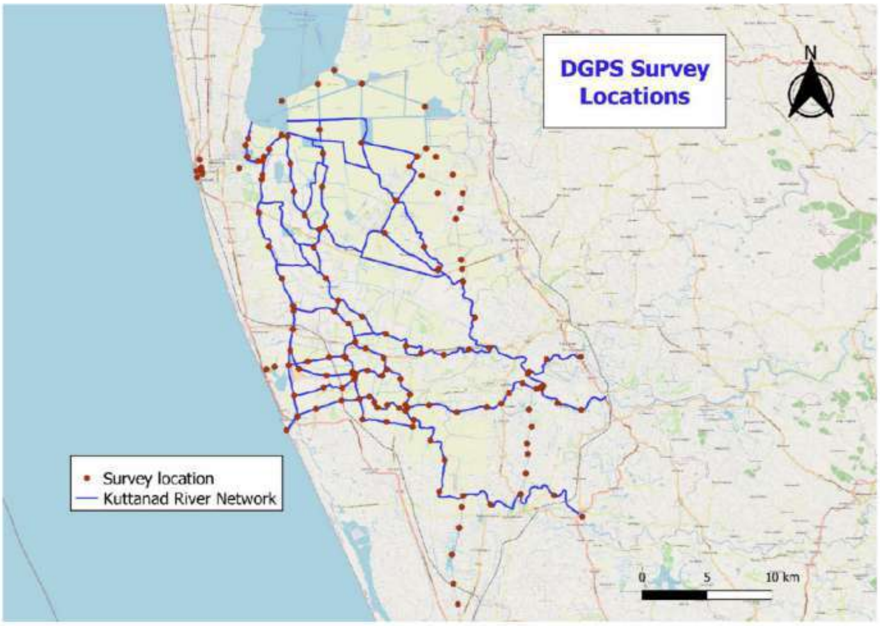


Figure 5.5: River-Network of the channels and cross-section data

Cross-section details along the rivers are crucial for effective modeling. Therefore, a detailed cross-section survey was conducted along the Achankovil, Pampa, and Manimala rivers, as well as throughout the network of channels. A total of approximately 200 cross-sections were planned for surveying. In addition to the river cross-sections, the survey also included detailed information about structures constructed across the rivers. A detailed study about the structural interventions has been carried out. The relevant points are added in the following sections.

5.2.1. Survey Methodology

The coordinates for approximately 200 cross-sections were surveyed in the study area. The survey was conducted using GPS coordinates, and the Mean Sea Level (MSL) was referenced from the benchmark established by the Survey of India near the Thottappally spillway. Control points with respect to MSL were set up at various locations throughout the study area.

For the riverbanks, cross-section survey lines were taken perpendicular to the direction of the river flow. Each cross-section typically included two bank points, one on each side of the river.

The coordinates of each cross-section, spanning from one bank to the other, were surveyed. Depths below the water surface (i.e., soundings) were measured from a boat using an electronic water level recorder. The coordinates for each cross-section line were recorded in the WGS-84 coordinate system, and a transverse Mercator projection was used for the mapping. All measurements were recorded in meters.

Table 5.1: Details of control stations

Station	Northing	Easting	Elevation	Remarks
Base station	1030092.1230	652585.8257	2.130	Survey of India BM near Thottappally spillway
Control station 1	1030124.5003	652463.7740	11.307	Top of Irrigation Office building near Thottappally spillway
Control station 2	1037363.8760	652417.0320	5.567	Top of building near Karumady
Control station 3	1050295.5422	648091.5325	12.159	Top of shop building near KSRTC depot Alappuzha

5.3. Input Data for Simulations

The Kuttanad region, which is the focus area, is represented by a channel network. This network consists of major rivers such as Achankovil, Pampa, Manimala and major channels and many minor channels. The rivers and major channels are alone considered in this analysis. The most important characteristics of the channels are (i) cross-section details of channels, (ii) Manning roughness coefficient for the link, and (iii) hydrograph and water level data

The study area consists of 85 channels and is described by 215 measured cross-sections at various locations of the rivers and channels through the field survey. These surveyed cross-sections are processed, and the channel details, such as width, depth and length, are analyzed. The channel connectivity is created based on the survey data. The connectivity details, such as channel number and node number, are shown in Figure 5.6 and Figure 5.6. In the simulations, the channel is divided into many reaches. A grid convergence study was carried out to find out the suitable distance. A computational distance step is taken as 400 m.

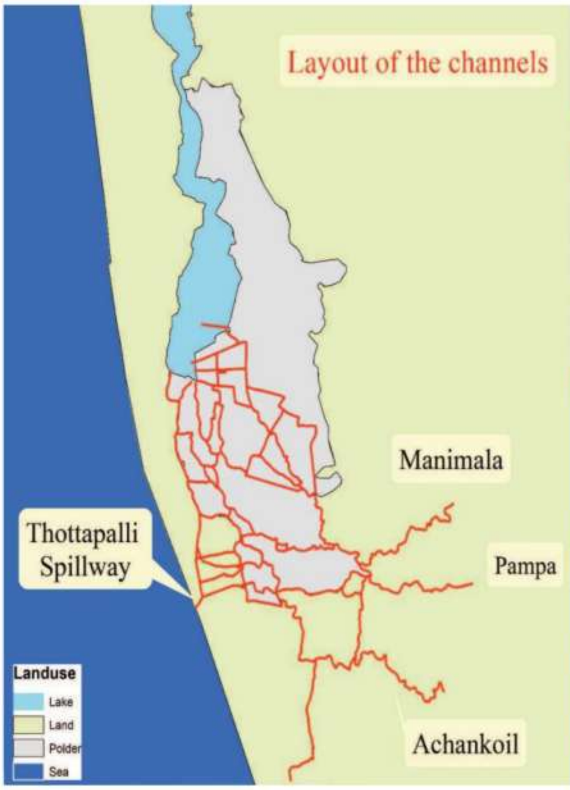


Figure 5.6: Layout of channels

Figure 5.7: Channel number of the network

5.4. Hydrograph and water level data

The channel roughness values ranged from 0.03 to 0.095. The high roughness value for some of the channels is primarily due to chocking of the channel by water hyacinth and other blockages. The measured hydrograph from June 1, 2010, to November 31, 2011, at Kollakadavu (Achankovil), Erapuza (Pampa), and Thonadara (Manimala) were collected from the CWC gauging stations (Figure 5.11). For the same period, the measured water level data at various locations were collected from the gauging stations established by the CWRDM. The locations of the observed data are shown in Figure 5.10. Water levels at Punnamda and Thottapally are used to impose the downstream boundary conditions (Figure 5.8) in the HEC-RAS model. For the 2019 flow event, hydrograph and water level (Figure 5.9) information were collected from the CWC and CWRDM stations. The 25- and 50- year return period hydrographs are generated using extreme value distribution with the help of the 1985-2000 flow data. The above- mentioned data are used to set up the model and to make scenarios for analyzing the impact of the various mitigation measures.

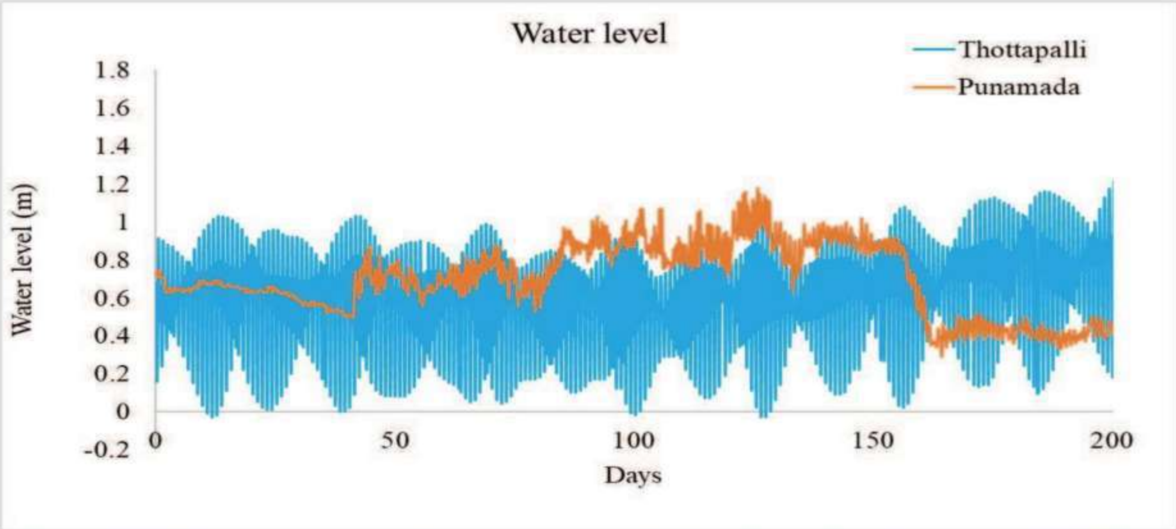


Figure 5.8: Water level data at Punnamada and Thottapally spillway from June 1, 2010, to November 30, 2011.

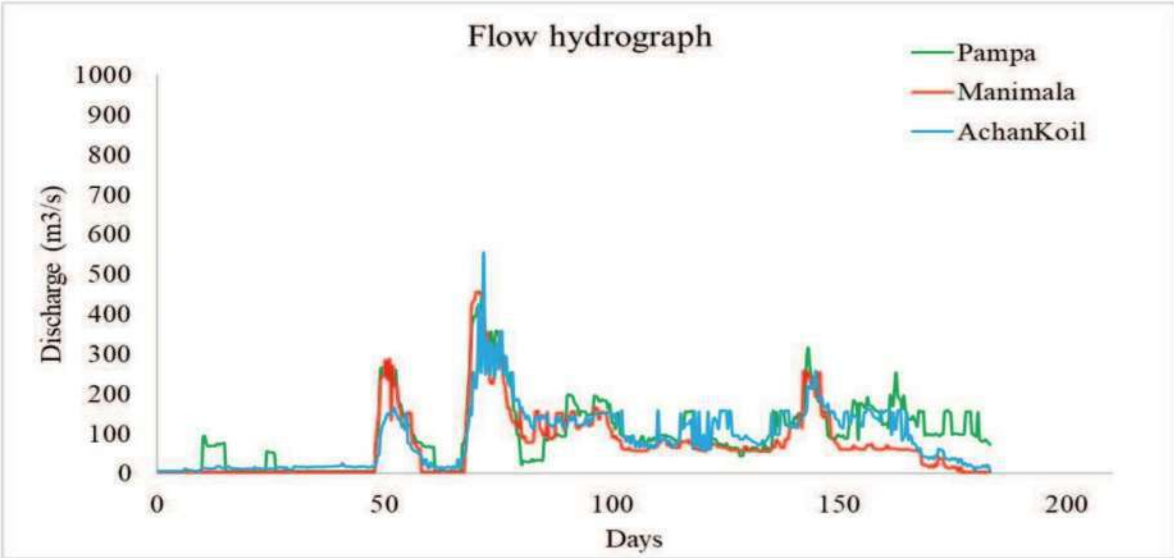


Figure 5.9: Hydrographs at the upstream of Pampa, Manimala and Achankovil from June 1, 2010, to November 30, 2019.

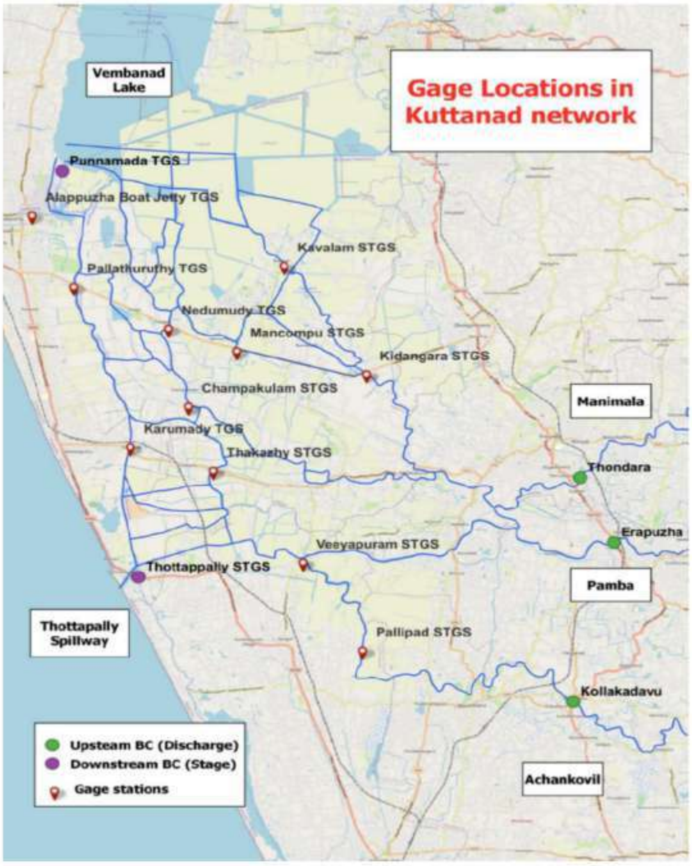


Figure 5.10: Locations of observed water level data

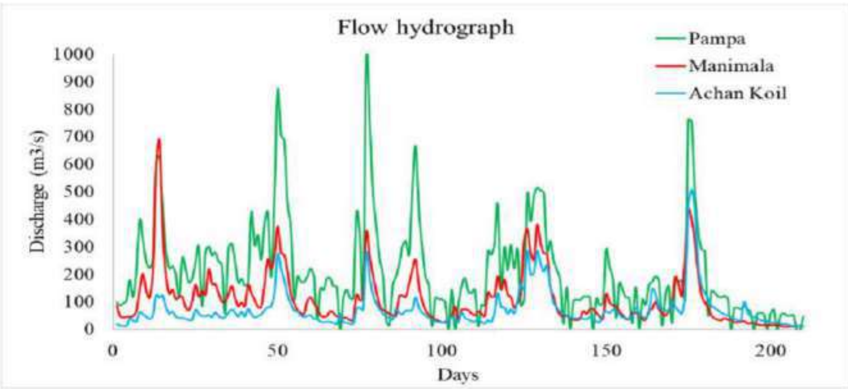


Figure 5.11: Hydrographs at the upstream of Pampa, Manimala and Achankovil from June 1, 2010, to November 30, 2011.

5.5. Hydraulic Model to Study the Flood inundation in Greater Pamba Basin

To prevent the accretion of sand at the mouth of Thottappally Pozhi mouth, the possibility of constructing a training wall at Pozhi mouth needs to be studied, and a detailed hydraulic design may be provided. Rivers in order to capture the backwater effect. A freely downloadable 1D river network model that guarantees sufficient accuracy for engineering intervention may be a suitable choice. The 1D network model, the Hydrologic Engineering Center-River Analysis System (HEC-RAS) developed by the U. S. Army Corps of Engineers is awidely used, verified, and validated model for several large-scale river network studies. The 1D HEC-RAS model is used in this study in all the simulations for its accuracy.

5.6. Model Calibration and Validation

The HEC-RAS network model was first calibrated using the inflow into the system from June 1, 2010 to November 31, 2011. The five-year-long discharge data at Kollakadavu (Achankovil), Erapuza (Pampa), and Thonadara (Manimala) were collected from the CWC gauging stations. Measured water levels at Punnamda and Thottapally spillways are used to impose the appropriate downstream boundary condition. The measured water level data may not be accurate for other events, but this is the best possible way to impose downstream boundary conditions. The simulation is run from June 1 to November 31, and the simulated water levels are compared against the measured water level data at various locations from the gauging stations established by the CWRDM. The locations of the water level gauging stations are shown in Figure 5.10. The calibration is carried out by changing Manning's roughness values to make the network model closer to reality. After the calibration process, the performance of the calibrated Manning's roughness values is evaluated in the validation process. For this purpose, the inflows into the system from the CWC gauging stations from June 1 to December 31, 2019 are given as the upstream boundary conditions at Kollakadavu, Erapuza, and Thonadara. The observed tide and water level data are taken as stage boundary conditions at Punnamada and Thottapally spillways for the corresponding period of upstream hydrographs. The time-series of simulated water levels are compared against the observed data from water level gauging stations, and the predictive ability of the HEC-RAS setup is evaluated.

Figure 5.12- Figure 5.21 shows the comparison of simulated and observed water levels at CWRDM gauges. It can be observed from the figures that the HEC-RAS model captures the temporal pattern quite closer to the observed data at all the gauges. The simulated water levels at Champakulam, Thakazhy, Kidangara, Kavalam, Mankombu, and Nedumudi show very good agreement with the observed data, as shown in Figure 5.12-Figure 5.17, respectively. At Pallipad (Figure 5.18) and Veeyapuram (Figure 5.19), which receive mostly water from the rivers Achankovil and Pampa, the simulated water levels agree well with the observed trend. There are differences in the peak by about 0.5 - 0.8 m due to overbank flow from Achankovil. The overflow in the upstream reaches causes the increase in water elevation as the 1D model is not designed to dispose of the overflow water to the adjoining floodplains. The water level is

underpredicted at Karumadi (Figure 5.20) and overpredicted at Pallathuruthy (Figure 5.21). However, the maximum difference in the simulated and observed flow depths at these gauges is approximately less than 0.5 - 0.6 m only. Considering the complex system and the associated uncertainties, it can be concluded that the agreement of simulated water levels against observed data is satisfactory. Similarly the model has been validated for the year 2019.

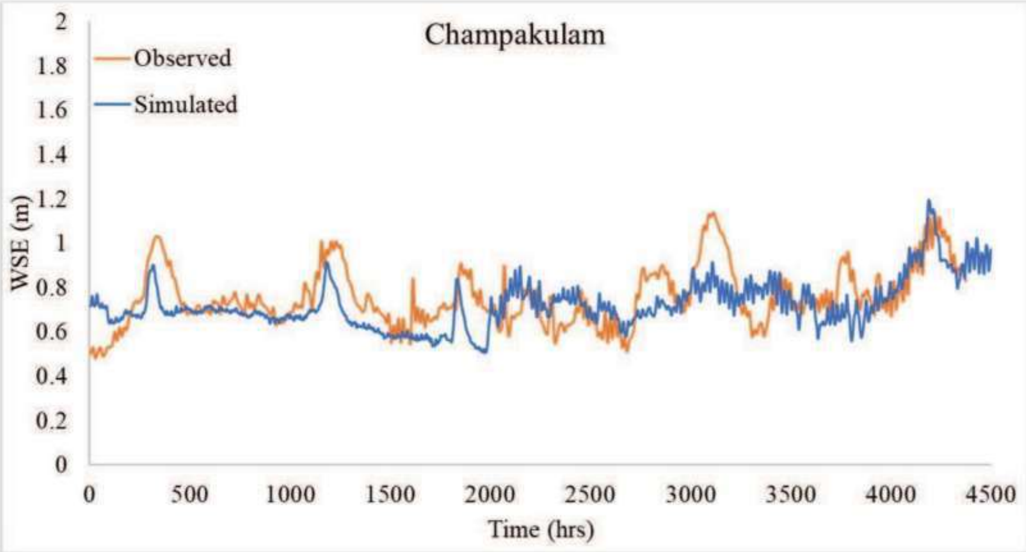


Figure 5.12: Comparison of simulated and observed water levels at Champakulam.

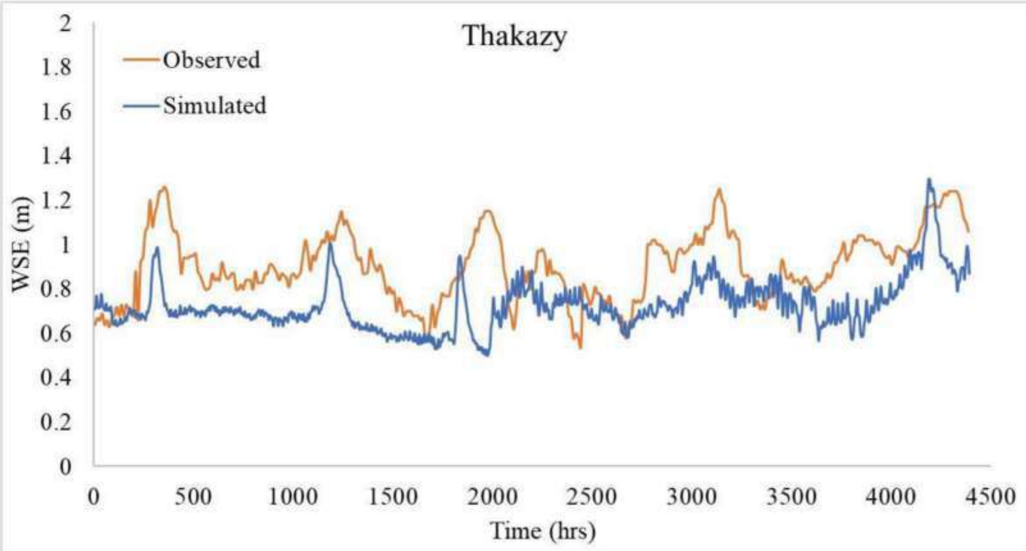


Figure 5.13: Comparison of simulated and observed water levels at Thakazhy.

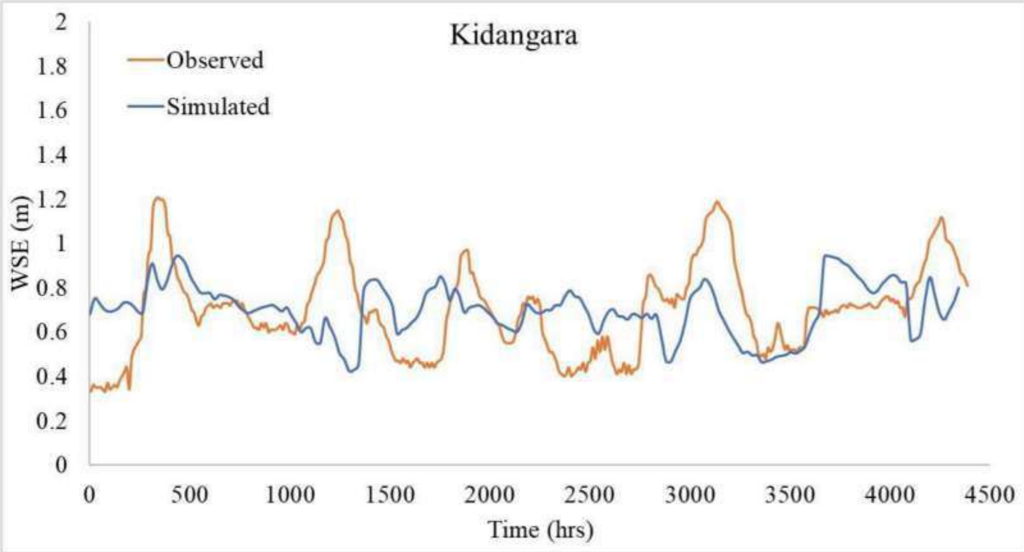


Figure 5.14: Comparison of simulated and observed water levels at Kidangara

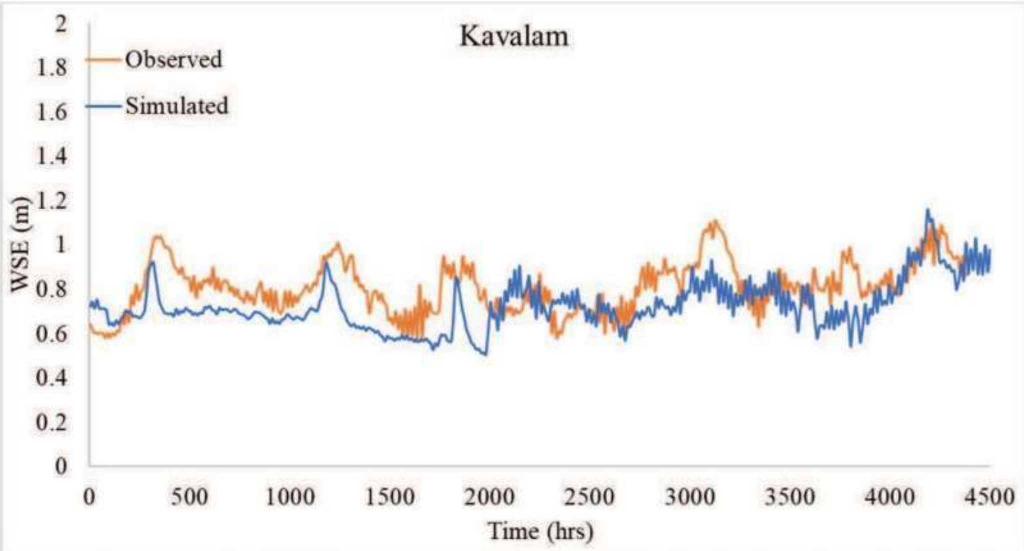


Figure 5.15: Comparison of simulated and observed water levels at Kavalam.

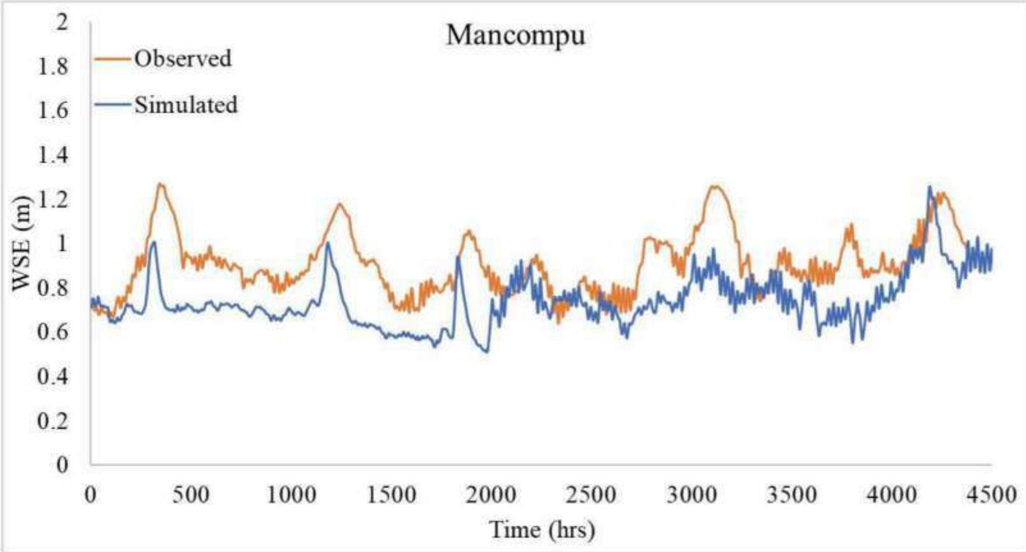


Figure 5.16: Comparison of simulated and observed water levels at Mankombu.

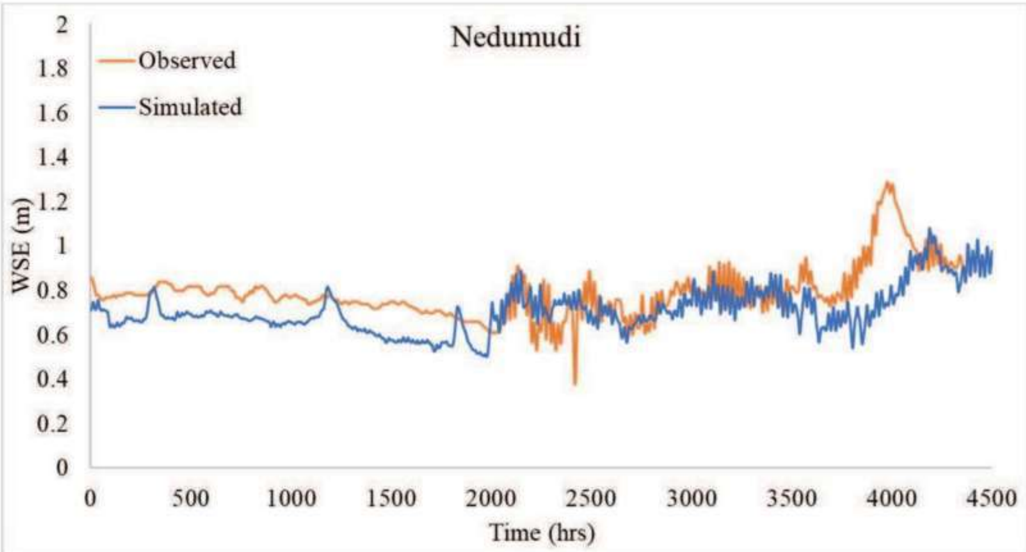


Figure 5.17: Comparison of simulated and observed water levels at Nedumudy.

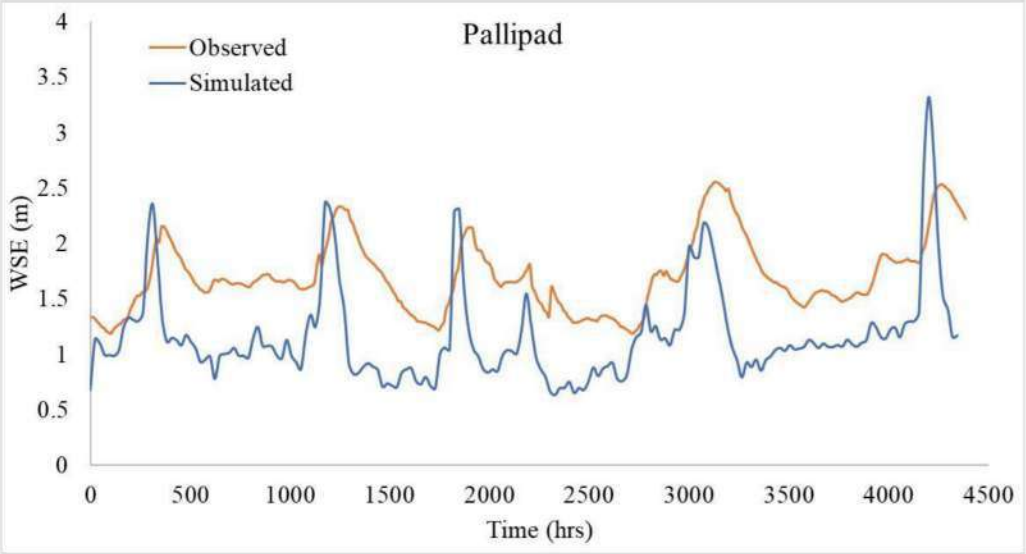


Figure 5.18: Comparison of simulated and observed water levels at Pallipad.

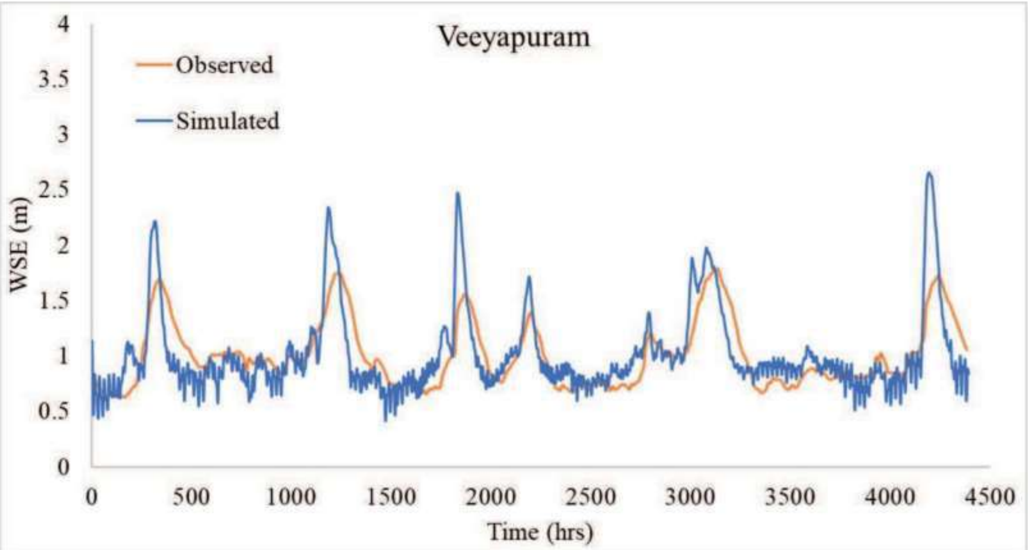


Figure 5.19: Comparison of simulated and observed water levels at Veeyapuram.

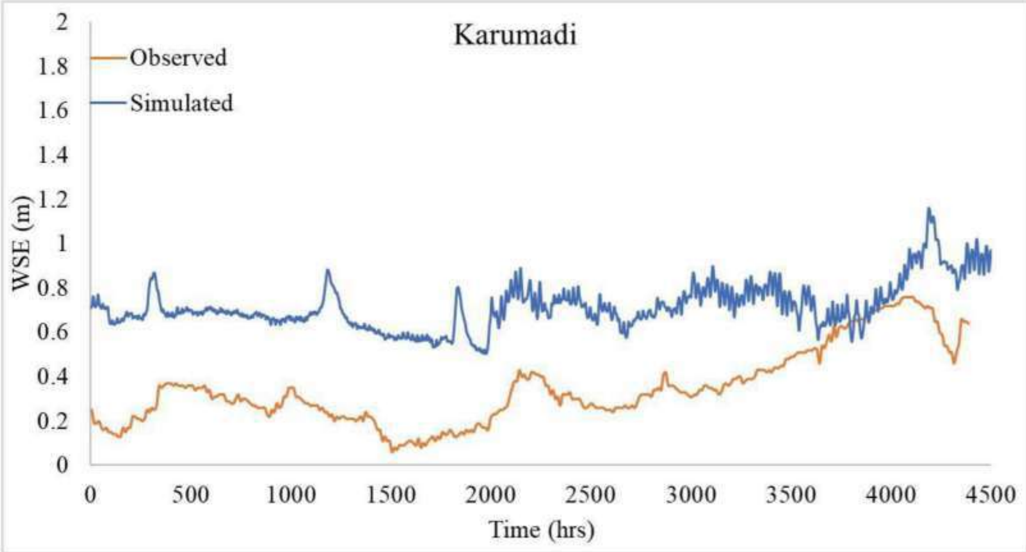


Figure 5.20: Comparison of simulated and observed water levels at Karumadi.

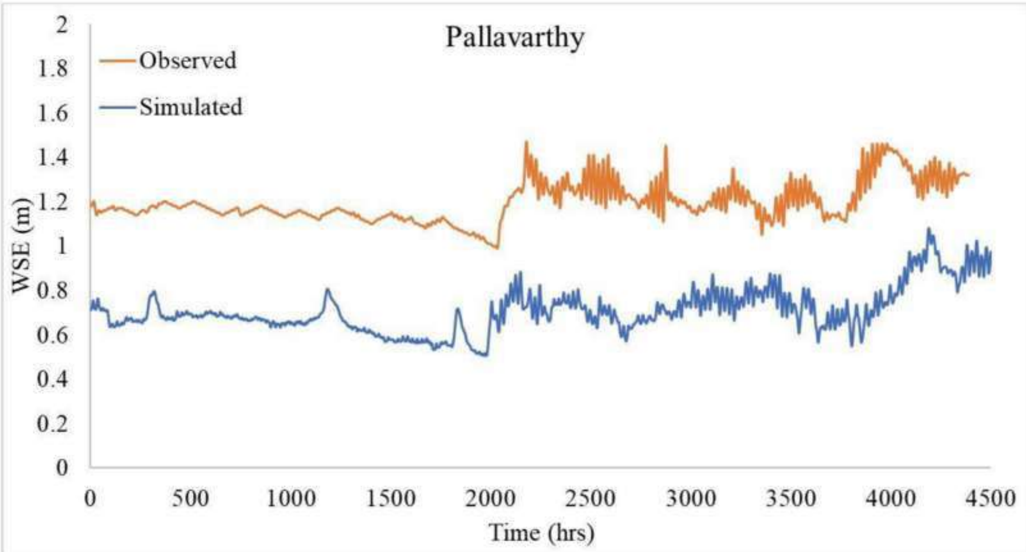


Figure 5.21: Comparison of simulated and observed water levels at Pallathuruthy

5.7. Major solution measures - 1

The hydraulic design is generally carried out based on the analysis of the return period of floods. The region of Kuttanad is a low-lying area and is naturally prone to flooding. Therefore, flood protection measures are analyzed for 25- and 50-year return period floods. The inflow hydrographs for the three rivers corresponding to 25- and 50-year floods are generated from the extreme value distribution

It should be noted that the return period flood hydrographs are constructed considering the extreme conditions that all three rivers will simultaneously receive the flows corresponding to the same return period flood. This is quite unlikely for a large area like the Kuttanad region. Therefore, the results should be considered qualitatively instead of quantitatively. Simulations of the return period floods are chosen to demonstrate the worst impact of floods that could occur in the river system. Further, the results from these simulations are chosen as a baseline or reference solutions to determine the effectiveness of various mitigation measures proposed for reducing water levels in the Kuttanad network.

The flow from the Pampa River divides into two parts near Kuthiyathodu. One joins the Manimala River through Channel 84, and the other flows to the west, towards the Thottapally spillway. The flow then joins with Achankovil near Veeyapuram and travels north to the Vembanad Lake outlet via Channels 4, 5, and 37. Some portion of the combined flow also drains to the sea via the Thottapally spillway. The maximum flow values for the 25- and 50-year return period floods are given in Table 5.2. It can be observed that a substantial part of the flow passes through the Thottapally spillway. Other parts go towards the Vembanad Lake, From the maximum water surface profiles, it was observed that water overflows the riverbanks by 1 to 3.8 m at different reaches. Rising the bund above the current level may not be viable to mitigate the flooding problem. Therefore, attempts are made to mitigate the problem using alternative solution measures. It is also important to note that the current simulations are performed considering the extreme conditions of simultaneous occurrence of 25- and 50-year return period flood hydrographs at all the river inlets. It is also obvious that such boundary conditions will result in excessive overflow from different reaches.

Table 5.2: Maximum flow values at major locations for the baseline simulation

Location	Discharge (m^3/s)	
	25-year	50-year
Channel 84	1200	1400
Channel 22	566	630
Channel 13	330	384
Channel 11	266	647
Thottapally outlet	1410	1600

Combined outflow Vembanad	2631	2769

5.7.1. Improvement of the Karipuzha channel.

Karipuzha river diversion is considered to divert flow from the Achankovil River into the Kayamkulam lake. The existing width upstream of Karipuzha is 25 meters, which is insufficient for diverting a significant amount of floodwater. The area consists mainly of paddy fields, suggesting the possibility of Increase the carrying capacity of the river upstream. The simulation is run with the widened channel of 60 m till upstream of Kayamkulam town. As a result, the maximum discharge of 100 m^3/s flows through the Karipuzha channel without any bank overtopping. The flow in the base simulation is found to be only 40 m^3/s. Thus, an extra flow of 60 m^3/s can be drawn from the Achankovil River due to the Increase the carrying capacity of of the Karipuzha channel. However, the reduction in the water level inside the network is negligible for the 25- and 50-year return period floods. The Increase the carrying capacity of of the Karipuzha channel may be considered to manage at least 10-year floods.

5.7.2. Flood regulator in the Pampa River at Kuthiyathodu

The flows from the Pampa and Manimala Rivers affect the Kuttanad region, especially the north side of the network system. Therefore, flow from the Pampa River is proposed to be regulated towards the Thottapally spillway. The simulation is carried out to check how the flooding situation is getting modified due to the introduction of the flood regulator in the Pampa River at Kuthiyathodu.. The flood regulators are modelled as barriers with gates. The gates can be vertically lifted from the crest placed on the river bed. Different gate openings are tried in this scenario to observe any flood reduction. The main objective here is to operate the gates during peak floods and keep them open during other times.

The effects of the flood regulator are first investigated for the 25-year return period flood. The maximum discharge values in the affected channels are given in Table 5.3.

Table 5.3: Maximum flow values at major locations for flood regulator at Pampa River

Location	Discharge for 25-year hydrographs (m^3/s)	
	base	Flood regulator
Channel 84	1200	869
Channel 22	566	661
Channel 13	330	408
Channel 11	266	598
Thottapally outlet	1410	1600
Combined outflow Vembanad	2631	2314

The flood regulator installed at Kuthiyathodu is found to divert water toward the Thottapally spillway. As a result, the water levels in the Kidangara and Kavalam regions reduce by 0.5 - 1.25 m. In contrast, the flood regulator does not affect the water surface profiles along Thakazhy and Karumadi. A major portion of the diverted water from the Pampa River flows through the Thottapally spillway, as the same can be seen in Table 5.3Table 5.4. Further, it can also be observed in Table 5.3 that the combined outflow to Vembanad Lake has reduced compared to the base simulation, indicating the effectiveness of the proposed flood regulator in the Pampa River. It can be observed that the flood regulator controls the water levels in the region of Kidangara, Kavalam, Mankombu, and Nedumudy. It can be said that the regulator has good control in reducing 25-year return period floods on the downstream side. The channels likely to flood and reduction in water levels are quantified. The channels in the region of Kavalam and north of the Mankombu area are also free from flooding because of the flood regulator. Although the region between Kidangara and the flood regulator still faces floods due to overflow over the regulator, the water level is significantly reduced. This local phenomenon can be taken care of during the construction of the regulator and by protecting the adjoining area. The water levels shown in green colour indicate the reduction of water level, which is seen downstream of the regulator. On the other hand, the regulator increases the water level by 0.5 - 1 m on its upstream side and along the channel towards Thottapally spillway. The water level increases on the backside of the regulator due to the impoundment of water. Therefore, this aspect must also be accounted for when deciding on installing the regulator. The additional diverted water from the Pampa River also causes an increase in water level along the Thottapally channel. Therefore, local channels need to be improved to divert additional water.

Table 5.4: Maximum flow values at major locations for flood regulator in the Pampa River

Location	**Discharge for 50-year hydrographs**	
	base	Flood regulator
Channel 84	1400	1033
Channel 22	630	736
Channel 13	384	469
Channel 11	647	663
Thottapally outlet	1600	1784
Combined outflow Vembanad	2769	2579

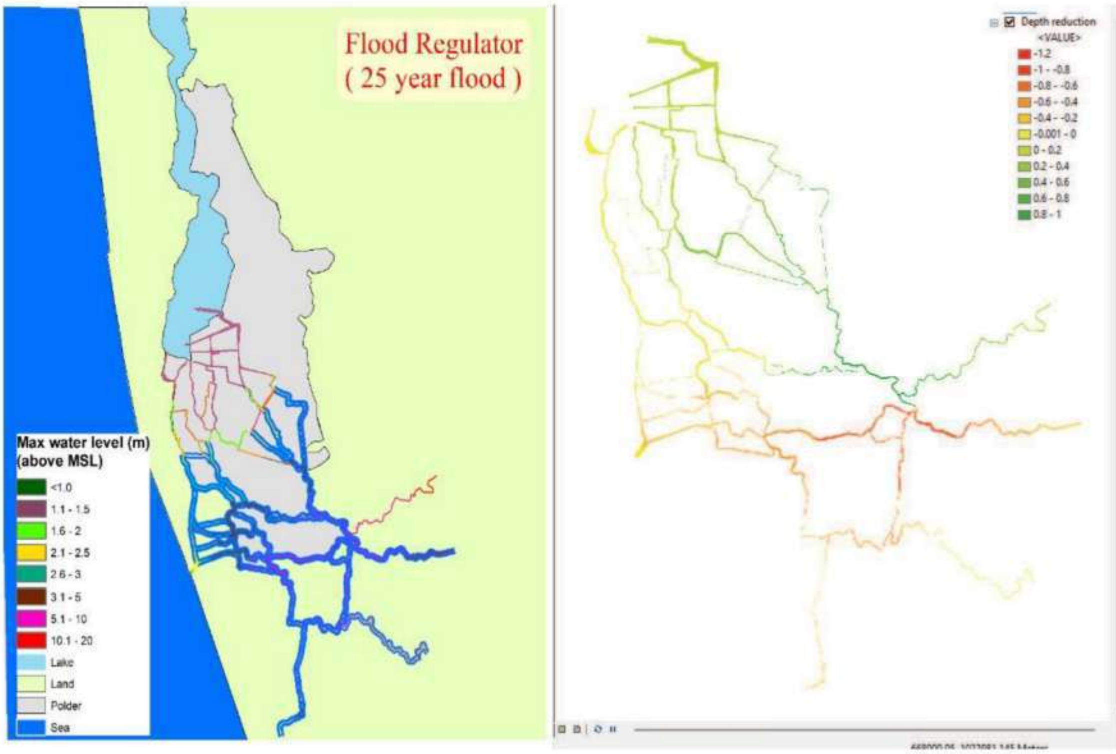


Figure 5.22: 25-year return period flood hydrograph – (a) channels which are likely to overflow and (b) change in water levels with the flood regulator in the Pampa River

The regulator is found to divert a significant amount of water. On the downstream side of the regulator, the discharge value decreases from 1400 m^3/s to 1033 m^3/s. The increase in discharges is seen in channels 37, 5, and 4. Table 5.4 indicates more water is diverted towards the Thottapally spillway for the 50-year return period hydrograph compared to the base and 25-year simulations. Once again, the reduction in water level is observed clearly in the lower Kuttanad region. The reduction of the water level is found to be in the range between 0.5 and 1.4 m at Kidangara and Kavalam. As expected, the water surface profiles along Thakazhy and Karumadi have a negligible impact due to the flood regulator.

It can be observed that overtopping from the river is avoided in the Kavalam region compared to the base simulation. In other channels, though the flood is not completely mitigated, there are changes in the water levels. Thus, the change in water levels caused by the regulator is quantified to appreciate its effect. A decrease of 0.5 - 0.8 m water level is seen on the downstream side. Also, it is observed that the overtopping of channels between Neerettupuram and Kidangara could be reduced significantly by raising the bund level by 0.6 m and 1.2 m for the hydrographs of 25- and 50-year return period floods.

Overall, it can be concluded that constructing a flood regulator in the Pampa River at Kuthiyathodue can reduce flood impact downstream of the Kidangara region. It needs to be mentioned that the gates were kept 90 % closed during the flood time. Consequently, water overflows the regulator locally in addition to impounding water upstream. The overflow varies between 2 - 4 m. The overflow and impoundment of water due to the complete closing of the gate might put huge pressure on the structure, which can lead to overtopping of the regulator structure itself. Therefore, the rule curves for the gate operation need to be established. In summary, the flood regulator controls 25- and 50-year return period floods downstream of Kidangara but worsens the situation at some upstream places. It needs to be mentioned that the return period flood hydrographs are imposed at all the rivers, and such a condition is unrealistic. Under this circumstance, the importance of the above simulations can be realized by the qualitative response of the system due to the flood regulator. The flood regulator can reduce water levels, but it should be accompanied by increased bund heights, improvements of local channels for diverting water, and efficient gate operation.

5.7.3. Flood Regulators at Karumadi, Thakazhy, and Cheruthana

In this scenario, three flood regulators are proposed at Karumadi, Thakazhy, and Cheruthana to regulate the flows in channels moving towards the north (Figure 5.23). Three regulators are chosen to prevent floodwaters from moving north of Karumadi and Thakazhy and drain them out via the Thottapally spillway. Regulators are modeled as weir structures with gates, as discussed before. The gates are closed partially during peak floods and are kept open during all other times. The results are summarized for both the 25- and 50-year return period floods. The flood regulators significantly reduce flooding on the north side of the regulators, i.e., towards the Vembanad Lake. Yet this is accompanied by backing up of flow towards Thottapally side (i.e., south of the regulators) up to a maximum height of 2 m. Developing an operating criterion for the flood regulators and measures to divert the backed- up flow needs to be considered. It is worth noting that the design capacity of the Thottapally spillway is 1915 m^3/s though the simulations predict a higher value of 1950 m^3/s. Nevertheless, flood regulators can effectively divert more flow towards the Thottapally spillway and out to the sea rather than moving into the Kuttanad region.

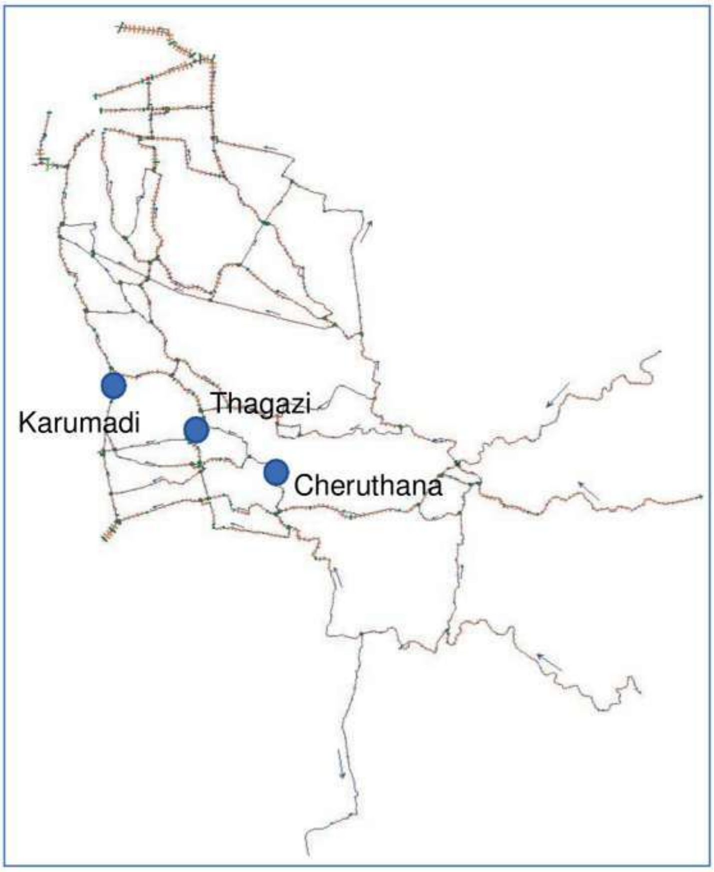


Figure 5.23: Location of the three regulators at Karumadi, Thakazhy and Cheruthana

5.7.4. Combined effects of all four flood regulators

This scenario is simulated to understand the overall effects of the flood regulators at Kuthiyathodu, Karumadi, Thakazhy, and Cheruthana (Figure 5.24). It is observed that the water diverted from the flood regulator at Kuthiyathodu flows west toward Veeyapuram. Beyond Veeyapuram, the water flows in two directions. The major portion flows toward Karumadi, Thakazhy, and Cheruthana, and the rest flows toward the Thottapally spillway. Therefore, regulators are provided at Karumadi, Thakazhy, and Cheruthana to divert more water toward the Thottapally spillway.

Due to the combined operation of all four regulators, water diverted from the Pampa River flows mainly via the Thottapally spillway (1900 m^3/s, which is like a full gate opening in the simulation, and about 400 m^3/s is more than a 25-year hydrograph base condition) of the three regulators.

Figure 5.24: Locations of the four flood regulators at Karumadi, Thakazhy, Cheruthana, and Kuthiyathodu.

It can be observed that the regulators reduce flood levels by 0.5 to 1.5 m in the Kuttanad region and north of the AC canal. This reduction in water levels is possible due to the combined operation of the flood regulators. It can be seen that near the Kavalam location, flooding is well mitigated, and water flows within the banks of the river. The trend continues from Kavalam to Vembanad Lake. Also, towards the north of Karumadi and Nedumudy, water flows within the river banks. It is also observed that the regulator at Karumadi might block diverted water flowing from the Pampa River towards Vembanad Lake during the peak flood time. Hence, careful operation of the gates is necessary, especially for this location. Water levels on the downstream side of the regulators significantly reduce. On the other hand, on the upstream sides of the regulators, the water levels increase by 0.6 - 1.0 m. This trend of increased water level is seen till the leading channel of Thottapally from Veeyapuram,. For a 50-year return period flood hydrograph, a similar trend is observed. On the downstream sides of the regulators, a water level reduction by 0.5 - 1.0 m is observed against the base scenario. Water flows within the banks on the north side of Kavalam and towards Vembanad Lake. Between Kidangara and

Kavalam regions, an overtopping of 0.3 to 0.6 m is observed. On the upstream side of the regulators, the water level increases, maximum by 1.0 m from the base scenario. Flood regulators are found to control floods in certain regions and divert more water through the Thottappally spillway. However, bund heights need to be increased at certain places. Nevertheless, the presence of the regulators mitigates the flood significantly on their downstream side without the need of increasing the bund height Overall, analysis shows that there is scope for flood regulators to mitigate the flood in the lower part of the Kuttanad region.

5.7.5. Increase the carrying capacity of Thottapally lead channel

The simulation is carried out by Increasing the carrying capacity of the lead channel between Veeyapuram and the junction upstream of the Thottapally spillway. This simulation explores the role of Increasing the carrying capacity of the lead channel to reduce flood risk at Thottapally. Increasing the carrying capacity of the channel has a significant impact on reducing the water level in the lead channel. About 400 and 460 m^3/s of additional flow can be conveyed through the lead channel without overtopping the river for 200 and 300 m of increased channel width. The flow towards Vembanad Lake through channels 5 and 4 is also reduced; consequently, water levels also decrease.

5.7.6. Combinations of all solution measures

This simulation is carried out by increasing the carrying capacity of the lead channel between Veeyapuram and the junction upstream of the Thottapally spillway and installing all four flood regulators and the diversion channels. In other words, this simulation combines all the solution measures discussed above including four regulators. The simulation will help to understand the maximum level of mitigation possible for the 25- and 50-year return period flood hydrographs.

It can be seen that on the downstream side of the regulators, the water levels are reduced by 1.0 m. The overtopping issue is very well handled in the regions marked in a black circle. It is also observed that increasing the carrying capacity of the channels helps to maintain the water level upstream of regulators, which is very similar to the base scenarios. The increase in water level is observed to be 0.4 m for the 25-year and 0.6 m for the 50-year floods compared to the corresponding base scenarios. The bund heights of 1.5 to 2.0 m in channels 80, 82, 8, 9 and 10 will significantly reduce the flooding on the upstream side as well. However, this solution measure cannot be considered if Increasing the carrying capacity of the lead channel is not possible. The detailed evaluation of this solution with respect to different year return periods is analysed.

5.8. Major solution measures-2

Flood-vulnerable regions of the network were identified qualitatively and quantitatively, by analysing historical events of various return periods. To reduce the overtopping height of the network, various measures are evaluated using model simulations. Simulation results show that the proposed flood regulators (in the form of sluice gates) effectively reduce flood impact in the lower regions of Kuttanad by diverting more water towards the Thottapally spillway. However, it also leads to increased water levels on their upstream side, requiring the construction of flood walls (i.e., bunds) with heights ranging from 0.5 to 1.5 meters along the channel between Pampa and Thottapally. The results of the simulations were discussed in a stakeholders' meeting on 10th January 2023. During the meeting, stakeholders expressed their concerns about the difficulties involved in installing flood walls and flood regulators in the field. They suggested that the number of regulators proposed in the network could be reduced by Increasing the carrying capacity of existing channels such as the Thottapally leading channel, Korankuzhy Thodu, Poleppadam Thodu and its adjacent connecting channel, and three alternate channels can be constructed parallel to the Thottapally leading channel. These suggestions are taken into account, and simulations are performed to evaluate their impact on the network. The suggested measures are

- Increasing the carrying capacity of Thottapally leading channel (right bank by 50, 100 and 200 m)
- Increasing the carrying capacity of Korankuzhy Thodu
- Increasing the carrying capacity of the Poleppadam Thodu, Thayamkari Thodu and its parallel channel on the northern side
- Proposal of an alternate channel between Thayamkari Thodu and Thennday
- Proposal of flood regulator at Pullangadi Thodu
- Proposal of an alternate channel parallel to Korankuzhy Thodu
- Proposal of an alternate channel between Pampa River and Korankuzhy Thodu
- Proposal of an alternate channel between Pampa River near Veeyapuram and Thottappaly spillway
- Proposal of an alternate channel between Pampa River near Veeyapuram and Thottappaly lead channel

Each of the above-mentioned flood control measures is evaluated by simulating the historical flood events of different return periods. The location of flood regulators is decided through several trials. The following sections discuss the effectiveness of each flood control measure.

5.8.1. Increasing the carrying capacity of the Thottapally leading channel

Increasing the carrying capacity of a channel can have a significant impact on its carrying capacity, as well as on the water levels in adjacent and upstream channels. To investigate this, the right bank side of the lead channel between the Veeyapuram and Thottapally spillway is widened by 50, 100, and 200 m, as suggested by stakeholders and are depicted in Figure 5.25. Simulations are then conducted to determine the total amount of flow redirected towards the Thottapally spillway and its effects on nearby channels with minimal number of flood regulators. However, the channel improvement alone is found to be inadequate for pushing a significant amount of water towards the Thottapally spillway, and thus, the channel is further widened with the addition of a flood regulator. Various locations for the regulator are also examined through simulations, and that resulted in the maximum reduction of overtopping height is identified, as shown in Figure 5.25. The results of the simulations highlight the importance of carefully selecting the location of a flood regulator to manage water levels along the channels and prevent overtopping. Ultimately, by Increasing the carrying capacity of the channel and strategically placing the flood regulator, it is possible to increase the river carrying capacity and consequently mitigate the risk of flooding in adjacent and upstream channels. The effectiveness of this mitigation measure is evaluated by simulating the historical events.

The scenario is tested for different return periods of flood. The simulation shows no overtopping issue for the events. This is because the carrying capacity of the network is more than the actual flow corresponding to the events. Therefore, water flows well within the network without overtopping issues The flood regulators at Thagzhi and Karumadi have an insignificant effect on reducing overtopping heights, so they are not considered in this scenario. Only one regulator at Veeypuram is considered, and it effectively diverts water towards the Thottapally spillway, reducing water levels on the northern side. The pre-feasibility shows that Increasing the carrying capacity of the lead channel by 200 or 100 m avoids overtopping issues in several channels within the network compared to the 50 m case. In the pre-feasibility study in the case of 50 m widening, water diverted from Pampa flows towards Chruthana, causing Korankuzhy Thodu and its parallel channels to overtop by 0.5 to 0.8 m. Mitigating overtopping requires additional regulators. The effectiveness of the flood mitigation measure is more apparent on the northern side of Kuthiyathodu, Kidangara, and Thazagi, where the water level is reduced by 0.4 to 1 m, avoiding overtopping. Furthermore, the pre-feasibility for 50 and 100 m widening, an increase in water level between Kuthiyathodu and Veeyapuram of 0.4 m is observed upstream of the flood regulator. The pre-feasibility study of 200 m widening, the increase is less than 0.1 m and requires the flood wall only near the upstream side of the regulator. Therefore, it is evident that increasing the carrying capacity of the channel with one regulator effectively handles a 5-year flood event.

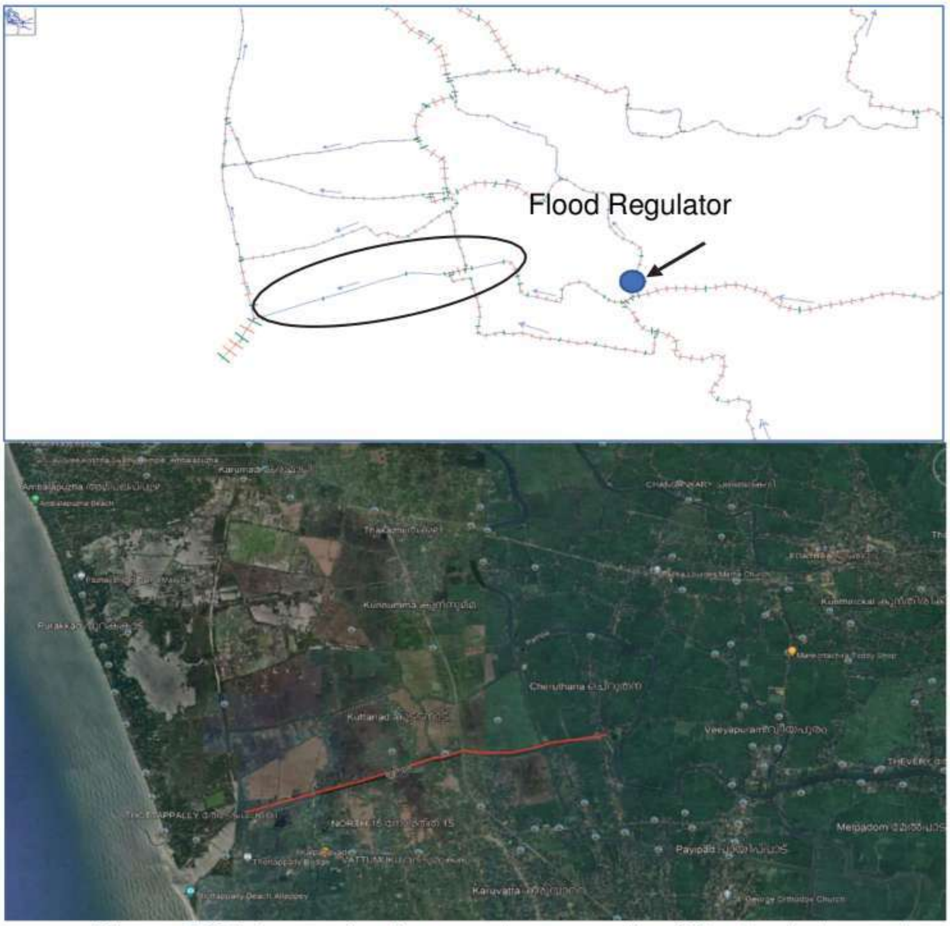


Figure 5.25: Increasing the carrying capacity of the lead channel

To better understand how Increasing the carrying capacity of of the lead channel and installing flood regulators can help mitigate overtopping issues, a simulation of the 1992 flow event is also conducted. The results show that increasing the carrying capacity of the channel does not significantly affect flooding patterns, so it is not considered further as a mitigation measure. Instead, a pre-feasibility of 100 and 200 m widening cases are analyzed. The flood mitigation measures are particularly effective in reducing water levels and avoiding overtopping in the Kidangara and Mankombu regions on the northern side of the Kuthiyathod regulator, with water levels decreasing by 0.5 to 1.1 m. In the Veeyapuram area, where only one regulator is considered in the simulation, water levels are reduced by 0.5 to 0.8 meters. The lead channel after increasing the carrying capacity, reducing water levels near Pullangady and Thagazi and avoiding overtopping in the channels between Edathua and Pullangady. In the pre-feasibility study, on the upstream side of the Kuthiyathod regulator, water levels increased by 0.3 to 0.8 meters for the 100 m widening case and 0.3 to 0.4 meters for the 200 m widening case (Figure 5.25). Constructing a flood wall of 0.3 to 0.5 meters on the downstream side of Kidangara can control the overtopping issue. Overall, the simulation shows that solution of increasing the carrying capacity of the lead channel can effectively reduce flooding of a 10-year-like flood.

The purpose of simulating the 1986 event is to further investigate the effectiveness of lead channel widening in mitigating a 25-year event. The simulation considers regulators at Kutiyathod and Veeyapuram. The northern regions of Kidangara and Mankombu and the regions north of Veeyepuram demonstrate the effectiveness of flood mitigation measures during this event. The water level is reduced by 0.6 to 1.25 m compared to the base simulation, and overtopping is avoided in Kidangara and Mankombu regions. The feasibility of widening of the lead channel at Veeyepuram with a regulator reduced the water level by 0.5 to 1 m north of the Veeyepuram area. The reduction indicates that channel modifications help to carry more water towards Thottapally and reduces the water level in nearby channels. An increase of 0.5 to 0.8 m in the water level is observed on the upstream side of the flood regulator between Kuthiyathodu and Veeyapuram. Constructing the flood wall or increasing the bund height can counteract the increased water level. A realistic value of bund heights between 0.5 and 1.0 m is recommended to prevent river overtopping.

5.8.2. Increasing the carrying capacity of Korankuzhy Thodu

The Increasing carrying capacity of the Korankuzhy Thodu as shown in Figure 5.26 is another channel improvement evaluated here. The simulations are carried out to analyze the impact of this channel improvement in reducing the overtopping heights. The effectiveness of the channel improvement is analyzed by simulating the historical events of different return periods similar to the previous cases.

The existing channel width of Korankuzhy Thodu varies between 40 and 60 m. This channel is widened by 100 m to carry more water from the Pampa River to the Thottapally spillway and assess the extent to which it could reduce the water level inside the network. Subsequently, simulations are run without considering the three flood regulators suggested previously. The results of these simulations indicated that channel modification alone does not reduce the water level or prevent overtopping issues. Therefore, flood regulators are also implemented in this scenario, and their locations are identified based on multiple simulations. The water diverted from the Kuthiyathodu regulator travels towards the Thottapally spillway and Cheruthuna channels near the Veeyepuram area. The flow in the Cheruthuna channel travels through Thagazi and reaches the Vembanad Lake. Approximately 40 to 60% of the flow in the Pampa River (i.e., near Korankuzhy Thodu) enters into Korankuzhy Thodu and is eventually discharged into the sea through the Thottapally spillway. Since the water is not regulated in the widened Korankuzhy Thodu, many channels on the north side of Thagazi are overtopped. Additionally, the Manimala and Pampa River flow overtop banks between Neerattupuram and Champakulam. Therefore, flood regulators are used to control the flow and divert more water into the widened channel. In this Increasing the carrying capacity scenario, two flood regulators are used to regulate the flow: one upstream of Korankuzhy Thodu and one near Veeyepuram, is found from the simulations that the present network can carry the flow equivalent to a 2-year return period without overtopping issues.

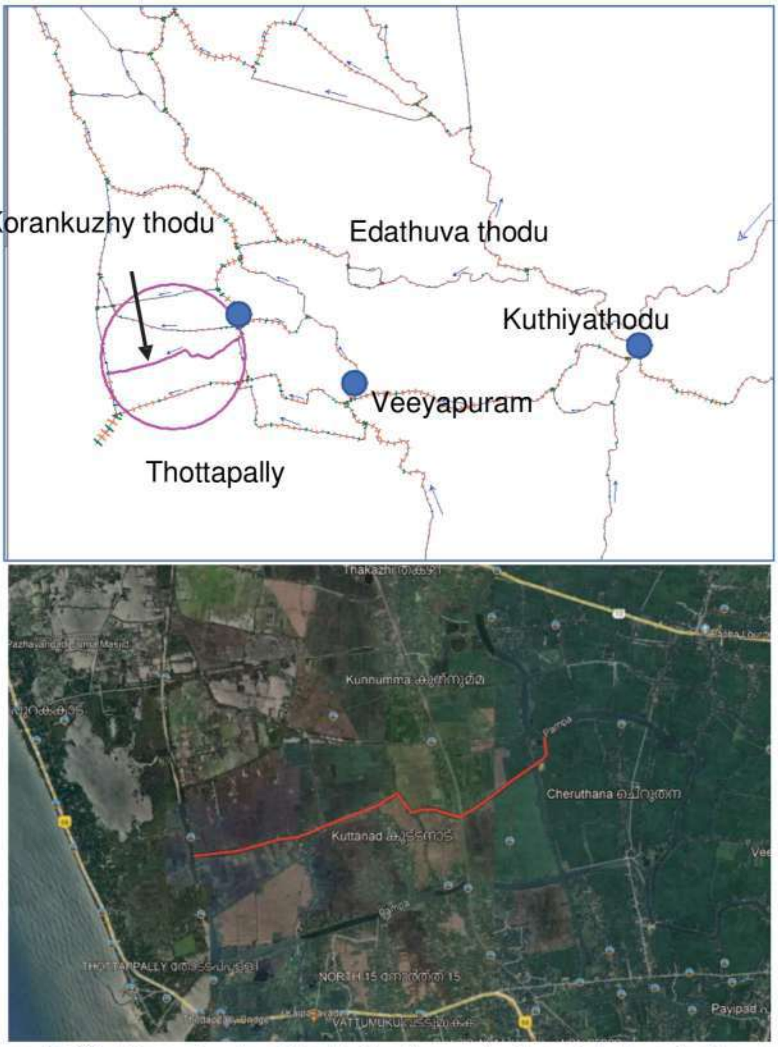


Figure 5.26: Korankuzhy Thodu is shown in the pink line in the model.

Increasing the carrying capacity of the channel and flood regulators play a crucial role in decreasing the water level by 0.5 to 1.3 m around Kidangara and Mankombu. The regulator positioned upstream of the Korankuzhy Thodu regulates the flow of the Pampa River and directs it to the Thottapally spillway, allowing more water from the Manimala and Pampa Rivers to pass through the channel, thereby reducing water levels by 0.5 to 1 m on the northern side of the Korankuzhy Thodu. Additionally, Increasing the carrying capacity the channel has helped to reduce water levels near locations like Pullangady and Thagazhi, thereby avoiding the overtopping issue in the channels between Edathua and Pullangady. Upstream of the gate, there is a rise of 0.3 to 0.8 meters in the water level dute to divertion of water and constructing a flood wall near the gate will offset this local increase. The effectiveness of flood mitigation measures becomes negligible due to the higher magnitude of river flows. Hence, flood mitigation measures will not play a role in mitigating flood events like those that occur once in a hundred years. However, the regulators can be operated to dewater the network system when the flood start receding. discharged into the sea through the Thottapally spillway. Since the water is not regulated in the widened Korankuzhy Thodu, many channels on the north side of Thagazi are overtopped. Additionally, the Manimala and Pampa River flow overtop banks between Neerattupuram and Champakulam. Therefore, flood regulators are used to control the flow and divert more water into the widened channel. It is found from the simulations that the present network can carry the flow equivalent to a 2-year return period without overtopping issues. Therefore, the 2004 event is not discussed.

5.8.3. Proposal of an alternate channel between Thayamkari Thodu and Thennday

The possibility of introducing four alternate channels has also been examined. This section focuses on evaluating the impact of a proposed channel connecting Thayamkari Thodu and Thennday. The suggested plan entails constructing a 100- m wide channel. To assess its effectiveness, simulations are conducted for various historical events as references. However, the simulation results indicate that this newly proposed channel has minimal impact on reducing water levels in either the Vembanad Lake or the Thottapally spillway area of the network. As a result, this particular option should be given a lower priority compared to other potential solutions in order to achieve the desired reduction in river overtopping and its associated consequences.

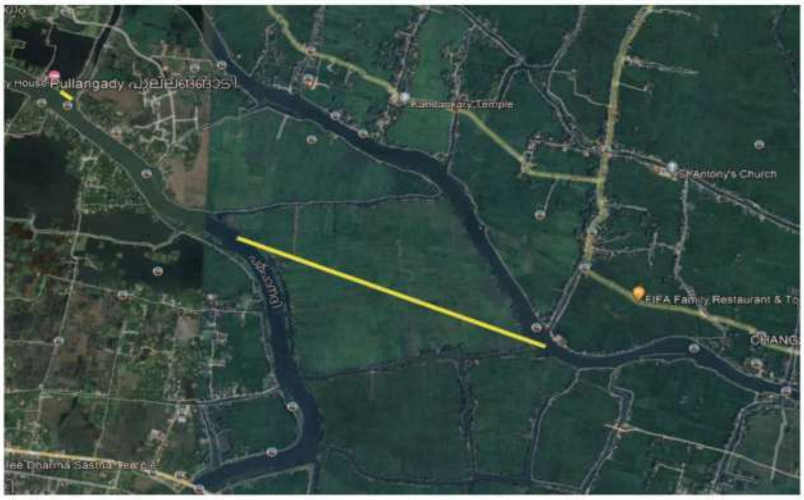


Figure 5.27: Proposal of an alternate channel between Thayamkari Thodu and Thennday

5.8.1. Proposal of a sluice gate at Pullangadi Thodu

The impact of a sluice gate located at Pullangadi Thodu as shown figure has been thoroughly analyzed in order to divert water and mitigate the problem of overtopping effectively. A series of simulations are conducted to evaluate its performance, considering different historical events. The results obtained from the simulations reveal that the sluice gate does not have a substantial effect in terms of reducing the water level in the nearby channel. Consequently, it would not significantly alleviate the issue of river overtopping. As a result, this solution should be assigned a lower priority in the pursuit of achieving the desired reduction in river overtopping and the associated consequences.

Figure 5.27: Proposal of a gate at Pullangadi Thodu

5.8.1. Proposal of an alternate channel parallel to Korankuzhy Thodu

The analysis aims to assess the impact of an alternate channel parallel to Korankuzhy Thodu. The primary focus is to determine the extent to which this channel diverts water towards the Thottapally spillway, thereby alleviating the problem of overtopping. The assumed width of the channel is 100 m, and its alignment can be seen in figure. To evaluate the efficacy of this proposed measure, a series of simulations are conducted, much like in previous cases, taking into account various historical events. The simulations aim to provide insight into the effectiveness of the alternate channel without considering the inclusion of regulators. The results indicate that the considered alternate channel alone would not fully exploit its potential. Therefore, it becomes necessary to install two regulators, with one placed at the beginning and the other at the end of the alternate channel. These regulators would enable better control over the flow of water and enhance the efficiency of the overall system. The simulations are then repeated, taking into account the presence of the regulators. The simulation highlight the significant role played by the alternate channel and flood regulators in reducing water levels by 0.4 to 1.6 m around Kidiangara and Mankombu, as indicated by the marked circles. Positioned upstream of the alternate channel, the regulator effectively controls the flow of the Pampa River and directs it towards the Thottapally spillway. This redirection allows a greater volume of water from the Manimala and Pampa rivers to pass through the channel, resulting in a reduction of water levels by 0.5 to 1 m on the northern side of Korankuzhy Thodu. Furthermore, the alternate channel has successfully lowered water levels in locations such as Pullangady and Thagazi, thus mitigating the risk of overtopping in the channels between Edathua and Pullangady. Upstream of the gate, there is a rise in water level ranging from 0.3 to 1.0 m, similar to the Increasing the carrying capacity of Korankuzhy Thodu. However, the construction of a flood wall can counteract this increase. Additionally, the entire network gets inundated for the 2018 event. It has been observed that this flood mitigation strategy causes minimal disruption to habitats compared to Increasing the carrying capacity the lead channel and Korankuzhy Thodu while serving a similar purpose. Therefore, this alternative can be considered a practically viable and superior option compared to the previously discussed alternatives.

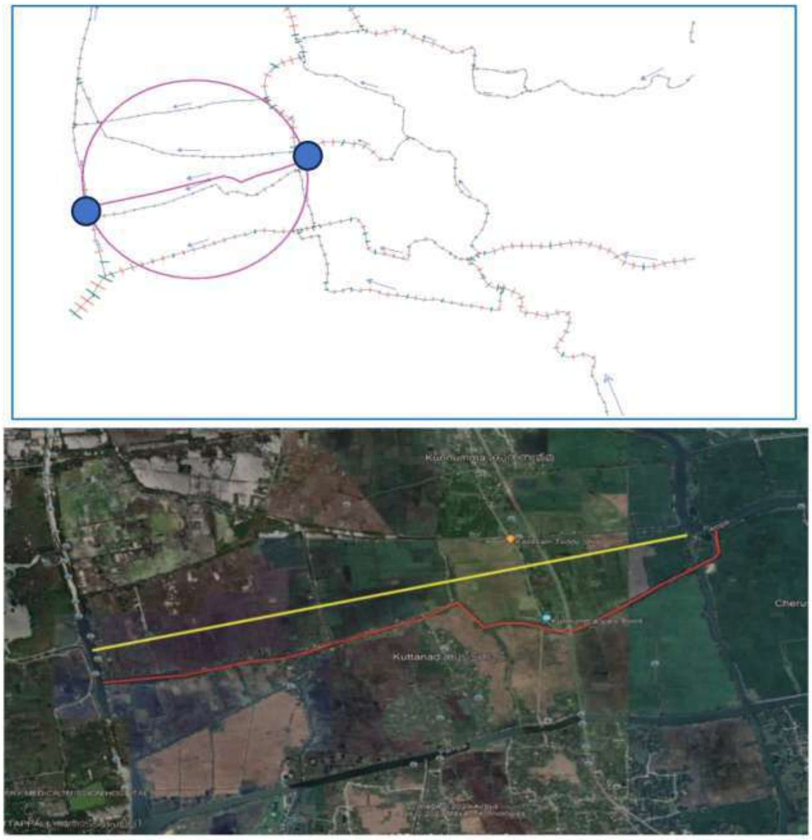


Figure 5.28: Proposal of an alternate channel parallel to Korankuzhy Thodu and the same considered in the model.

5.8.2. Proposal of an alternate channel Between Pampa River near Veeyapuram and Thottappaly Spillway

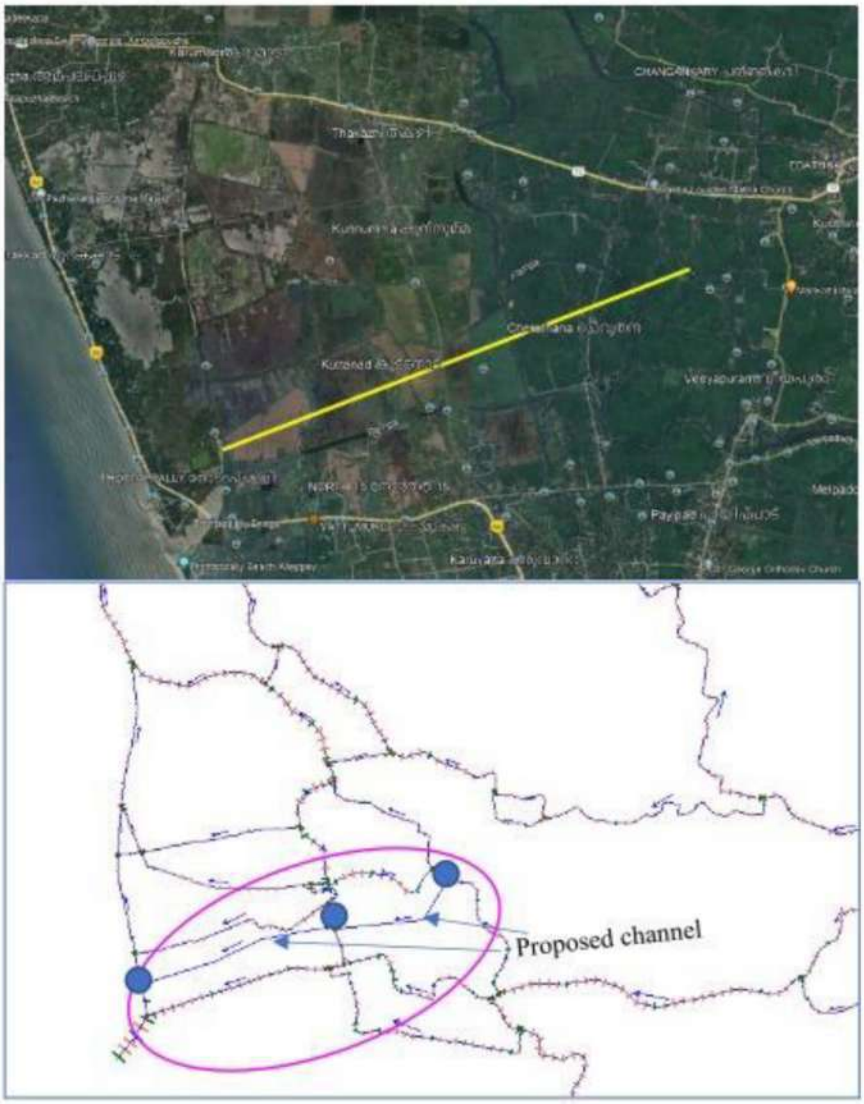


Figure 5.29: Proposal of an alternate channel Between Pampa River near Veeyapuram and Thottappaly Spillway and the same considered in the numerical model (filled circle indicates the sluice regulators).

A channel between the Pampa River near Veeyapuram and Thottappaly Spillway has been proposed as a solution to address the overtopping issue. The main objective of this channel is to divert water towards the Thottapally spillway, thereby reducing the risk of overtopping. The alignment of the channel, which causes the least disturbances to the inhabitants of the area, is depicted in Figure. For simulation, the channel is assumed to have a rectangular shape with a width of 100 m. In order to evaluate the effectiveness of this proposed measure, simulations are carried out, similar to the previous cases, which take into account various historical events. By analyzing the simulations, the regulators' positions are identified through trial simulations. The impact of the proposed channel is carefully analyzed, and the findings are discussed below. The analysis focuses on four different events: 2013 (flow with a 5-year return period), 1992 (flow with a 10-year return period), 1986 (flow with a 25-year return period), and 1994 (flow with a 50-year return period). The simulation clearly illustrate the effectiveness of the flood regulator at Kuthiyathod in reducing water levels downstream, particularly in the vicinity of Kidiangara and Mankombu. The flood regulator successfully lowers the water level by approximately 0.5 to 1.2 m, effectively mitigating overtopping issues in those areas. Furthermore, the analysis reveals that the proposed channel significantly reduces the risk of overtopping with its carefully planned alignment and regulated flow through the regulators. In locations such as Pullangady and Thagazi on the northern side of the channel, the risk of overtopping is reduced by approximately 0.5 to 1 m.

However, upstream of the Kuthiyathod gate, there is an increase in water level ranging from 0.3 to 1.0 m, consistent with the previous cases. This increase is a result of diverting water from the Kuthiyathod side. Nevertheless, this rise can be mitigated by constructing floodwalls for a small section. The simulation shows that the entire network experiences flooding for the 2018 event. In instances of severe flooding, the effectiveness of flood mitigation measures becomes less significant due to the high magnitude of river flows. Overall, it can be concluded that the proposed channel plays a crucial role in mitigating flood events with return periods of less than 50 years. It is important to note that these findings are based on simulated scenarios and should be further confirmed through extensive field observations. However, the initial results provide promising evidence that the proposed channel can effectively address the overtopping problem while minimizing disruptions to the local population. Additionally, it should be mentioned that the performance of this option is similar to the case of an alternate channel parallel to Korankuzhy Thodu but with more disturbance to the habitat compared to the latter. Hence, this option can be considered as an alternative after the alternate channel parallel to Korankuzhy Thodu.

5.8.3. Proposal of an alternate channel Between Pampa River near Veeyapuram and Thottappaly lead channel

This section examines the consequences of introducing an alternate channel connecting the Pampa River near Veeyapuram and the Thottappaly lead channel. The channel's alignment (as shown in Figure) was specifically chosen to minimize disruptions for the local residents. It is assumed that the channel has a rectangular shape with a width of 100 m. To assess the efficacy of this proposed solution, simulations were conducted, following a similar approach used in previous cases, considering different historical events. The effects of the suggested channel were thoroughly analyzed, and the results are discussed in the following section.

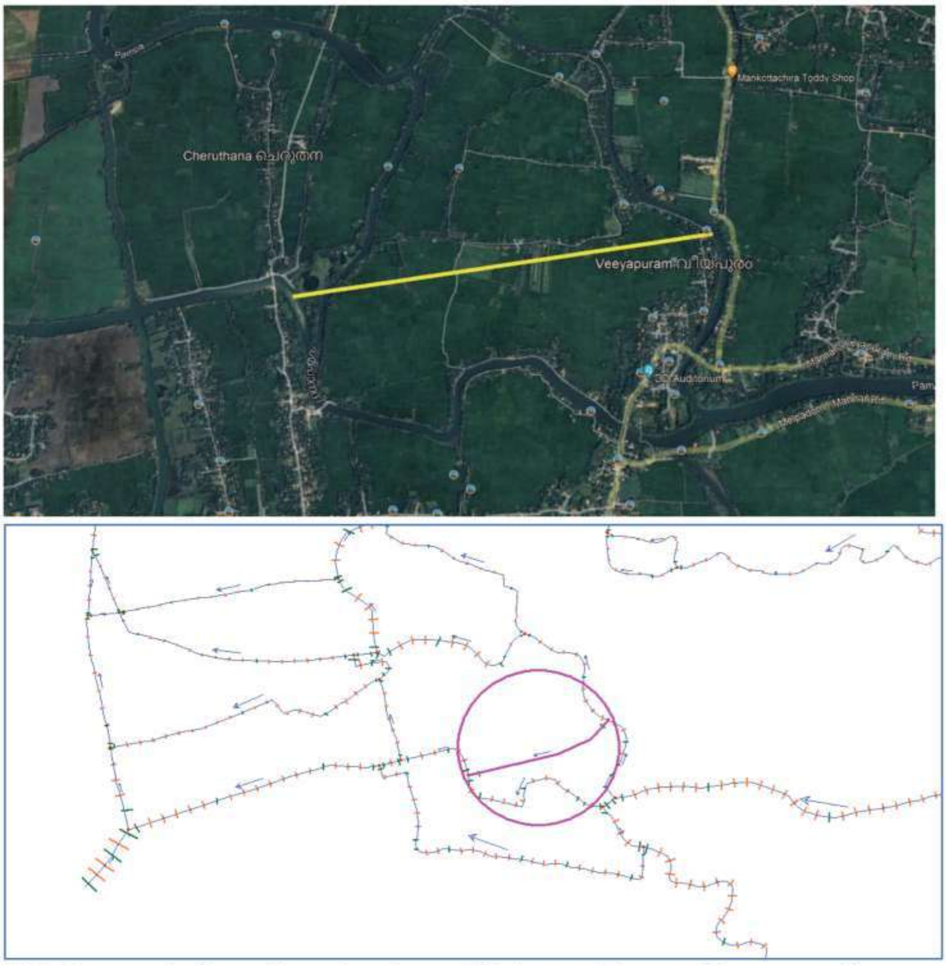


Figure 5.30: Proposal of an alternate channel Between Pampa River near Veeyapuram and Thottappaly lead channel and the same considered in the numerical model

The maximum water levels recorded in four different years, namely 2013 (flow with a return period of 5 years), 1992 (flow with a return period of 10 years), 1986 (flow with a return period of 25 years), and 1994 (flow with a return period of 50 years), are simulated. It is evident from the block circles in figures that the introduction of the suggested channel does not significantly alter the water level compared to scenarios where no measures were taken to mitigate the situation. This is possibly because the alternate channel essentially becomes an additional pathway in the existing network, resulting in the diverted water returning to the Pampa River instead of being directed towards the Thottapally spillway. This indicates the need to widen the lead channel, as discussed earlier. In conclusion, it can be inferred that the proposed channel discussed in this study will not effectively mitigate flood events.

5.8.4. Evaluation of the combination of all the proposed major mitigation measures-2

The evaluation of the combination of all the relevant major mitigation measures-*2* requires a simultaneous assessment of their performance with respect to historical flood events. The primary objective is to determine the overall effectiveness of the proposed measures in mitigating floods in the Kuttanad region. To ensure a focused analysis, only the channels that demonstrated a significant impact on reducing overtopping heights are considered in the simulations. All the historical events as discussed before are again simulated considering the impactful mitigation measures. Through the simulation process, it is evident that the four strategies that are examined, shows only marginal improvements compared to their individual base simulations. The outcome indicates that achieving significant improvements in addressing the overtopping issue requires implemention of a major intervention. Specifically, two potential measures have proven to have significant impact on flood mitigation

i. Pre-feasibility of 100 to 150 m widening of the lead channel or creation of an entirely alternate channel parallel to the lead channel. In addition, creation of some more alternate channels and proposal of modification of existing channels are required.
ii. The alternate channels and modification of existing channels alone cannot push water to the Thottappally spillway. For this purpose, flood regulators are suggested.

5.9. Mitigation measures that have insignificant or minimal impact

- Channel modification of the Karipuzha River has a moderate impact in diverting flood water from the Achankovil River. The extra water that can be diverted due to channel modification is only 40-60 m^3/s. However, the diverted flow rate can increase if the channel can be improved more than what is considered in the analysis.
- AC canal between Mankombu and Nedumudy canal may not play a significant role in reducing the flood impact. Extension of the AC canal to the national waterway and up to Pallathuruthy has only negligible impact in carrying the flood water. Hence, the new extension may not be required for flood mitigation.
- The simulation results for the sluice gate at Pullangadi Thodu demonstrates that it has an insignificant impact on reducing the water level in the nearby channel. Consequently, it would not effectively address the issue of river overtopping.
- The proposal for an alternate channel between Thayamkari Thodu and Thennday also shows minimal effectiveness in reducing water levels in Vembanad Lake or the Thottapally spillway area. Therefore, this particular option should be given lower priority than other potential solutions.
- The outcomes of simulating the Increase of the carrying capacity of Poleppadam Thodu, Thayamkari Thodu, and its parallel channel on the northern side indicate that this approach does not significantly decrease water levels in Vembanad Lake or the

Thottapally spillway area of the network. Hence, it can be concluded that this specific option should be considered less important when compared to other potential solutions.
- The newly proposed channel between the Pampa River and Korankuzhy Thodu does not contribute to flood mitigation.

5.10. Mitigation measures that have a considerable impact

The channel improvement by means of Increasing of the carrying capacity the existing channels and creation of alternate channels alone is found to be inadequate for pushing a significant amount of water towards the Thottapally spillway. Thus, flood regulators are used in addition to the proposed measures. Among the proposed flood regulators, one at Kuthiyathod is required in all the simulations, and the location and number of other regulators change depending upon the adopted measures. The following are the major measures which have shown major impacts on flood mitigation.

- The modification of the lead channel of the Thottapally spillway significantly reduces flooding in the network and avoids overtopping issues in many places. This measure involves totally two regulators. It needs to be mentioned that this modification also involves relocating the settlements (as seen in Google Earth in 2023) somewhere else.

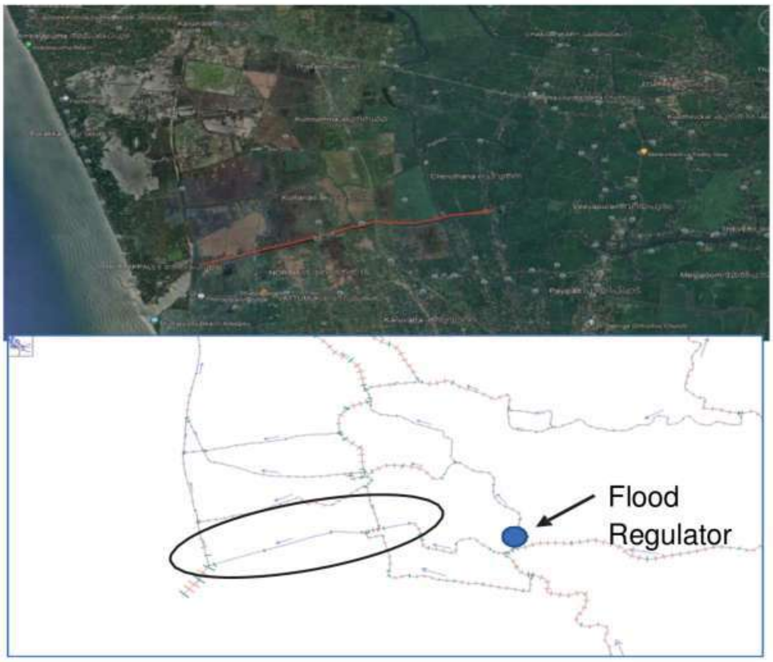


Figure 5.31:Modification of lead channel of Thottapally spillway

- The modification of the Korankuzhy Thodu channel causes minimal disruption to local settlements (as seen in Google Earth in 2023) compared to modifying the lead channel while serving a similar purpose. Three regulators are required for this measure.

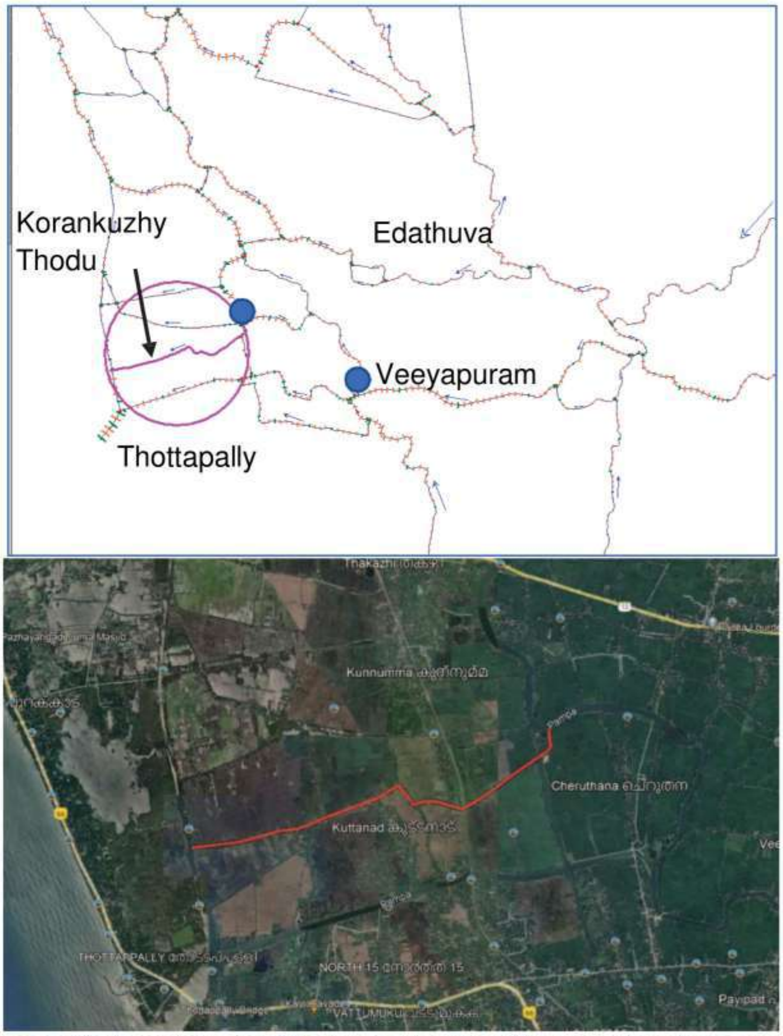


Figure 5.32: Korankuzhy Thodu is shown in the pink line in the model.

- The new parallel channel to Korankuzhy Thodu minimally disturbs local settlements in comparison to modification the main channel and Korankuzhy Thodu while fulfilling a similar objective. Additionally, this option is found to address overtopping issues with flood regulators. This measure requires three flood regulators as shown in the image below.

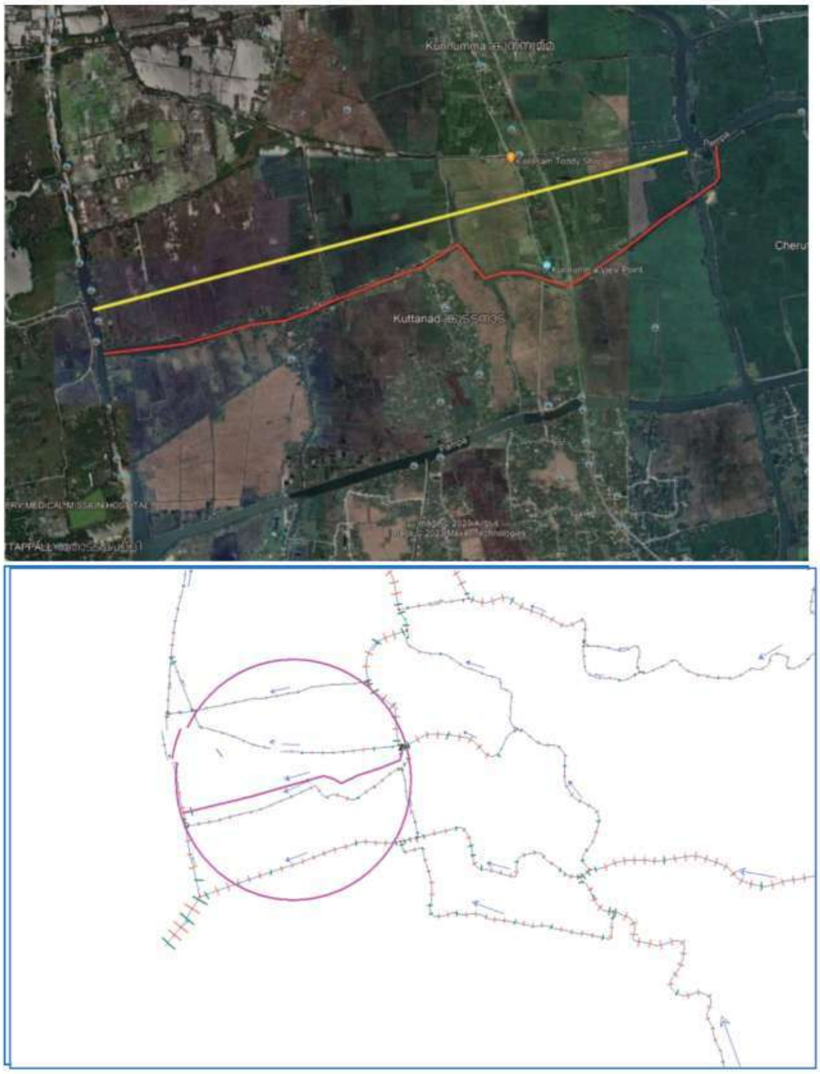


Figure 5.33: Proposal of an alternate channel parrel to Korankuzhy Thodu and the same considered in the model.

- The performance of a proposed alternate channel between the Pampa River near Veeyapuram and Thottappaly Spillway is similar to that of an alternate channel parallel to Korankuzhy Thodu. However, it requires four flood regulators.

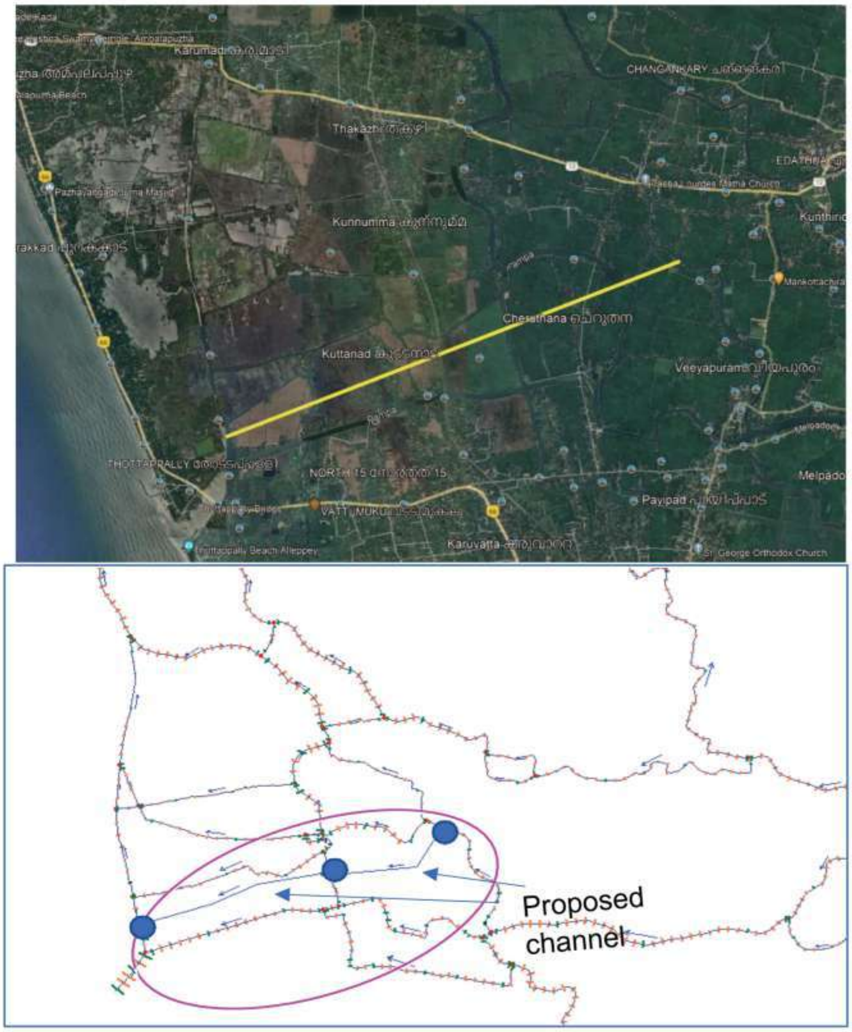


Figure 5.34: Proposal of an alternate channel Between Pampa River near Veeyapuram and Thottappaly Spillway and the same considered in the numerical model.

- Combination of the above methods

Figure 5.35: Combination of modification of existing channels and alternate channels in the numerical model

The above mitigation measures are suggested considering available space and desired outcomes. The recommendations are also made based on the above two strategies.

5.10.1. Thottappally Spillway Shutter Maintenance for Flood Management in Kuttanad Region

The Thottappally Spillway, which is an important flood control structure in the region, regulating water levels and preventing inundation. Regular maintenance of the spillway shutter is important for its efficient operation and to ensure flood mitigation.

The planned maintenance of the Thottappaly Spillway shutter is aimed at improving its overall functionality and enhancing flood management capabilities in the Kuttanad region. The maintenance plan involves checking the structural integrity of the shutter, cleaning, lubrication, and making any necessary repairs.

5.10.1.1. Details of the Maintenance Plan

The first phase of the maintenance involves a thorough inspection of the spillway shutter's mechanical components. This includes evaluating the hinges, gears, and locking mechanisms to ensure they are in good working order. Regular cleaning of the spillway is necessary to remove debris, sediment, and other materials that could obstruct its operation. Lubrication of the moving parts is also crucial to prevent corrosion and ensure smooth functioning during emergency water release. Any damaged parts identified during the inspection will be replaced or repaired. If required, the maintenance team will implement upgrades to the system, including enhancing the capacity to handle larger volumes of water. After the repairs and maintenance activities, the spillway will undergo testing to verify its operational capacity. This includes checking the sealing mechanism and ensuring that the shutter can open and close properly under high-pressure conditions.

5.10.2. River Training Works for Flood Protection Near the River Mouth of the Pamba River

The River Training Works project is focused on strengthening the banks of the Pamba River, particularly the stretch leading to the Thottappally Spillway, which plays a crucial role in draining excess floodwater into the Arabian Sea. The existing capacity of the leading channel is around 500 cumecs, whereas the actual river can handle a much larger volume. This project focuses on improving the efficiency of the leading channel, optimizing its ability to manage floodwaters effectively. The River Training Works for Flood Protection near the River Mouth of the Pamba River is an important project aimed for flood mitigation in the Kuttanad region from the threat of floods. By strengthening riverbanks, enhancing drainage infrastructure, and implementing flood mitigation measures, this project addresses the risks posed by flooding and contributes to the long-term resilience of the region. Once completed, it will significantly reduce the vulnerability of Kuttanad to future flood events, protecting this agriculturally important area.

5.11. A Series of Interventions for low Return Period Floods

Apart from the proposed major interventions, a series of minor interventions are necessary to address the root causes of flooding in the Pamba, Manimala, and Achankovil river basins. This includes stabilizing river banks, preventing erosion, and reinforcing embankments to mitigate flood damage at different stretches, repair and maintain critical infrastructure, restore damaged flood control structures, and enhance overall water management systems of Pamba basin. By implementing these measures, the goal is to reduce the severity of flooding having lesser return periods, while promoting long-term resilience and sustainability in the vulnerable stretches of river basins.

5.12. Categorisation of Interventions

Through this IRBM plan, interventions have been strategically categorized into three types: “Must-Do” Projects, Light-Touch Projects, and Heavy-Touch Projects, ensuring that both immediate and systemic needs of the basin are met effectively. This categorization helps prioritize the interventions based on their significance, providing a framework for addressing the critical issues while ensuring resource allocation. The list of interventions corresponding to these categories is appended.

5.12.1. “Must-Do” projects

“Must-Do” projects focus on addressing immediate hazards caused by recent floods. These interventions prioritize mitigating risks to the environment, property, and human lives that could worsen if left unaddressed. Unlike other project types, “Must-Do” interventions do not require the completion of the IRBM plan. These are critical projects designed to stop hazards even without a detailed plan in place. They emphasize rapid hazard assessments and mapping of affected locations, enabling timely identification of critical areas for intervention. Although not explicitly listed beforehand by location and type, the IRBM Plan will, however, foresee this type of emergency projects which therefore become part of the entire portfolio of interventions.

5.12.2. Light-Touch projects

Light-Touch projects are transitional initiatives that support recovery efforts while aligning with developmental objectives and integrating into the IRBMP framework. These projects have shorter preparation and implementation timelines, requiring the rapid development of Detailed Project Reports (DPRs) and basic Environmental and Social Impact Assessments (EIA/SIA) for efficient execution. By addressing flood recovery needs while ensuring compatibility with long-term plans, they help establish resilience within a year of approval.

Targeted, low-impact interventions should be implemented to mitigate moderate risks while preserving ecological balance. In high-risk zones, community-led flood protection measures such as raising bund levels, constructing local retention structures, and upgrading drainage systems should be prioritized using cost-effective, context-appropriate technologies. Additionally, existing water management infrastructure, including check dams, canals, and irrigation systems, should be renovated and upgraded to enhance efficiency and resilience against floods.

5.12.3. Heavy-Touch projects

Heavy-Touch projects are large-scale, long-term interventions designed to address systemic challenges within the Pamba Basin. These transformative projects focus on resolving complex issues through comprehensive hydrological, ecological, and socioeconomic studies, ensuring alignment with the broader objectives of integrated river basin management. Extensive stakeholder consultations and detailed planning are essential to developing sustainable and climate-resilient solutions.

A holistic river basin management approach is required, integrating hydrological modelling, ecological assessments, and socioeconomic analysis to guide large-scale ecosystem restoration and water management improvements. Strategic alternate channels and conveyance systems should be developed to alleviate flood pressure on existing rivers, incorporating climate-resilient designs to accommodate future flood volumes. Additionally, major infrastructure projects, such as spillway upgrades, leading channel upgrades, and flood regulators, should be implemented based on rigorous engineering studies to provide long-term protection against extreme flood events.

By embedding these interventions into the overarching IRBMP framework, Heavy-Touch projects will ensure enduring benefits to the basin's ecosystem and the communities that depend on it.

5.13. Summary

The study employed a comprehensive one-dimensional hydrodynamic model using HEC-RAS to analyze flooding in the Pamba Basin and Kuttanad region. Field surveys collected detailed cross-section data along major rivers and channels, which were integrated into the model alongside historical hydrograph and water level data from 2010-2019. The model was calibrated and validated against observed water levels, showing satisfactory agreement despite the complex system and associated uncertainties.

Simulations were conducted for 25-year and 50-year return period floods, revealing substantial overflow across most channels. The study evaluated multiple mitigation measures, including increased carrying capacity of channels, flood regulators, and alternate channel construction after impact studies. Key findings indicated that increase the carrying capacity of the Thottapally leading channel and Korankuzhy Thodu, combined with strategic placement of flood regulators, could significantly reduce water levels in vulnerable areas like Kidangara and Mankombu. Alternate channels parallel to existing ones showed promise in diverting water toward the Thottappally spillway, though they required additional regulators for maximum effectiveness.

The research recommended a combination of structural interventions categorized as "Must-Do," "Light-Touch," and "Heavy-Touch" projects.

"Must-Do" projects address immediate hazards through rapid assessments and critical infrastructure repairs.

"Light-Touch" initiatives involve community-led protection measures and upgrades to existing water management systems.

"Heavy-Touch" projects encompass large-scale channel modifications, alternate channel construction, and major infrastructure improvements based on comprehensive hydrological and socioeconomic studies.

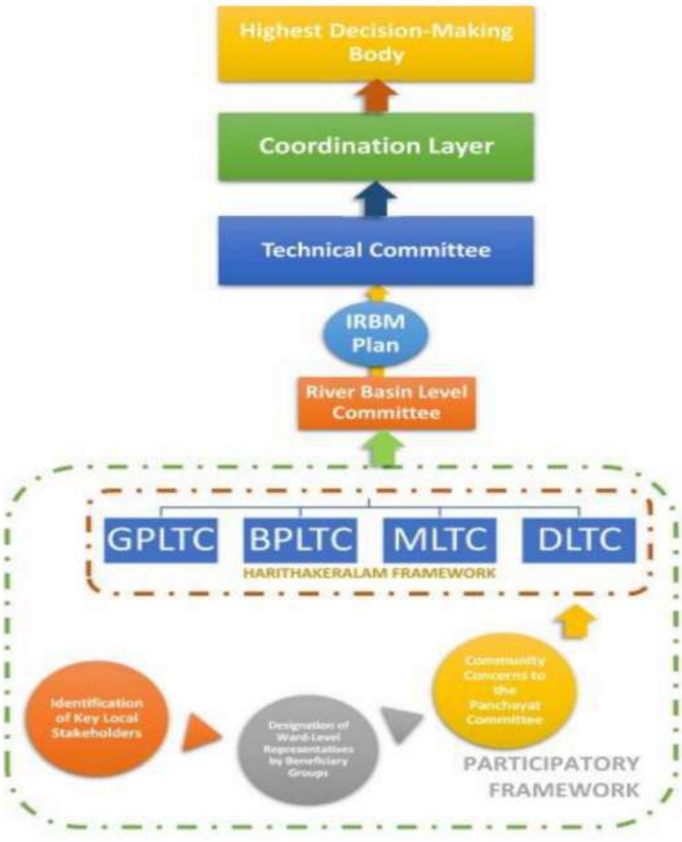
The chapter emphasized the importance of regular maintenance for flood control structures like the Thottappally Spillway and advocated for non-structural measures such as flood forecasting systems to provide early warnings. The integrated approach combines immediate actions with long-term planning to enhance the region's resilience against flooding, protecting both human communities and ecological systems in this agriculturally vital area.

6. Implementation Framework

6.1. Introduction

Kerala’s vulnerability to water-related disasters, exemplified by the devastating 2018 floods, underscores the urgent need for a science-based, participatory approach to water resource management. The floods exposed critical gaps in reservoir coordination, and institutional capacity, exacerbated by rapid urbanization, climate variability, and unsustainable practices like sand mining and wetland degradation. Current water management approaches, divided among multiple government departments and local bodies, struggle to address these interconnected challenges. Fragmented governance leads to conflicting policies, duplicated efforts, and gaps in responsibility. An Integrated River Basin Management (IRBM) framework enables coordinated decision-making across administrative boundaries, balances competing water needs, and creates sustainable solutions that respect Kerala's unique geographical realities. An implementation framework for executing the plan is presented in this chapter.

6.2. Implementation Framework



6.3. Governance Structure

6.3.1. Highest Decision-Making Body

The apex led by the Chief Minister, and comprising key ministerial heads, this body will ensure alignment with state development policy. Its responsibilities include approving River Basin Management Plans, ensuring policy coherence across sectors, resolving interdepartmental conflicts, allocating funds, and monitoring IRBMP implementation.

6.3.2. Coordination Layer

A senior-level group (headed by the Chief Secretary) and comprising ACS/Principal Secretaries of Water Resources, Planning, Revenue, LSGD, Finance, Agriculture, Forest, Environment, Tourism, Law, and stakeholder departments, will oversee IRBM plan preparation, alignment with state policies, climate resilience, and national water standards. It reviews and recommends IRBM plans, monitors implementation progress, integrates sectoral strategies (agriculture, disaster management, urban planning), and resolves interdepartmental conflicts unresolved by lower committees.

6.3.3. Technical Committee

The Technical Committee for Integrated River Basin Management (IRBM), comprising heads of key departments, serves as a technical advisory body to the Coordination Layer. It ensures sectoral plans (e.g., irrigation, urban water supply) align with IRBM goals, identifies interdepartmental overlaps, and fosters coordination to eliminate redundancies. The committee reviews policies for consistency with sustainable water use, climate adaptation, and pollution control, while providing a platform for cross-departmental communication. It monitors on-ground policy implementation, delivers technical feedback on water management practices and technologies, and mandates environmental impact assessments for major projects.

6.3.4. The River Basin Level Committee (RBLC):

The River Basin Level Committee (RBLC), chaired by the District Collector of the largest basin district with Co-Chairs from other basin districts, comprises local body heads, district officers, Technical experts and NGOs. Tasked with participatory, decentralized planning, it coordinates sectoral plans for IRBM plans integrating local stakeholder input. Technical experts consolidate these into a comprehensive Integrated River Basin Management Plan (IRBMP), ensuring scientific rigor and alignment with sustainability, equity, and climate resilience. The RBLC resolves local disputes, oversees project implementation (timelines, budgets, environmental compliance), and monitors outcomes (water security, pollution reduction). It reviews progress, and reports to higher committees for approval.

6.4. Participatory mechanism:

Key local stakeholders shall be systematically identified, with their active participation ensured through formal channels to integrate their inputs into sectoral plans. Each beneficiary group will designate a ward-level representative to articulate community concerns to the panchayat committee. To facilitate this, the existing institutional framework of Haritha Keralam should be leveraged to operationalize a multi-tiered engagement process, ensuring alignment with local governance norms. These representatives will consolidate and escalate prioritized issues to the river basin-level committee for decision-making. Technical experts in RBLC will lead the preparation of the comprehensive IRBM Plan, incorporating stakeholder feedback while ensuring scientific rigor and coherence with the plan's sustainability objectives. This approach fosters inclusive planning, strengthens accountability, and bridges grassroots perspectives with basin-level strategies.

6.5. Financial Strategy

The financial strategy combines core funding from existing departmental budgets with a state-managed pool fund overseen by the coordination body. This pool will support cross-basin initiatives, technology adoption, and capacity building. Additional resources can be leveraged through corporate social responsibility programs, grants, and public-private partnerships for large-scale projects. Dedicated budget lines can ensure transparency, with separate allocations for local projects and inter-basin coordination efforts.

6.6. Summary

The Integrated River Basin Management (IRBM) framework offers Kerala a practical path forward to address its water resource challenges. By creating a clear governance structure that involves all levels of government and local communities, this plan helps balance the needs of people, the economy, and the environment. The framework focuses on using community input to make decisions about water management. This approach will help Kerala avoid future water crises, protect against natural disasters, and ensure that water resources are used sustainably for generations to come.

7. Conclusions

The Greater Pamba Basin, comprising the Pamba, Manimala, and Achankovil rivers, is an important water resources and handling major ecosystems in the region for five districts of Kerala. The region faces recurring challenges such as floods, water scarcity, pollution, and ecological degradation. In the aftermath of the 2018 floods, the need for an integrated approach to water resource management became important. Integrated River Basin Management (IRBM) offers a framework that combines hydrological, ecological, and socio-economic considerations to promote sustainable water management. This basin management plan seeks to mitigate flood risks, ensure water security, and resilient communities by implementing evidence-based, stakeholder-driven solutions.

The present Phase of plan integrates data from all the sectors and a detailed study about the resources has been conducted. A hydrological modelling using the Soil and Water Assessment Tool (SWAT) has been setup for water balance assessment. Stakeholder consultations, were conducted and detailed flood impact assessments were made Future water availability scenarios under various climate projections have been analyzed. By incorporating both structural and non-structural interventions, a new governing mechanism, This plan proposes actionable strategies to improve the basin's resilience to climate change and extreme weather events. Following specific conclusions were derived from the study.

1. The current scenario of the Greater Pamba River Basin has been assessed, focusing on its geomorphology and topography. The physical characteristics of the basin, including variations in elevation, slope patterns, and landforms, have been described to better understand its natural setting. The socio-economic and environmental status of the basin has also been examined. This basin profiling can serve as a baseline guideline for the further phase of the basin plan also.

2. The SWAT has been used to evaluate the water availability in the basin. The historical water availability in the GPB highlights the complex interplay between rainfall, runoff, soil moisture, and ET, which collectively determine the hydrological balance and water resources in the region. The rainfall patterns indicate significant spatial variability across the catchment

3. Considering the modelled runoff, the runoff magnitude during high-flow periods (lower exceedance probabilities) is notably increased in the future scenarios compared to historical conditions across all stations. The sharp increase in the high-flow values indicate high sensitivity to increasing rainfall in the GPB. This indicates significant increase in the extreme flow events in the catchment and point to an increased risk of flood events in GPB. The low-flow values (higher exceedance probabilities) remain

same in the future scenarios considered, indicating stable baseflow conditions in the GPB.

4. Based on the two stakeholder workshops, where flooding was identified as the most urgent issue affecting both upstream and downstream communities. While other challenges, such as water scarcity, pollution, and ecosystem degradation, were acknowledged, these are slated for future action. For now, the primary focus is on flood mitigation strategies, which are informed by comprehensive hydrodynamic analysis.

5. A Risk Matrix assessment highlighted flooding as a critical, cross-sectoral concern for residents, agricultural communities, and industries. Although sector-specific risks, like salinity intrusion affecting coastal farmers, were noted, these will be addressed in future interventions. Proposed solutions include a mix of structural measures aimed at reducing flood risk.

6. Four strategic locations were identified for constructing flood regulators to manage water flow effectively. These locations include Karumadi, Thakazhy, Cheruthana, and Kuthiyathodu. Additionally, the Increasing the carrying capacity of existing channels was recommended at key points, notably the Thottappally leading channel, to enhance water conveyance and reduce overflow risks.

7. To further mitigate flooding, the proposals suggests constructing alternate channels after detailed impact studies, including one connecting the Pampa River near Veeyapuram to the Thottappally lead channel. Another channel linking Thayamkari Thodu and Thennday is planned to improve water drainage. Localized flood mitigation efforts, consisting of minor structural interventions, are also recommended to address specific flooding challenges and enhance water security.

8. The proposed interventions are classified into three categories based on their significance and impact: "Must Do" for critical flood management measures, "Light Touch" for minimal structural adjustments, and "Heavy Touch" for large-scale projects. Additionally, a flood forecasting system is recommended as a non-structural measure to provide early warnings, enabling timely actions to reduce flood-related damages.

9. A governance structure has been proposed for Integrated River Basin Management (IRBM) consists of a hierarchical framework, with the highest decision-making body led by the Chief Minister. A Coordination Layer, chaired by the Chief Secretary, oversees the preparation and implementation of IRBM plans, while a Technical Committee provides sectoral expertise and monitors sustainability and climate resilience. At the local level, the River Basin Level Committee (RBLC) facilitates participatory planning,

resolves disputes, and ensures alignment with environmental goals, supported by a financial strategy combining state funds, CSR programs, grants, and public-private partnerships.

The IRBM plan recognizes the dynamic nature of water resource management and the evolving needs of diverse stakeholders. To ensure continuous improvement and adaptation to emerging challenges, the plan emphasizes the importance of incorporating future sectoral plans from all stakeholders, including government agencies, local communities, agricultural interests, industrial sectors, and environmental organizations. By establishing mechanisms for regular stakeholder engagement and plan revision, the Greater Pamba Basin can maintain a forward-looking, comprehensive strategy that addresses both immediate concerns and long-term sustainability goals. The action plans listed below will include detailed implementation roadmaps with specific timelines, responsible agencies, and monitoring mechanisms to ensure progress toward the basin's sustainability goals.

7.1. Action plan

Action Item	Description	Implementation Timeline	Responsible Agencies	Key Performance Indicators (KPIs)
Flood Forecasting System	Implement a flood forecasting system for early warning and response.	Completed	Irrigation Department	Number of flood alerts issued, reduction in flood-related damages.
River Basin Management Framework	Establish a River Basin Management and Conservation Framework.	Q2 2025	Government of Kerala	Framework adoption rate, stakeholder engagement metrics.
Water Allocation Framework	Create a water allocation framework for agricultural, domestic, and industrial use.	Q4 2025	Irrigation Department	Percentage of sectors with allocated water, reduction in disputes.
Flood Regulators Construction	Build flood regulators at strategic locations to control water flow.	Q4 2025 - Q3 2030	Irrigation Department	Number of regulators constructed, reduction in flood frequency.
Increasing the carrying capacity of channels & New Construction	Increasing the carrying capacity of Thottappally leading channel and construct an alternate channel between Pampa River (Veeyapuram) and Thottappaly Spillway.after impact studies	Q4 2025 - Q3 2030	Irrigation Department	Length of channels increased carrying capacity/newly built, reduction in flood frequency.

Spillway Shutter Maintenance	Maintain Thottappally Spillway shutters for flood management in Kuttanad.	2025-2027	Irrigation Department	Reduction in spillway malfunctions, timely floodwater release.
River Bank Protection	Rehabilitate and protect river banks along the Pampa River.	Ongoing	Irrigation Department	Area of river banks protected, reduction in erosion.
Flood Mitigation in Kuttanadu	Restore embankments, install flood barriers, and build groundwater recharge structures.	Ongoing	Irrigation Department, Local Self Government Institutions (LSGs)	Reduction in flood impact.
Rainwater Harvesting Systems	Install rainwater harvesting systems in urban and rural areas.	2025-2030	LSGs, GWD	Number of systems installed, increase in groundwater levels.
Post-Flood Infrastructure Repair	Rehabilitate damaged irrigation infrastructure post-flood.	Ongoing	Irrigation Department	Percentage of infrastructure restored, reduced downtime.
New Irrigation Infrastructure	Develop new irrigation projects for long-term water security.	2025-2030	Irrigation Department	Area brought under irrigation, improved water availability.
Water Resources Database	Create a comprehensive database for water resources in the Pamba Basin.	2025-2027	WRD, State Planning Board	Data accuracy, accessibility, and update frequency.
Community-Based Flood Preparedness	Train communities on flood preparedness and response.	2025-2030	Kerala State Disaster Management	Number of trained participants, community response efficiency.

			Authority (KSDMA), LSGs	
Groundwater Monitoring Network	Establish a network of groundwater monitoring wells.	2025-2030	Central Ground Water Board, GWD	Number of wells installed, data collection accuracy.
Water Quality Monitoring	Conduct regular water quality testing and reporting.	2025-2030	Kerala State Pollution Control Board	Number of samples tested, pollution level reduction.
Financial Framework for Basin Management	Create a dedicated fund for river basin conservation.	Q2 2026	Government of Kerala	Fund utilization rate, projects funded.
Participatory Governance Mechanisms	Establish ward-level community input systems for water management.	Q3 2025	LSGs, Harithakeralam	Number of community inputs incorporated, satisfaction surveys.
Flood Control Infrastructure Maintenance	Schedule maintenance for spillways, channels, and regulators.	2025-2030	Irrigation Department	Reduction in infrastructure failures, maintenance compliance rate.
Emergency Response Plans	Develop detailed flood response plans for high-risk areas.	Q1 2026	KSDMA, District Collectors	Plan implementation rate, response time during floods.
Awareness Campaigns	Promote flood preparedness and water conservation through public campaigns.	2025-2030	LSGs, Harithakeralam	Number of campaigns conducted, public awareness levels.

Water Audit	Conduct a comprehensive water balance study for the Pamba Basin.	Q2 2026	Irrigation Department	Accuracy of water balance data, policy recommendations generated.
Hydrological Monitoring Systems	Install additional gauging stations and monitoring equipment.	2025-2030	Central Water Commission, Irrigation Department	Number of stations installed, improvement in data granularity.
Real-Time Flood Forecasting Model	Develop a model for controlled reservoir water release using real-time data.	2025-2030	Irrigation Department, KSEB, Central Water Commission	Timeliness and accuracy of forecasts, reduction in downstream flooding.
Automated Flood Forecasting Systems	Integrate automated systems with IMD and state networks.	2025-2030	KSDMA, Irrigation Department, KSEB, Central Water Commission	Reduction in flood response time, accuracy of warnings.
Wetland Restoration Projects	Identify and prioritize wetland restoration sites.	2025-2030	DoECC, LSGs, Irrigation Department	Area of wetlands restored, biodiversity indicators.
Community Water Conservation Programs	Organize workshops on sustainable water practices.	2025-2030	LSGs, Harithakeralam	Number of participants, adoption of conservation practices.

Catchment Area Management	Implement afforestation and soil conservation in upper catchments.	2025-2030	Forest Department	Area under afforestation, soil erosion reduction.
Groundwater Recharge Infrastructure	Build check dams, percolation ponds, etc., to enhance recharge.	2025-2030	GWD	Increase in groundwater levels, structures constructed.
Water Allocation Policies	Formulate equitable water distribution policies.	2026-2028	State Planning Board, WRD	Reduction in water conflicts, efficiency improvements.
Reservoir Modernization	Upgrade dam infrastructure and automate sluice gates.	2025-2030	Irrigation Department, KSEB	Improvement in operational efficiency, reduced flood/drought events.
Climate-Resilient Agriculture	Promote drought-resistant crops and efficient irrigation techniques.	2028-2030	Agriculture Department	Reduction in agricultural water use, adoption rates of resilient practices.
Wetland Monitoring Programs	Implement long-term wetland conservation and biodiversity restoration.	2028-2030	DoECC, LSGs, Irrigation Department	Area of wetlands restored, biodiversity health metrics.
Integrated Road-Drainage Systems	Design and construct roads with built-in drainage systems to prevent waterlogging and reduce runoff into the Pamba River.	2025-2027	Public Works Department	Kilometers of roads with integrated drainage, reduction in runoff volume.
Bridge and Culvert Upgradation	Upgrade bridges and culverts in flood-prone areas to increase	2025-2028	Public Works Department, LSGs,	Number of structures upgraded, reduction in flood-

	hydraulic capacity and prevent debris blockage.		Irrigation Department	related damage to infrastructure.
Floodplain Zoning and Infrastructure Control	Develop and enforce floodplain zoning regulations to prevent inappropriate infrastructure development in high-risk areas.	2025-2028	Land Use, Town Planning Department	Percentage of floodplain area regulated, reduction in unauthorized constructions.
Flood Risk Zoning	Develop detailed flood risk maps and establish zoning regulations to prevent development in high-risk areas and guide safe construction practices.	2025-2026	Kerala State Disaster Management, LSGD	Completion of risk maps, reduction in new constructions in flood zones.
Ecosystem Monitoring Systems	Establish monitoring programs for forest health, wildlife populations, and river ecosystem conditions to inform management decisions.	2025-2028	Forest Department	Number of monitoring sites established, data collection and reporting frequency.
Ecosystem Restoration Programs	Implement large-scale restoration of degraded ecosystems, including wetlands, forests, and riverbanks, to enhance ecological services.	2025-2030	Department of Environment & Climate Change, Forest Department	Area restored, improvement in ecosystem health indicators.
Urban Master Plan	Integrate water management considerations into local development plans through regulations promoting permeable	2025-2028	LSGD, Town Planning Department	Percentage of new developments complying with water-sensitive design principles.

	surfaces, rainwater harvesting, and stormwater management.			
Integrated Coastal Management Plans	Develop and implement comprehensive management plans for coastal areas that address development, conservation, and disaster preparedness.	2025-2028	Kerala Coastal Zone Management Authority, Irrigation Department, HED	Number of plans developed, coverage of coastal areas.
Coastal Infrastructure Resilience	Design and construct coastal infrastructure with climate resilience considerations, including protection against sea level rise and increased storm intensity.	2025-2028	Irrigation Department, HED	Number of resilient infrastructure projects completed, reduction in climate vulnerability.
Fisheries Monitoring Systems	Establish monitoring programs for fish populations, catches, and fishing activities to inform management decisions and track sustainability.	2025-2028	Fisheries Department	Number of monitoring sites established, data collection and reporting frequency.
Sanitation Infrastructure Improvement	Upgrade and expand sanitation facilities in rural and urban areas to prevent contamination of water sources.	2025-2030	KWA, LSGs, KPCB	Reduction in water contamination incidents, improvement in sanitation coverage.

Tourism Impact Assessments	Conduct assessments of tourism activities on water resources and implement mitigation measures to address negative impacts.	2025-2028	Tourism Department	Number of assessments completed, implementation of mitigation measures.
Temple Water Management Systems	Implement water conservation and management systems in temples and religious complexes within the basin.	2025-2028	Travancore Devaswom Board	Reduction in water consumption, improvement in water management practices.
Water Distribution Efficiency Improvements	Optimize water distribution networks to reduce non-revenue water and improve service reliability for domestic and industrial users.	2025-2027	Kerala Water Authority	Reduction in non-revenue water, improvement in service reliability metrics.
Water-Sensitive Land Use Planning	Integrate water resource considerations into land use planning through zoning regulations, development controls, and incentive mechanisms.	2025-2028	Land Use Board, Town Planning Department	Percentage of land use decisions incorporating water considerations, reduction in conflicting developments.
Emergency Water Supply Systems	Establish emergency water supply systems for drought-vulnerable communities	2025-2028	Kerala Water Authority, LSGs	100% coverage of high-risk areas, reliable water supply during drought periods
Water Rationing Framework	Develop water rationing framework for domestic and industrial use during drought emergencies	Q4 2026	Kerala Water Authority, LSGs	Reduction in non-essential water use by 40% during rationing periods, public compliance rate exceeding 90%

Early Warning Systems for Landslides	Deploy real-time landslide early warning systems monitoring soil moisture and slope stability	2025-2027	Kerala State Disaster Management Authority	Timely evacuation of 95% of at-risk populations, reduction in landslide-related casualties
Landslide Risk Zoning	Develop detailed landslide risk maps and establish zoning regulations	2025-2026	Kerala State Disaster Management Authority	Completion of risk maps covering 100% of vulnerable regions, reduction in new constructions in high-risk zones
Salinity Monitoring Network	Establish a network of monitoring stations to track salinity levels in coastal aquifers and water bodies	2025-2027	Kerala Water Authority	Number of monitoring stations installed, accuracy and timeliness of salinity data collection
Encroachment Mapping and Documentation	Develop detailed geospatial maps identifying encroached areas and prioritize removal	2025-2030	Revenue Department	Completion of comprehensive encroachment map, identification of 100% high-priority areas

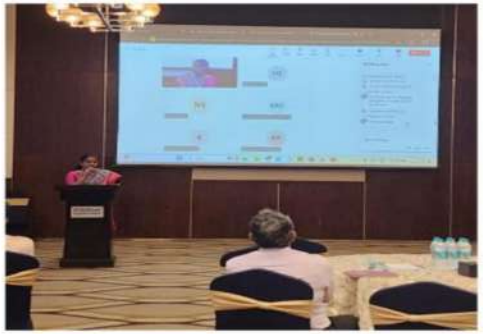


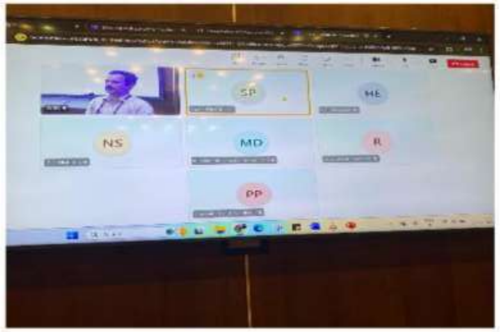




Stakeholder Engagement :Risk Mat


Major Challenges in the B




SP
HE
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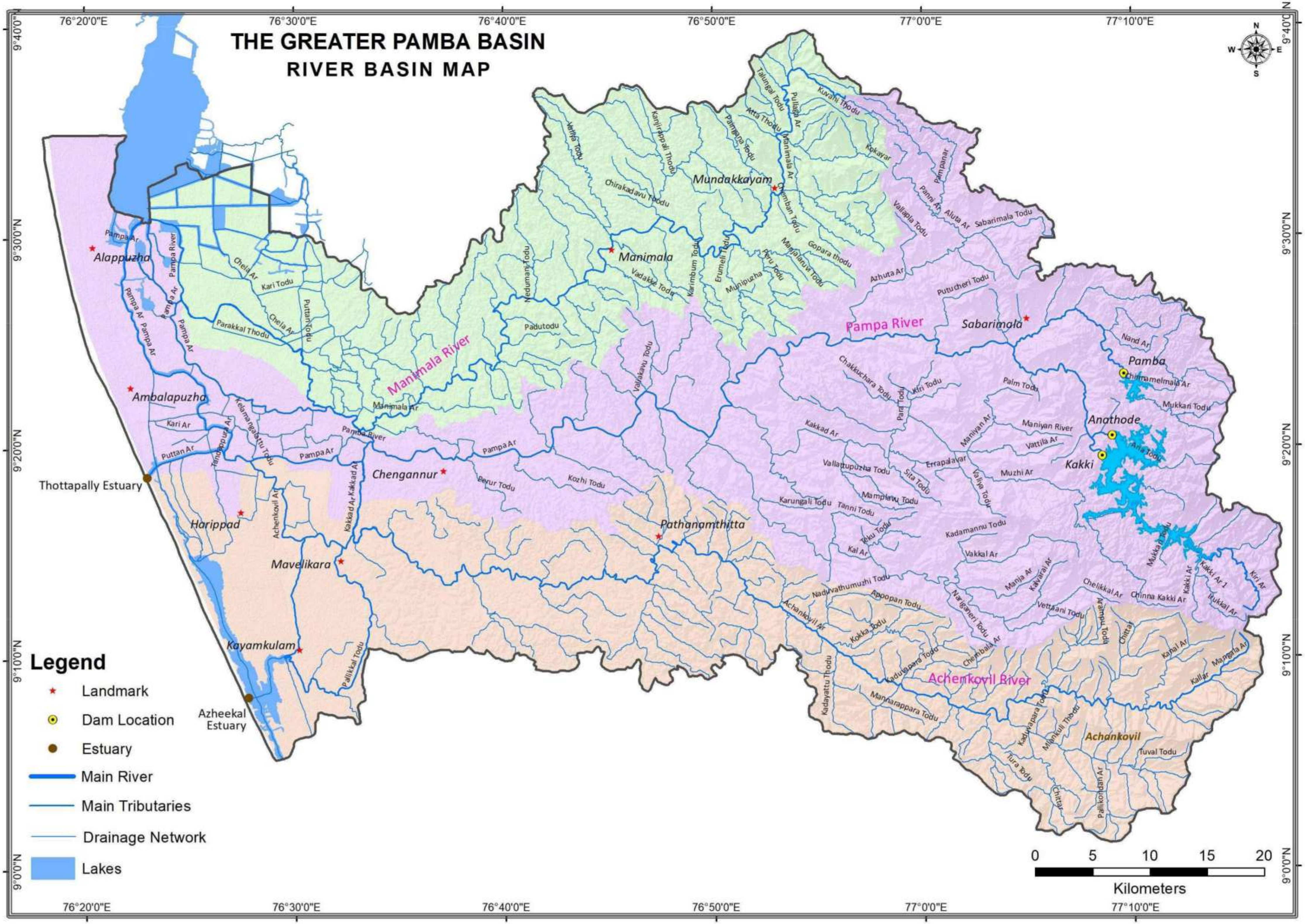
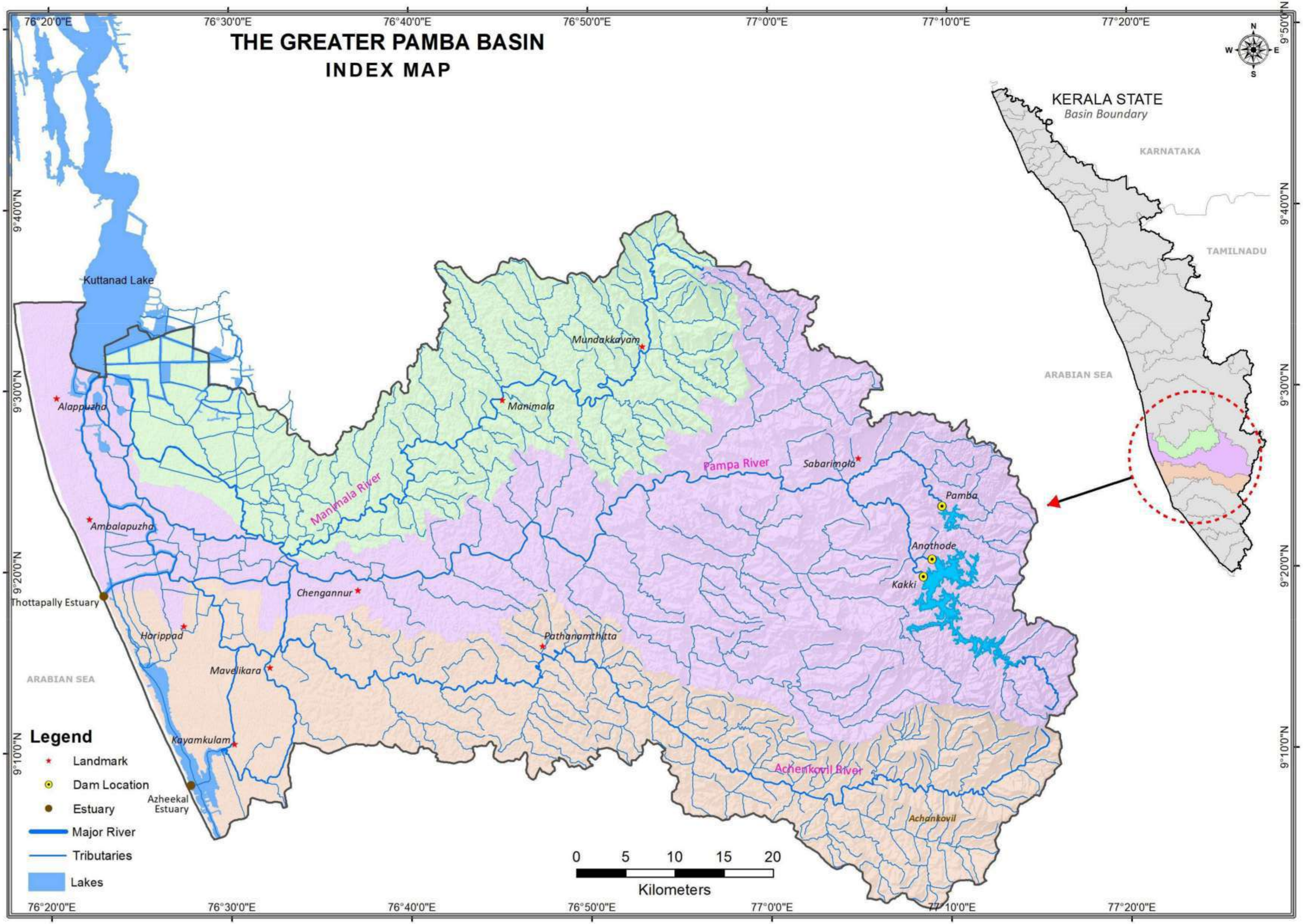
RIVER BASIN PLAN FOR
THE GREATER PAMBA BASIN

Volume of Maps

APPENDIX - I



THE GREATER PAMBA BASIN
RIVER BASIN MAP
Pampa River
Manimala River
Achenkovil River
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Pathanamthitta
Manimala
Mundakkayam
Sabarimala
Pamba
Anathode
Kakki
Achankovil
Legend
Landmark
Dam Location
Estuary
Main River
Main Tributaries
Drainage Network
Lakes
0 5 10 15 20
Kilometers
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N


THE GREATER PAMBA BASIN
INDEX MAP
KERALA STATE
Basin Boundary
KARNATAKA
TAMILNADU
ARABIAN SEA
Kuttanad Lake
Mundakkayam
Manimala
Manimala River
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Alappuzha
Ambalapuzha
Thottapally Estuary
Chengannur
Harippad
Pathanamthitta
Mavelikara
Kayamkulam
Azheekal Estuary
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
0 5 10 15 20
Kilometers
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
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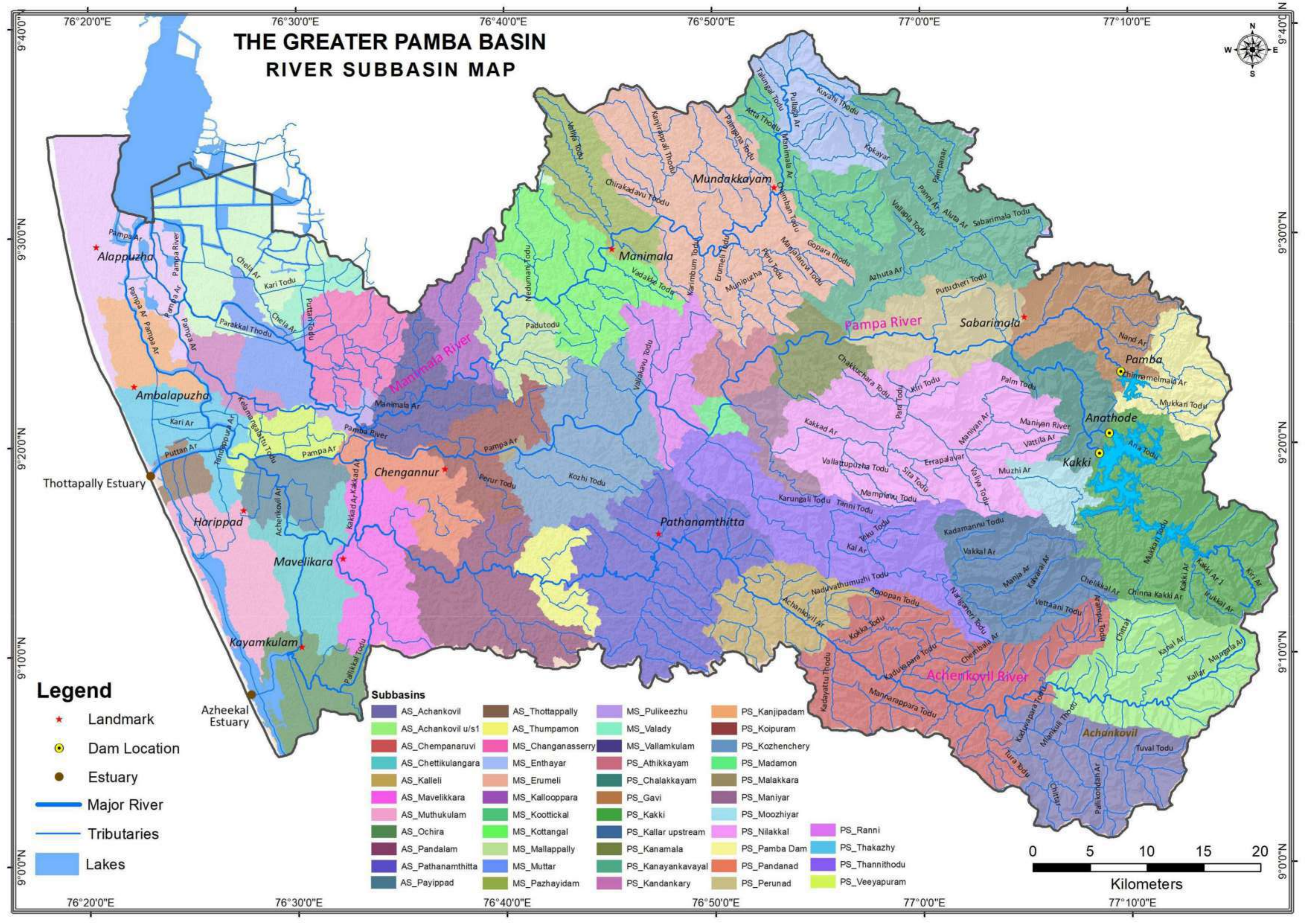
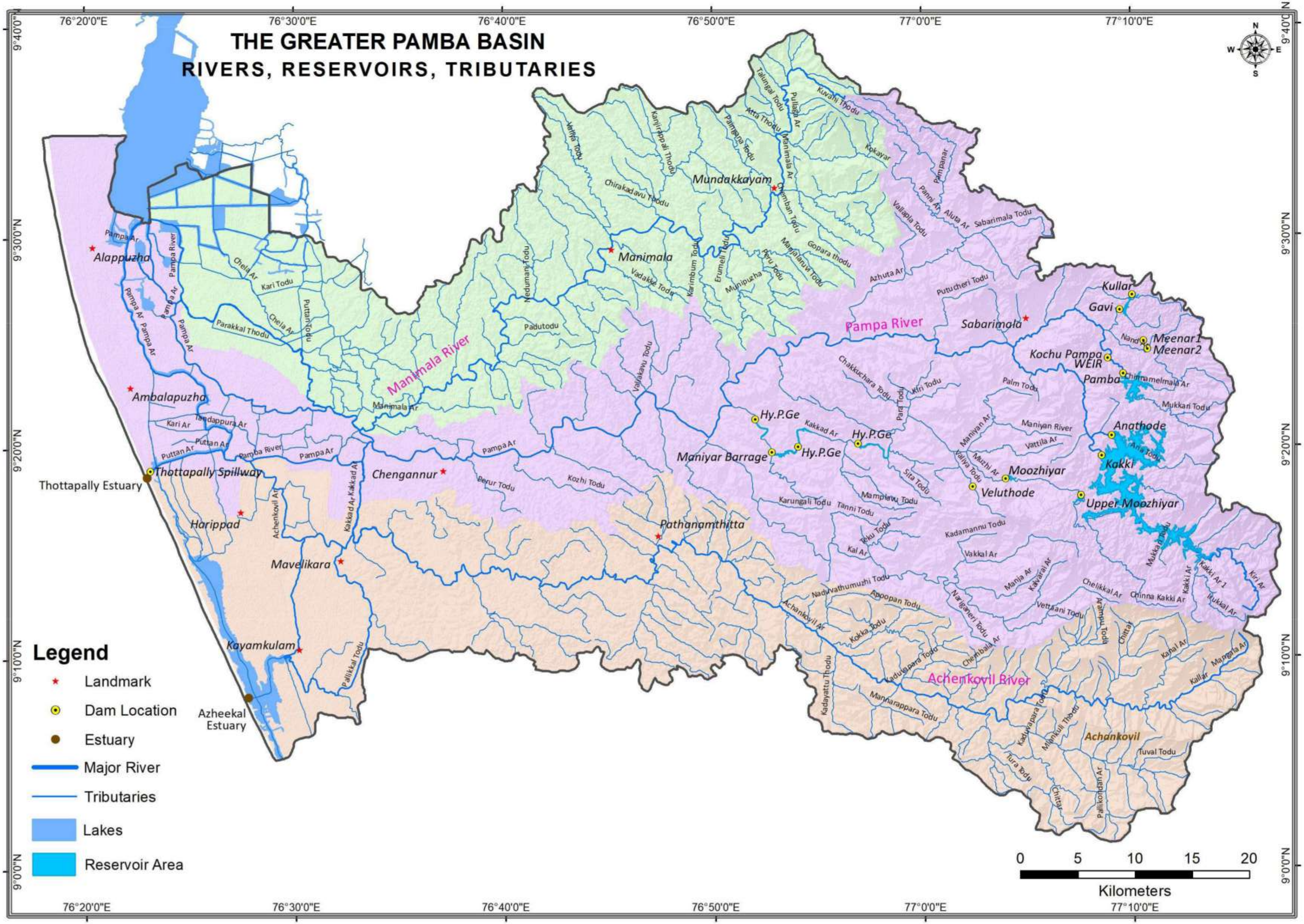
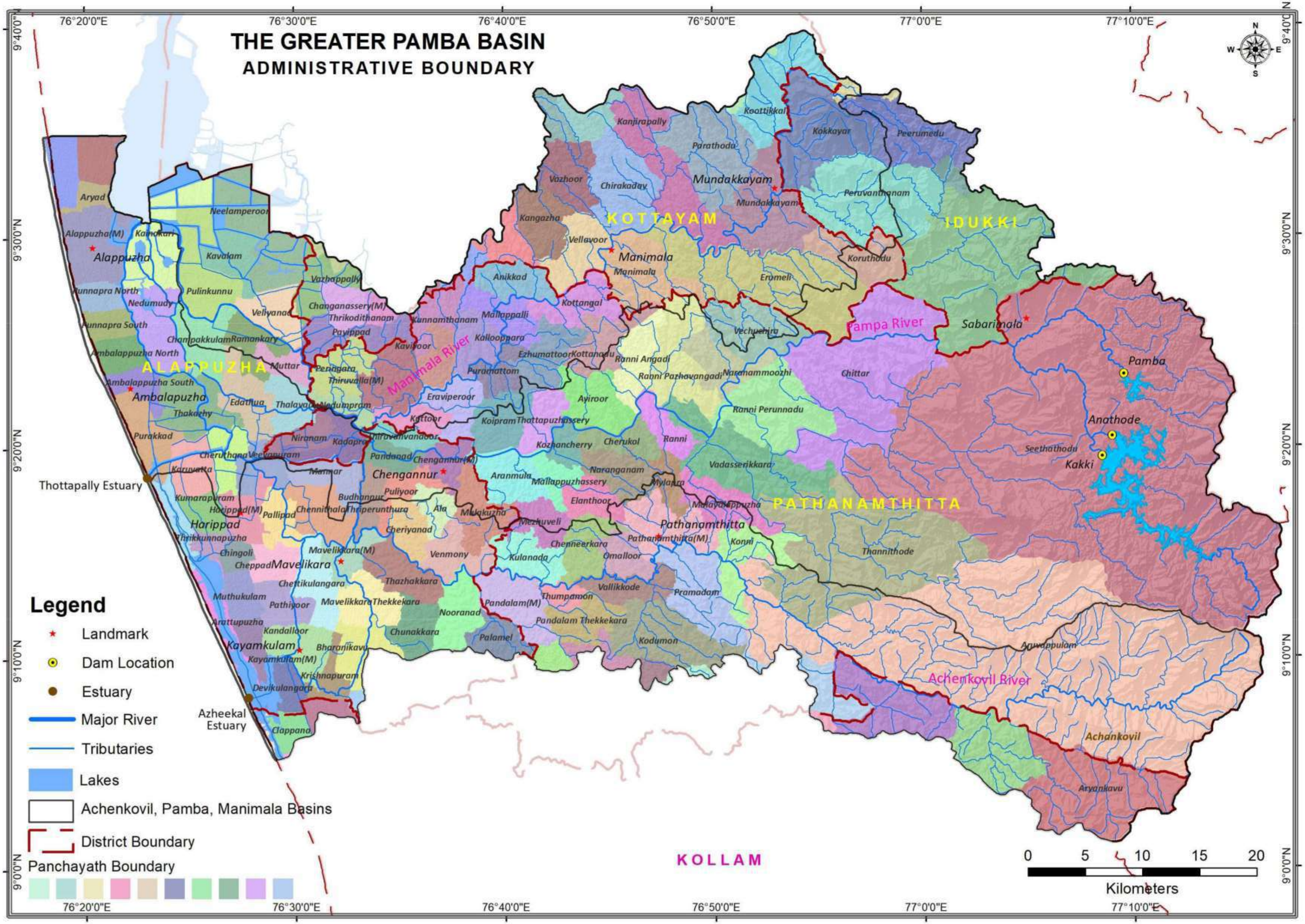
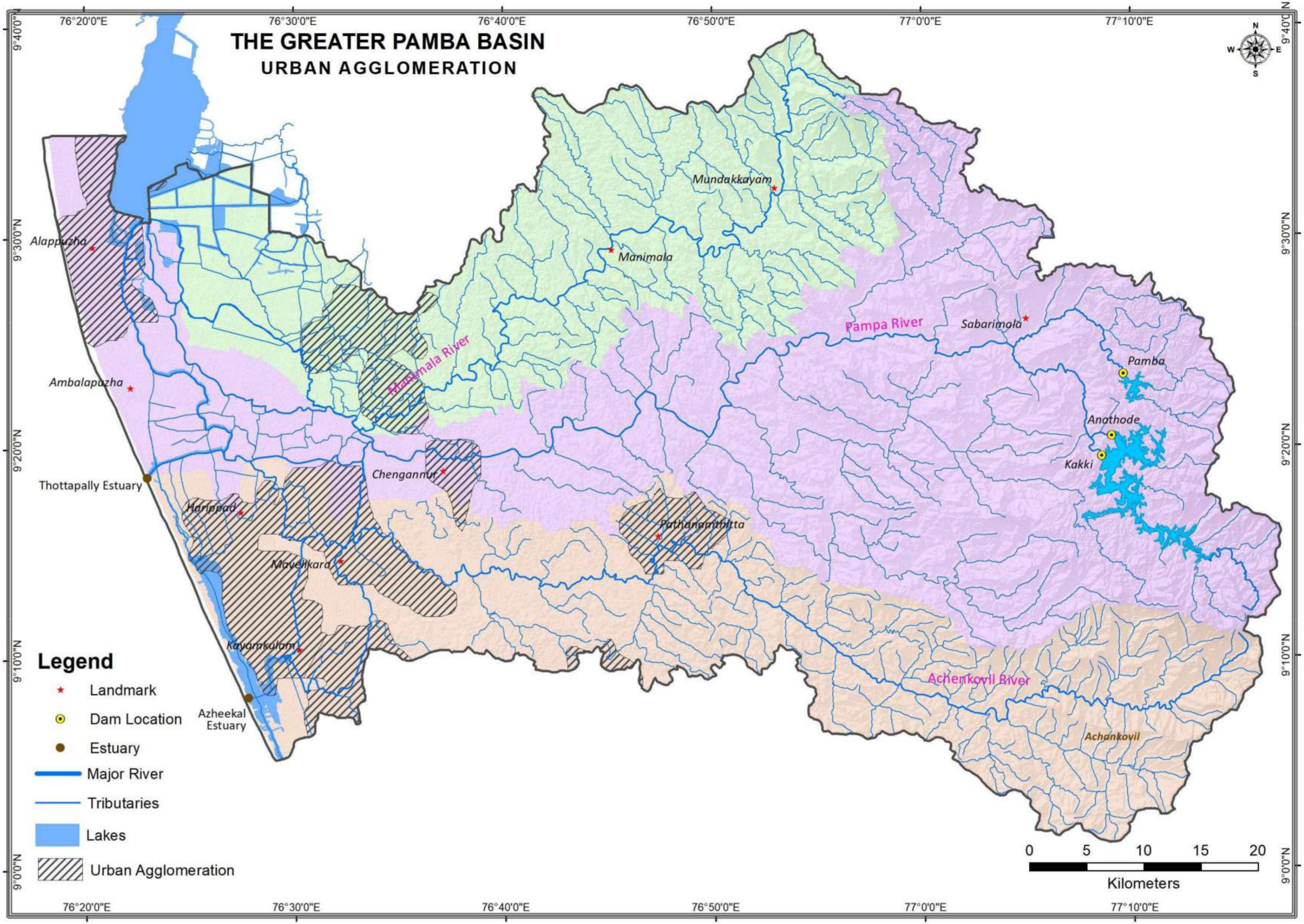
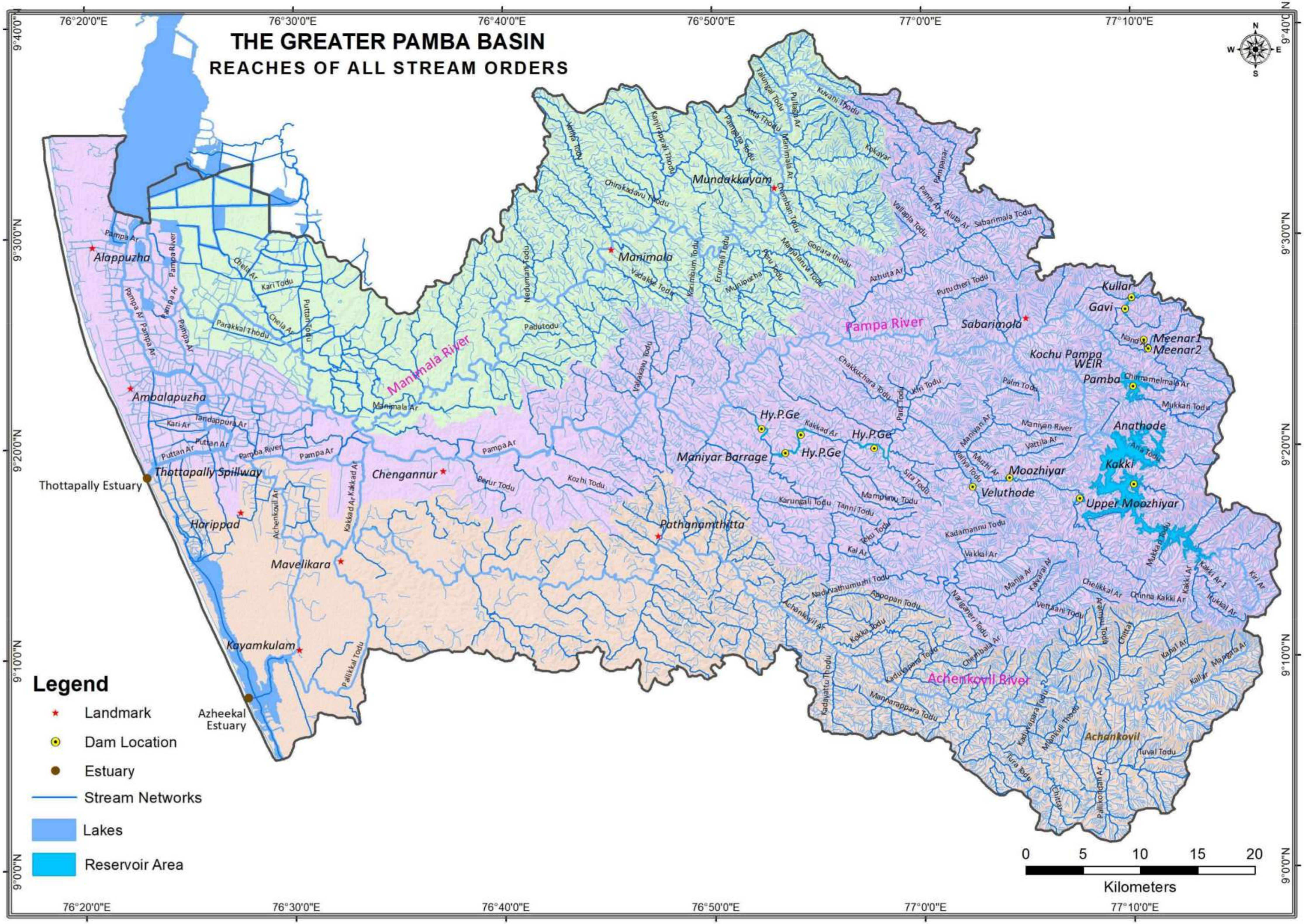
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N

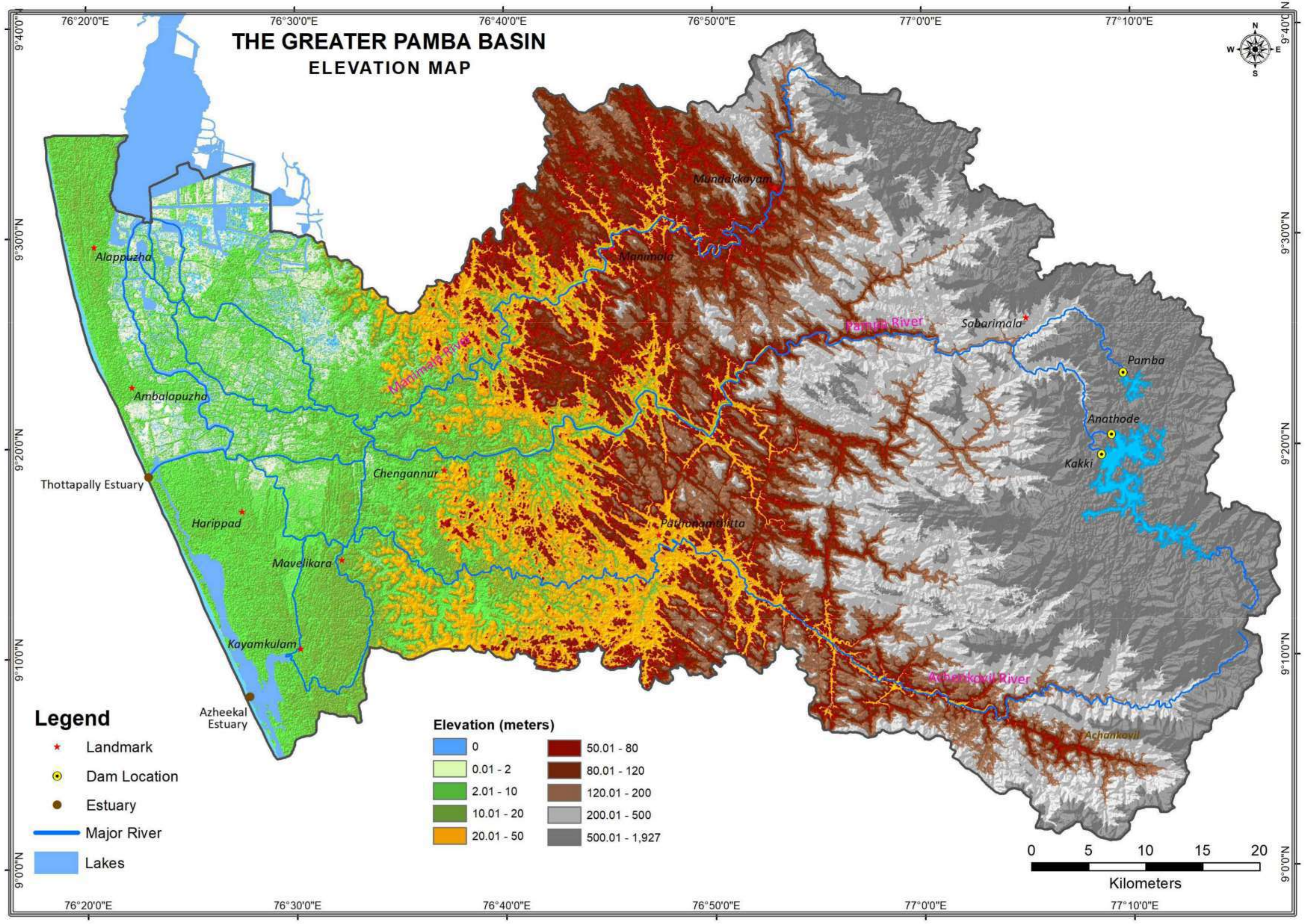

THE GREATER PAMBA BASIN
RIVER SUBBASIN MAP
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
Subbasins
AS_Achankovil
AS_Achankovil u/s1
AS_Chempanaruvi
AS_Chettikulangara
AS_Kalleli
AS_Mavelikkara
AS_Muthukulam
AS_Ochira
AS_Pandalam
AS_Pathanamthitta
AS_Payippad
AS_Thottappally
AS_Thumpamon
MS_Changanasserry
MS_Enthayar
MS_Erumeli
MS_Kallooppara
MS_Koottickal
MS_Kottangal
MS_Mallappally
MS_Muttar
MS_Pazhayidam
MS_Pulikeezhu
MS_Valady
MS_Vallamkulam
PS_Athikkayam
PS_Chalakkayam
PS_Gavi
PS_Kakki
PS_Kallar upstream
PS_Kanamala
PS_Kanayankavayal
PS_Kandankary
PS_Kanjipadam
PS_Koipuram
PS_Kozhenchery
PS_Madamon
PS_Malakkara
PS_Maniyar
PS_Moozhiyar
PS_Nilakkal
PS_Pamba Dam
PS_Pandanad
PS_Perunad
PS_Ranni
PS_Thakazhy
PS_Thannithodu
PS_Veeyapuram
0 5 10 15 20
Kilometers
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
N
E
S
W
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Pathanamthitta
Manimala
Mundakkayam
Sabarimala
Pamba
Anathode
Kakki
Achankovil
Pampa River
Manimala River
Achenkovil River


THE GREATER PAMBA BASIN
RIVERS, RESERVOIRS, TRIBUTARIES
Pampa River
Manimala River
Achenkovil River
Sabarimala
Mundakkayam
Manimala
Alappuzha
Ambalapuzha
Chengannur
Pathanamthitta
Harippad
Mavelikara
Kayamkulam
Achankovil
Thottapally Spillway
Thottapally Estuary
Azheekal Estuary
Kullar
Gavi
Meenar1
Meenar2
Kochu Pampa WEIR
Pamba
Anathode
Kakki
Moozhiyar
Veluthode
Upper Moozhiyar
Maniyar Barrage
Hy.P.Ge
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
Reservoir Area
0 5 10 15 20
Kilometers
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N


THE GREATER PAMBA BASIN
ADMINISTRATIVE BOUNDARY
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
N
E
S
W
KOTTAYAM
IDUKKI
ALAPPUZHA
PATHANAMTHITTA
KOLLAM
Pampa River
Manimala River
Achenkovil River
Thottapally Estuary
Azheekal Estuary
Sabarimala
Pamba
Anathode
Kakki
Seethathodu
Alappuzha
Alappuzha(M)
Aryad
Kainakari
Neelamperoor
Kavalam
Pulinkunnu
Punnapra North
Punnapra South
Nedumudy
Champakkulam
Ramankary
Ambalappuzha North
Ambalappuzha South
Ambalapuzha
Thakazhy
Edathua
Purakkad
Karuvatta
Cheruthana
Veeyapuram
Kumarapuram
Harippad(M)
Harippad
Thrikkunnapuzha
Chingoli
Cheppad
Mavelikara
Mavelikkara(M)
Chettikulangara
Muthukulam
Pathiyoor
Arattupuzha
Kandalloor
Kayamkulam
Kayamkulam(M)
Bharanikavu
Krishnapuram
Devikulangara
Clappana
Pallipad
Chennithala
Thriperunthura
Mannar
Budhanoor
Niranam
Kadapra
Thalavady
Nedumpram
Muttar
Veliyanad
Vazhappally
Changanassery(M)
Thrikodithanam
Payippad
Peringara
Thiruvalla(M)
Kaviyoor
Kunnamthanam
Mallappalli
Kallooppara
Anikkad
Kottangal
Puramattom
Eraviperoor
Kuttoor
Thiruvanvandoor
Pandanad
Chengannur
Chengannur(M)
Puliyoor
Ala
Mulakuzha
Cheriyanad
Venmony
Thazhakkara
Mavelikkara Thekkekara
Chunakkara
Nooranad
Palamel
Pandalam(M)
Thumpamon
Pandalam Thekkekara
Kulanada
Mezhuveli
Chenneerkara
Omalloor
Vallikkode
Kodumon
Pramadam
Konni
Pathanamthitta
Pathanamthitta(M)
Malayalappuzha
Mylapra
Elanthoor
Naranganam
Aranmula
Mallappuzhassery
Kozhancherry
Cherukol
Koipram
Thottapuzhassery
Ayiroor
Ranni
Vadasserikkara
Ranni Perunnadu
Ranni Angadi
Ranni Pazhavangadi
Naranammoozhi
Ezhumattoor
Kottanadu
Vechuchira
Chittar
Thannithode
Aruvappulam
Achankovil
Aryankavu
Vazhoor
Kangazha
Vellavoor
Manimala
Chirakadav
Kanjirapally
Parathodu
Mundakkayam
Koottikkal
Kokkayar
Peerumedu
Peruvanthanam
Koruthodu
Erumeli
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
Achenkovil, Pamba, Manimala Basins
District Boundary
Panchayath Boundary
0
5
10
15
20
Kilometers


THE GREATER PAMBA BASIN
URBAN AGGLOMERATION
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
N
S
E
W
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala River
Manimala
Mundakkayam
Pathanamthitta
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
Urban Agglomeration
0
5
10
15
20
Kilometers


THE GREATER PAMBA BASIN
REACHES OF ALL STREAM ORDERS
Legend
Landmark
Dam Location
Estuary
Stream Networks
Lakes
Reservoir Area
0
5
10
15
20
Kilometers
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
Alappuzha
Ambalapuzha
Thottapally Spillway
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Pathanamthitta
Manimala
Mundakkayam
Manimala River
Pampa River
Achenkovil River
Achankovil
Sabarimala
Kochu Pampa WEIR
Kullar
Gavi
Meenar1
Meenar2
Pamba
Anathode
Kakki
Upper Moozhiyar
Moozhiyar
Veluthode
Maniyar Barrage
Hy.P.Ge


THE GREATER PAMBA BASIN
ELEVATION MAP
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
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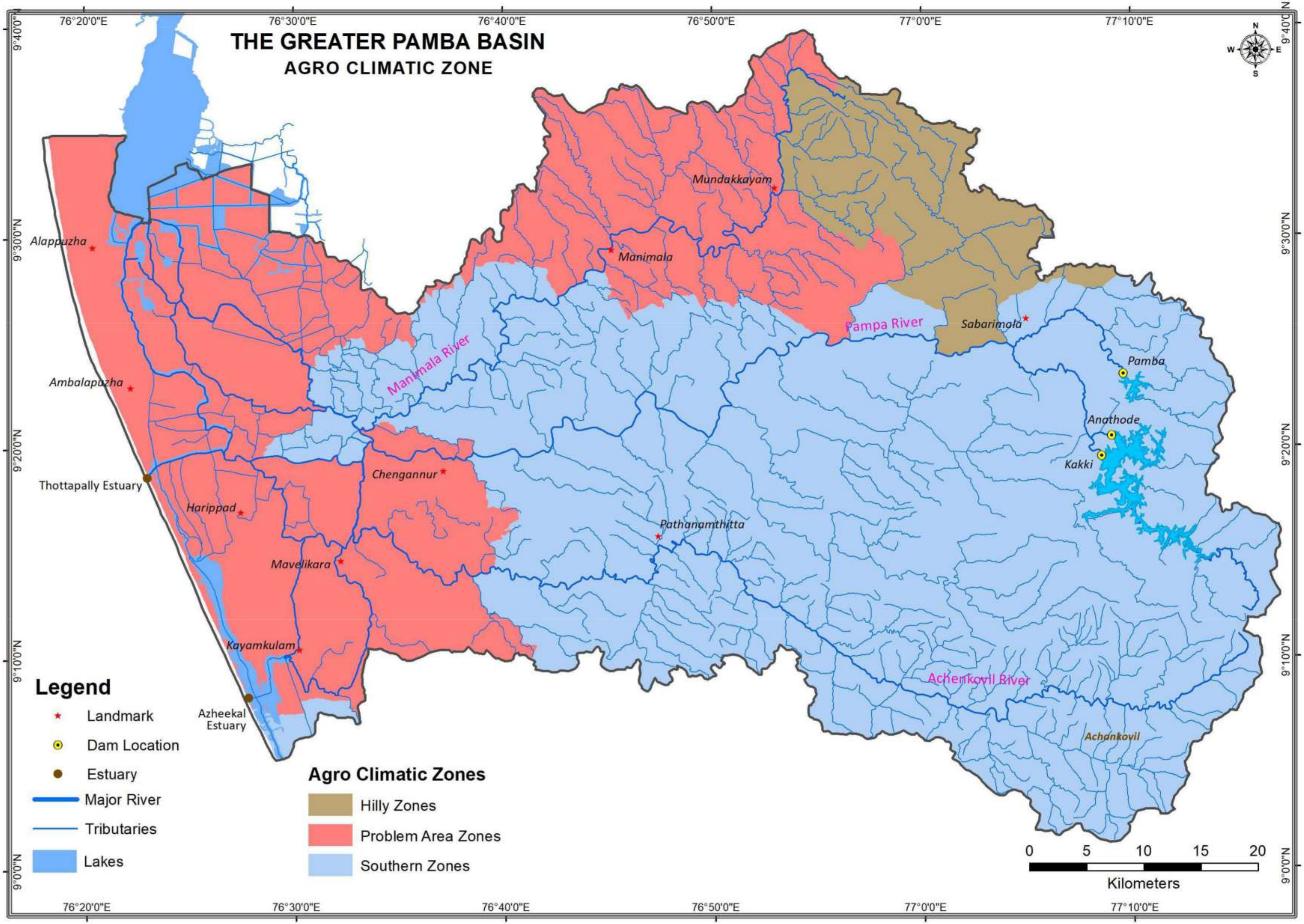
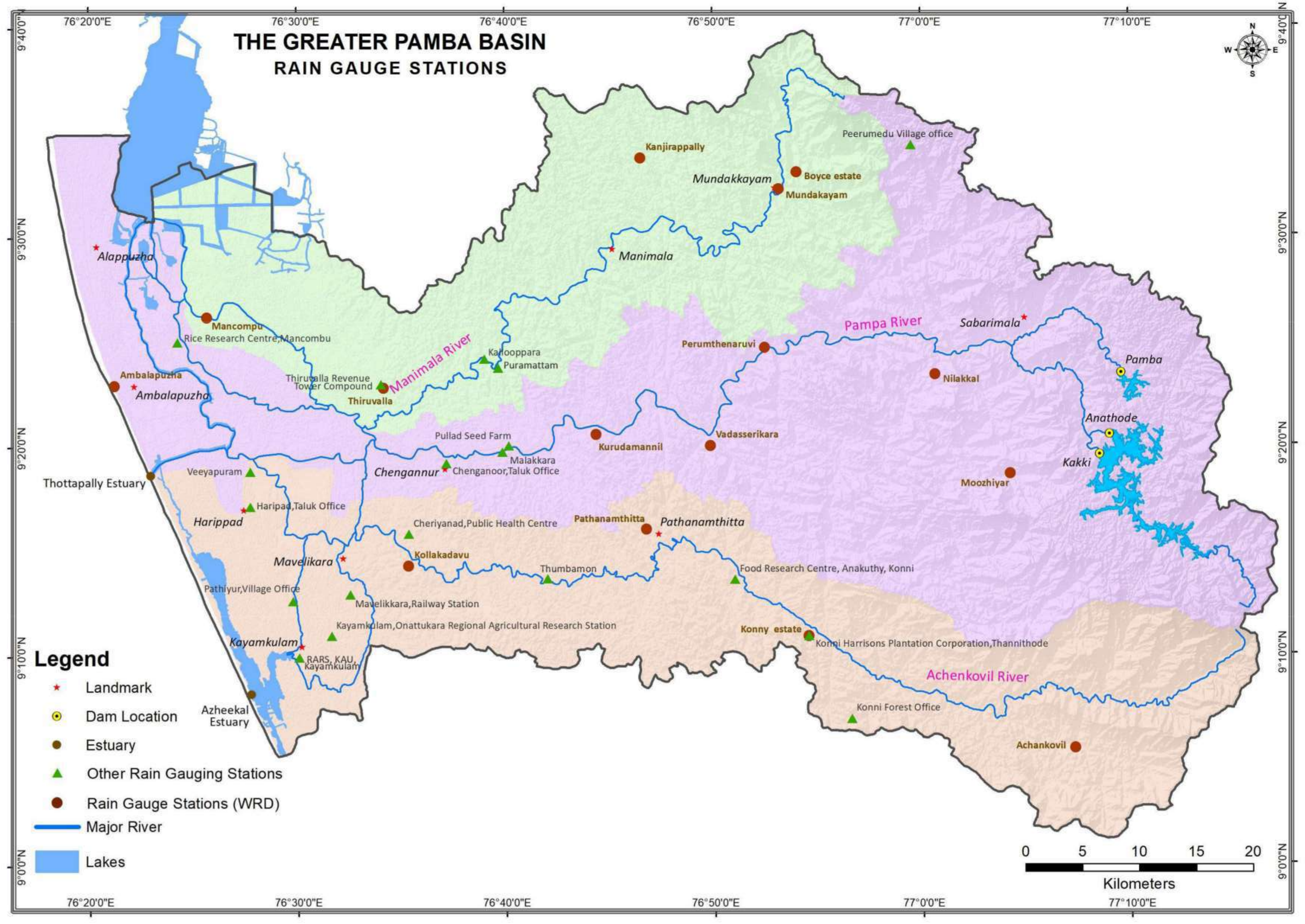
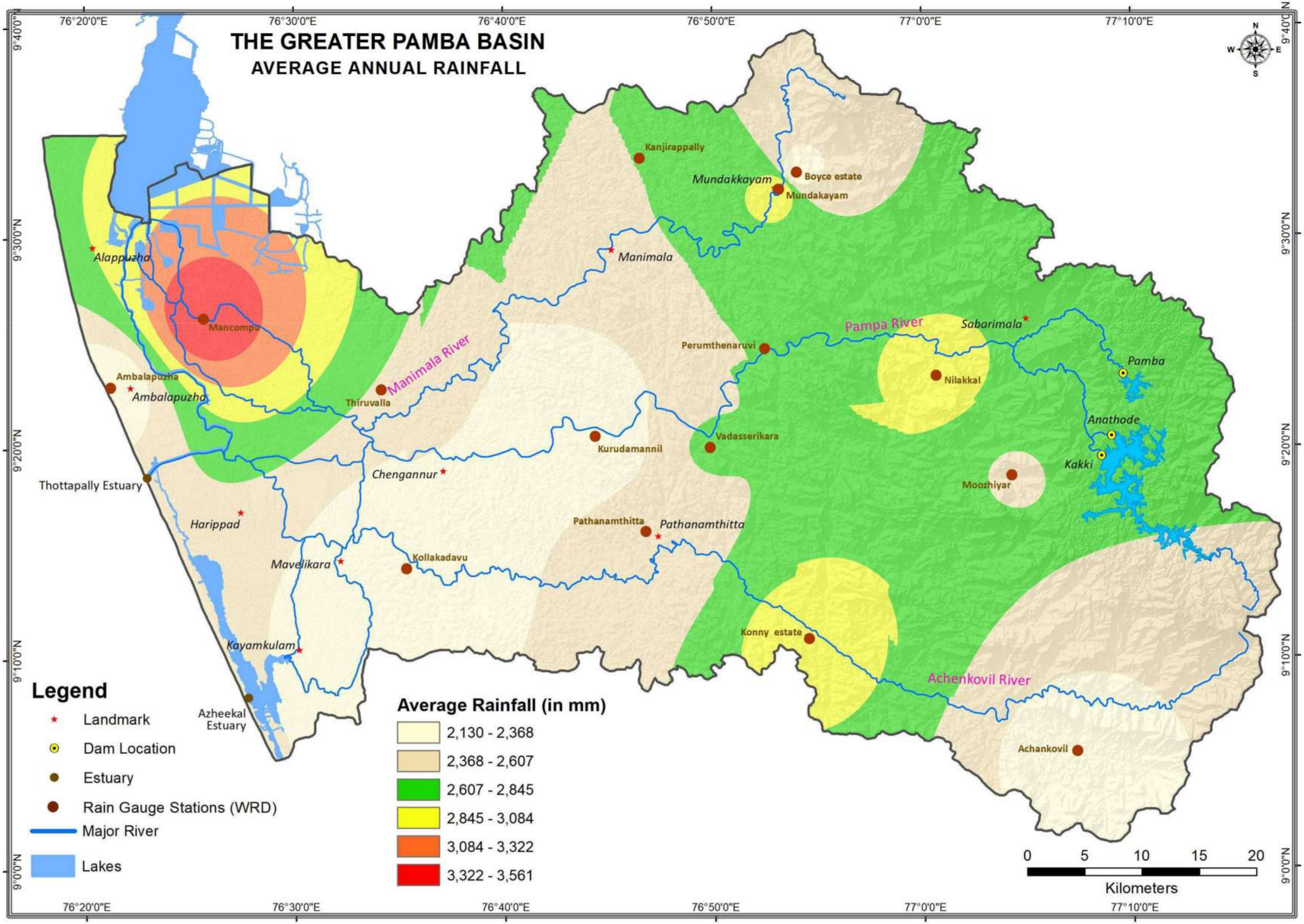
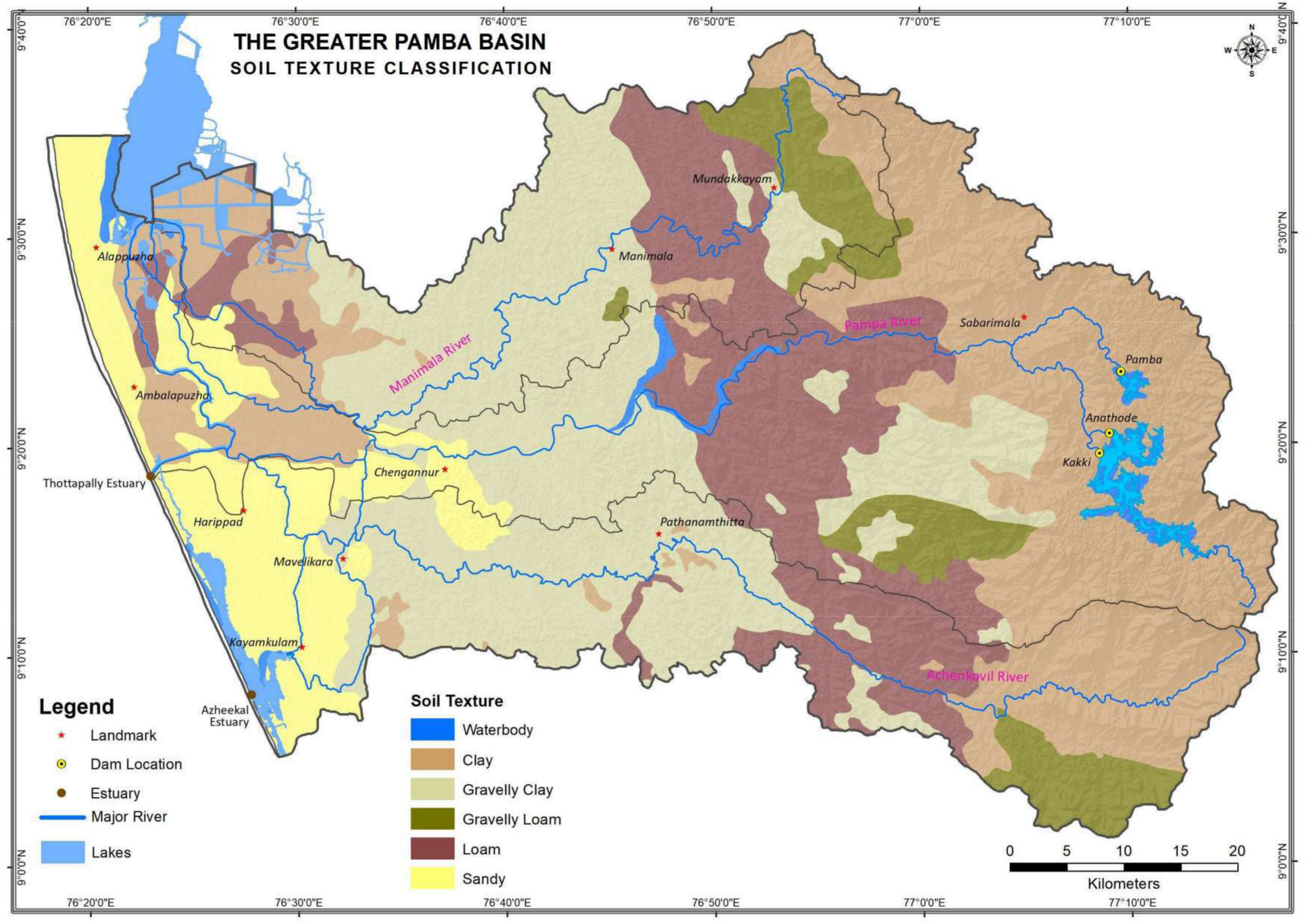
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
N
S
E
W
Mundakkayam
Manimala
Alappuzha
Ambalapuzha
Manimala River
Pamba River
Sabarimala
Pamba
Anathode
Kakki
Chengannur
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Major River
Lakes
Elevation (meters)
0
0.01 - 2
2.01 - 10
10.01 - 20
20.01 - 50
50.01 - 80
80.01 - 120
120.01 - 200
200.01 - 500
500.01 - 1,927
0 5 10 15 20
Kilometers


THE GREATER PAMBA BASIN
AGRO CLIMATIC ZONE
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
N
S
E
W
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala River
Manimala
Mundakkayam
Pathanamthitta
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
Agro Climatic Zones
Hilly Zones
Problem Area Zones
Southern Zones
0
5
10
15
20
Kilometers


THE GREATER PAMBA BASIN
RAIN GAUGE STATIONS
Legend
Landmark
Dam Location
Estuary
Other Rain Gauging Stations
Rain Gauge Stations (WRD)
Major River
Lakes
Kilometers
0 5 10 15 20
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
Pampa River
Manimala River
Achenkovil River
Alappuzha
Ambalapuzha
Mancompu
Rice Research Centre,Mancombu
Thiruvalla Revenue Tower Compound
Thiruvalla
Kallooppara
Puramattam
Kanjirappally
Mundakkayam
Mundakayam
Boyce estate
Peerumedu Village office
Manimala
Sabarimala
Pamba
Anathode
Kakki
Nilakkal
Moozhiyar
Perumthenaruvi
Vadasserikara
Kurudamannil
Pullad Seed Farm
Malakkara
Chengannur
Chenganoor,Taluk Office
Thottapally Estuary
Veeyapuram
Haripad,Taluk Office
Harippad
Cheriyanad,Public Health Centre
Pathanamthitta
Kollakadavu
Thumbamon
Food Research Centre, Anakuthy, Konni
Mavelikara
Pathiyur,Village Office
Mavelikkara,Railway Station
Kayamkulam,Onattukara Regional Agricultural Research Station
Kayamkulam
RARS, KAU, Kayamkulam
Konny estate
Konni Harrisons Plantation Corporation,Thannithode
Azheekal Estuary
Konni Forest Office
Achankovil


THE GREATER PAMBA BASIN
AVERAGE ANNUAL RAINFALL
Legend
Landmark
Dam Location
Estuary
Rain Gauge Stations (WRD)
Major River
Lakes
Average Rainfall (in mm)
2,130 - 2,368
2,368 - 2,607
2,607 - 2,845
2,845 - 3,084
3,084 - 3,322
3,322 - 3,561
Kilometers
0 5 10 15 20
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
Alappuzha
Mancompu
Ambalapuzha
Thottapally Estuary
Harippad
Kayamkulam
Azheekal Estuary
Mavelikara
Chengannur
Thiruvalla
Manimala River
Manimala
Kanjirappally
Mundakkayam
Mundakayam
Boyce estate
Kurudamannil
Kollakadavu
Pathanamthitta
Vadasserikara
Perumthenaruvi
Pampa River
Nilakkal
Sabarimala
Pamba
Anathode
Kakki
Moozhiyar
Konny estate
Achenkovil River
Achankovil


THE GREATER PAMBA BASIN
SOIL TEXTURE CLASSIFICATION
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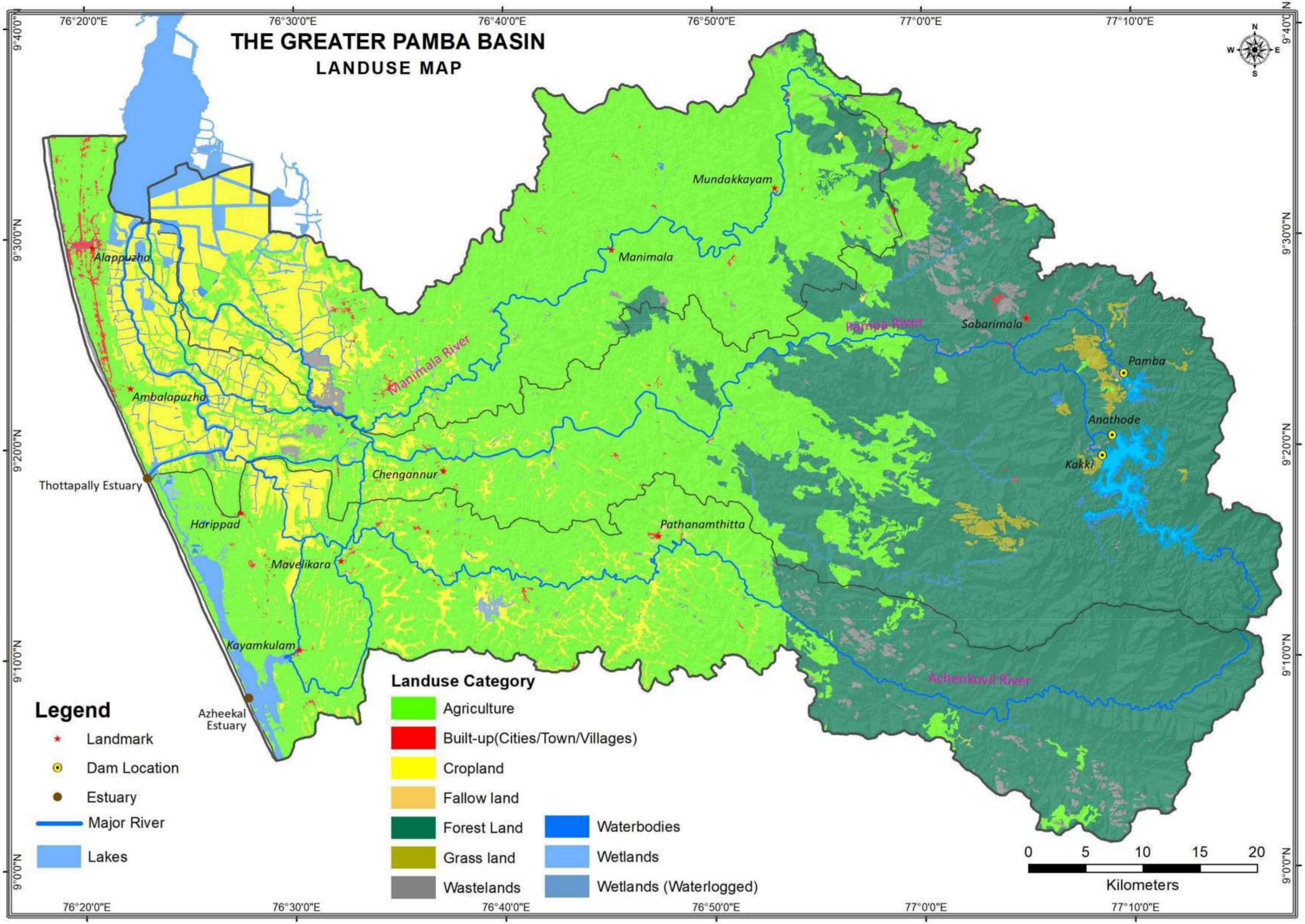
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
N
S
E
W
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala
Mundakkayam
Pathanamthitta
Sabarimala
Pamba
Anathode
Kakki
Manimala River
Pampa River
Achenkovil River
Legend
Landmark
Dam Location
Estuary
Major River
Lakes
Soil Texture
Waterbody
Clay
Gravelly Clay
Gravelly Loam
Loam
Sandy
0
5
10
15
20
Kilometers


THE GREATER PAMBA BASIN
LANDUSE MAP
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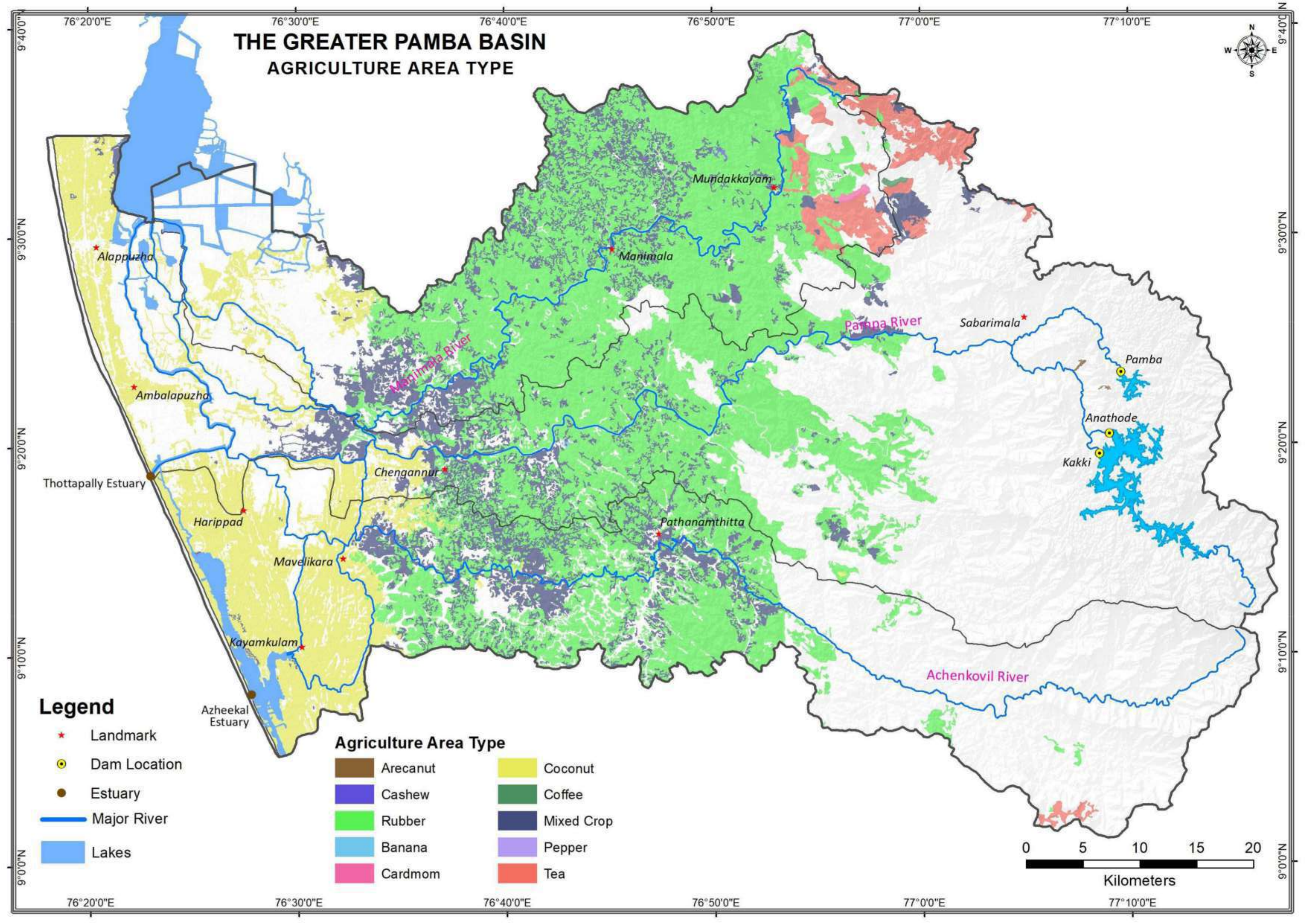
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
N
S
E
W
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Pathanamthitta
Manimala
Mundakkayam
Sabarimala
Pamba
Anathode
Kakki
Manimala River
Pampa River
Achenkovil River
Legend
Landmark
Dam Location
Estuary
Major River
Lakes
Landuse Category
Agriculture
Built-up(Cities/Town/Villages)
Cropland
Fallow land
Forest Land
Grass land
Wastelands
Waterbodies
Wetlands
Wetlands (Waterlogged)
0 5 10 15 20
Kilometers


THE GREATER PAMBA BASIN
AGRICULTURE AREA TYPE
76°20'0"E
76°30'0"E
76°40'0"E
76°50'0"E
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9°30'0"N
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Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala River
Manimala
Mundakkayam
Pathanamthitta
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Achenkovil River
Legend
Landmark
Dam Location
Estuary
Major River
Lakes
Agriculture Area Type
Arecanut
Cashew
Rubber
Banana
Cardmom
Coconut
Coffee
Mixed Crop
Pepper
Tea
0
5
10
15
20
Kilometers
N
S
E
W


THE GREATER PAMBA BASIN
JURISDICTIONS (TALUK DISTRICT)
Kottayam District
Idukki District
Alappuzha District
Pathanamthitta District
Kollam District
Ambalappuzha
Kuttanad
Changanassery
Kanjirappally
Peerumade
Mallappally
Thiruvalla
Ranni
Chengannur
Karthikappally
Mavelikkara
Adoor
Kozhenchery
Pathanapuram
Karunagappally
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala
Mundakkayam
Pathanamthitta
Sabarimala
Pamba
Anathode
Kakki
Achankovil
Pampa River
Manimala River
Achenkovil River
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
District Boundary
Taluk Boundary
0 5 10 15 20
Kilometers
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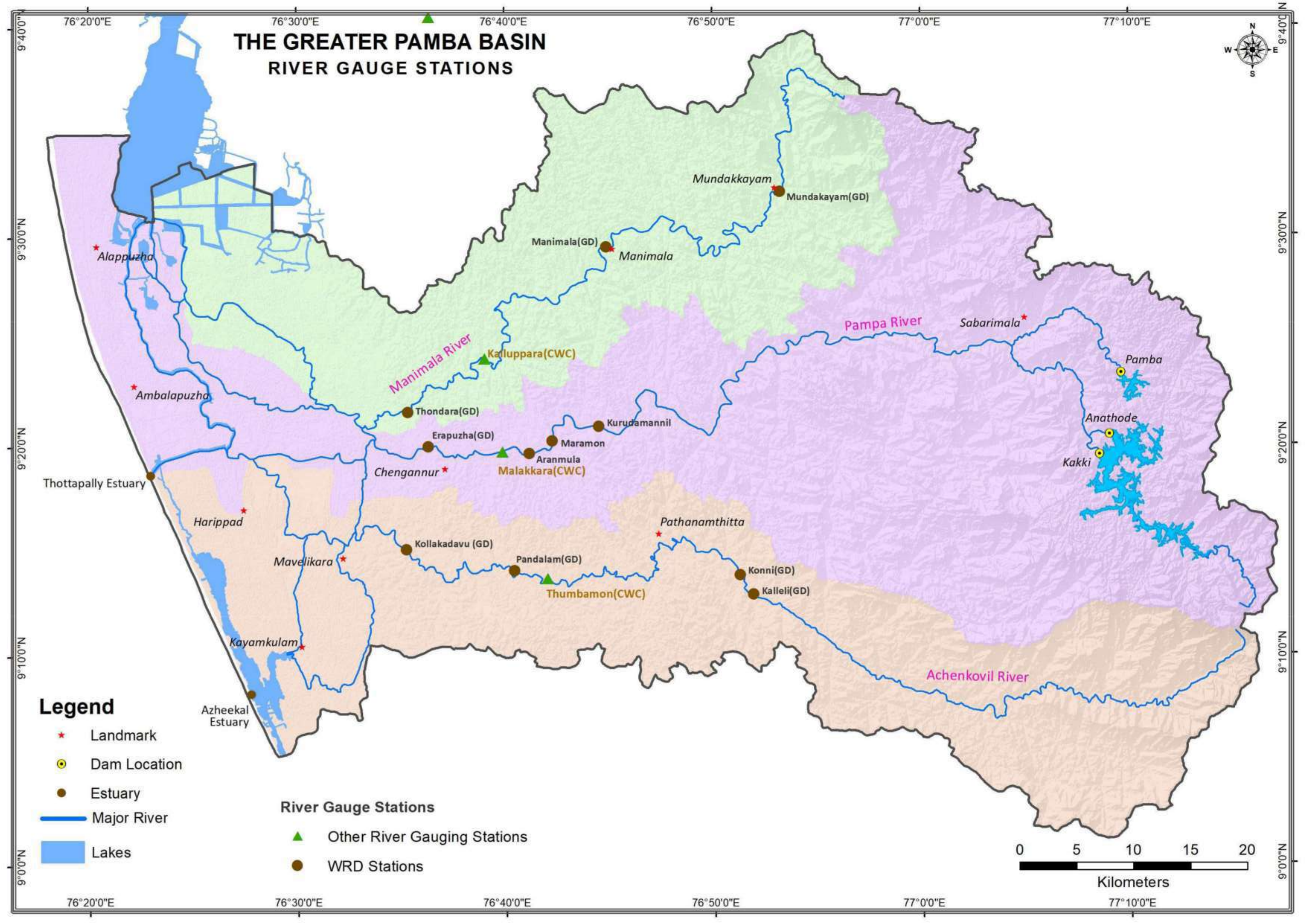
W


THE GREATER PAMBA BASIN
RIVER GAUGE STATIONS
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N
S
E
W
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Manimala River
Kalluppara(CWC)
Thondara(GD)
Erapuzha(GD)
Chengannur
Malakkara(CWC)
Aranmula
Maramon
Kurudamannil
Manimala(GD)
Manimala
Mundakkayam
Mundakayam(GD)
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Pathanamthitta
Kollakadavu (GD)
Pandalam(GD)
Thumbamon(CWC)
Konni(GD)
Kalleli(GD)
Achenkovil River
Legend
Landmark
Dam Location
Estuary
Major River
Lakes
River Gauge Stations
Other River Gauging Stations
WRD Stations
0
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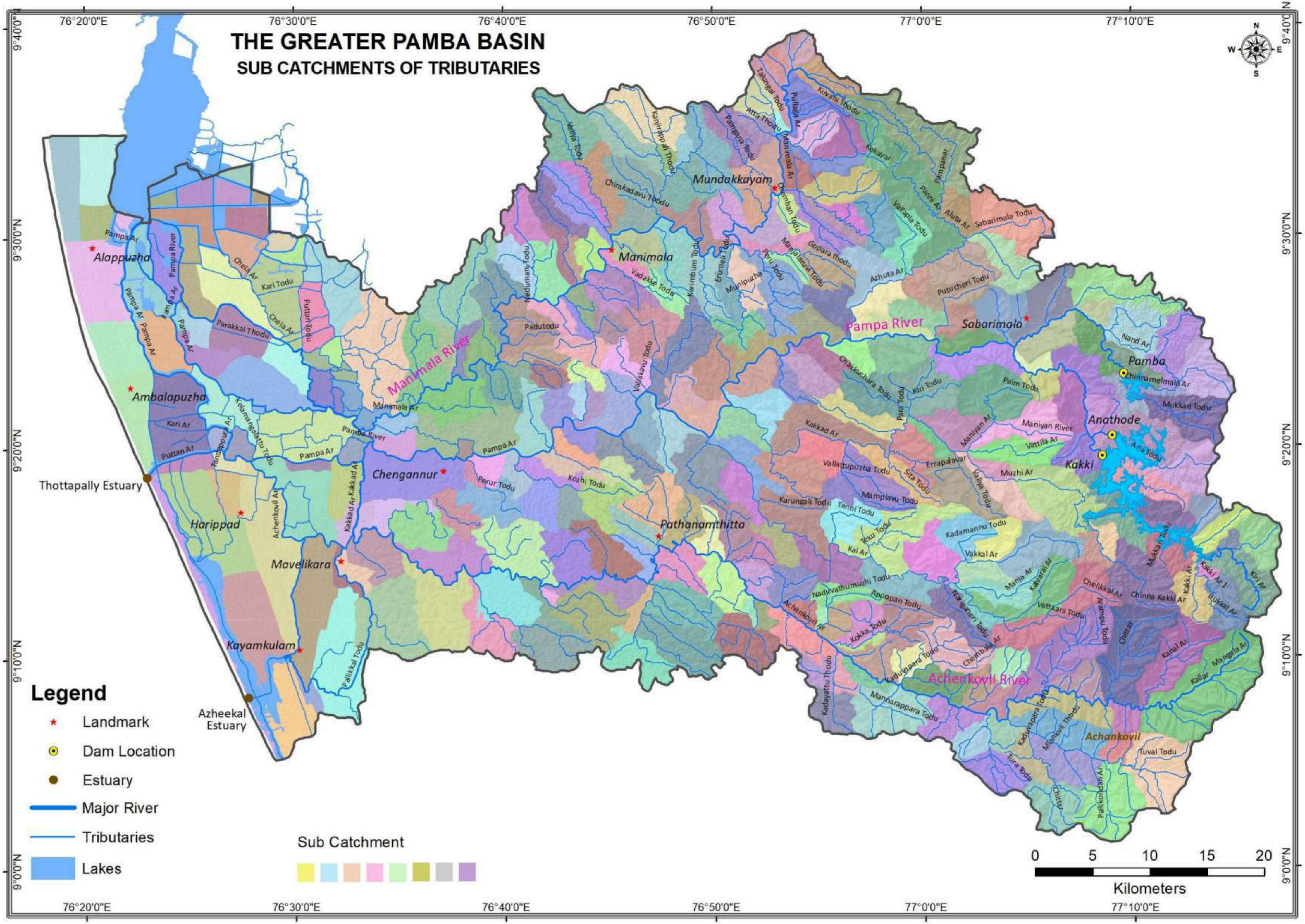
10
15
20
Kilometers


THE GREATER PAMBA BASIN
SUB CATCHMENTS OF TRIBUTARIES
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
Sub Catchment
Kilometers
0 5 10 15 20
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Pathanamthitta
Manimala
Mundakkayam
Sabarimala
Pamba
Anathode
Kakki
Achankovil
Pampa River
Manimala River
Achenkovil River
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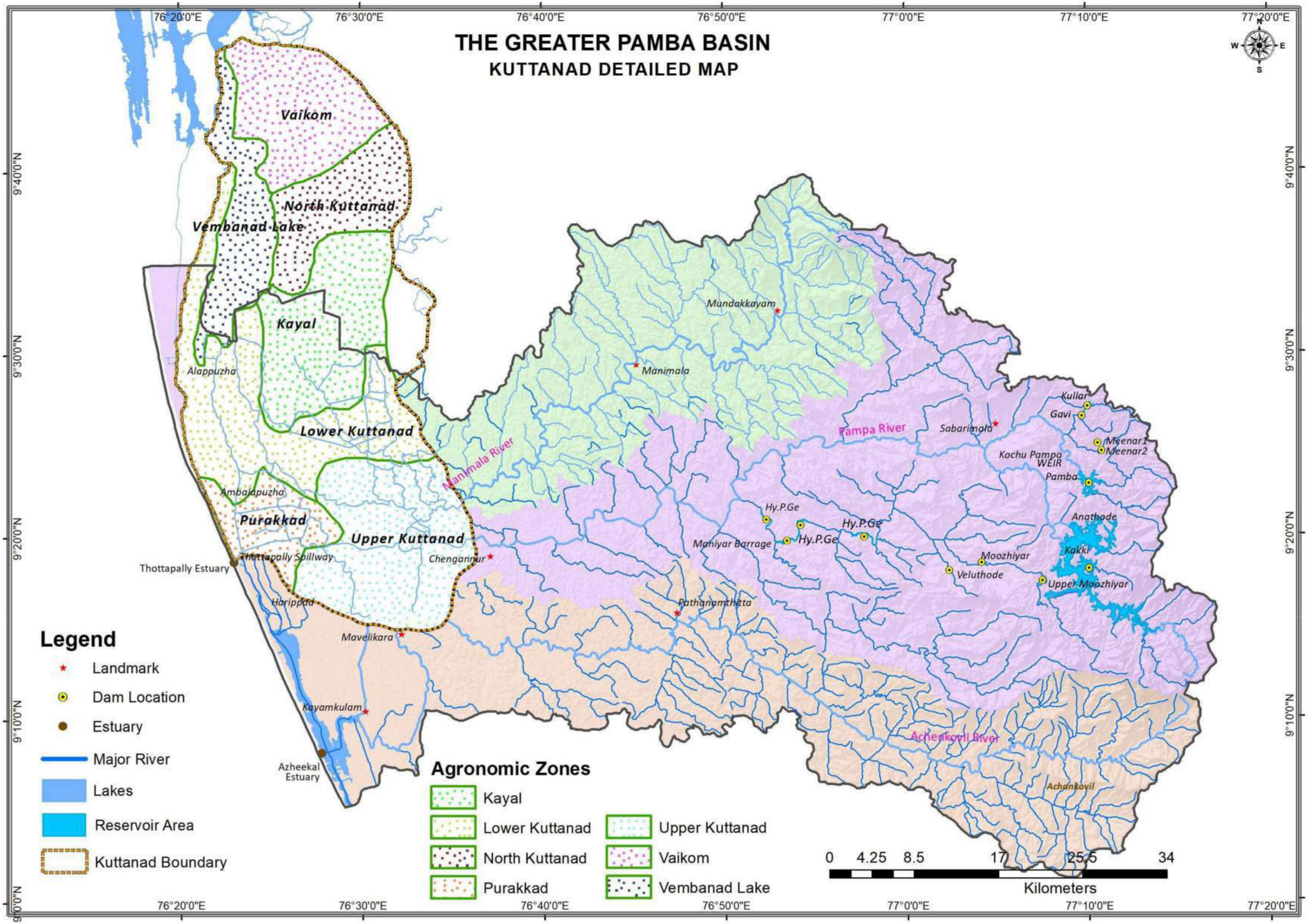
THE GREATER PAMBA BASIN
KUTTANAD DETAILED MAP
Vaikom
North Kuttanad
Vembanad Lake
Kayal
Lower Kuttanad
Purakkad
Upper Kuttanad
Alappuzha
Ambalapuzha
Thottapally Spillway
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala River
Manimala
Mundakkayam
Pampa River
Sabarimala
Pathanamthitta
Maniyar Barrage
Hy.P.Ge
Hy.P.Ge
Hy.P.Ge
Veluthode
Moozhiyar
Upper Moozhiyar
Kakki
Anathode
Pamba
Kochu Pampa
WEIR
Kullar
Gavi
Meenar1
Meenar2
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Major River
Lakes
Reservoir Area
Kuttanad Boundary
Agronomic Zones
Kayal
Lower Kuttanad
North Kuttanad
Purakkad
Upper Kuttanad
Vaikom
Vembanad Lake
0 4.25 8.5 17 25.5 34
Kilometers
76°20'0"E
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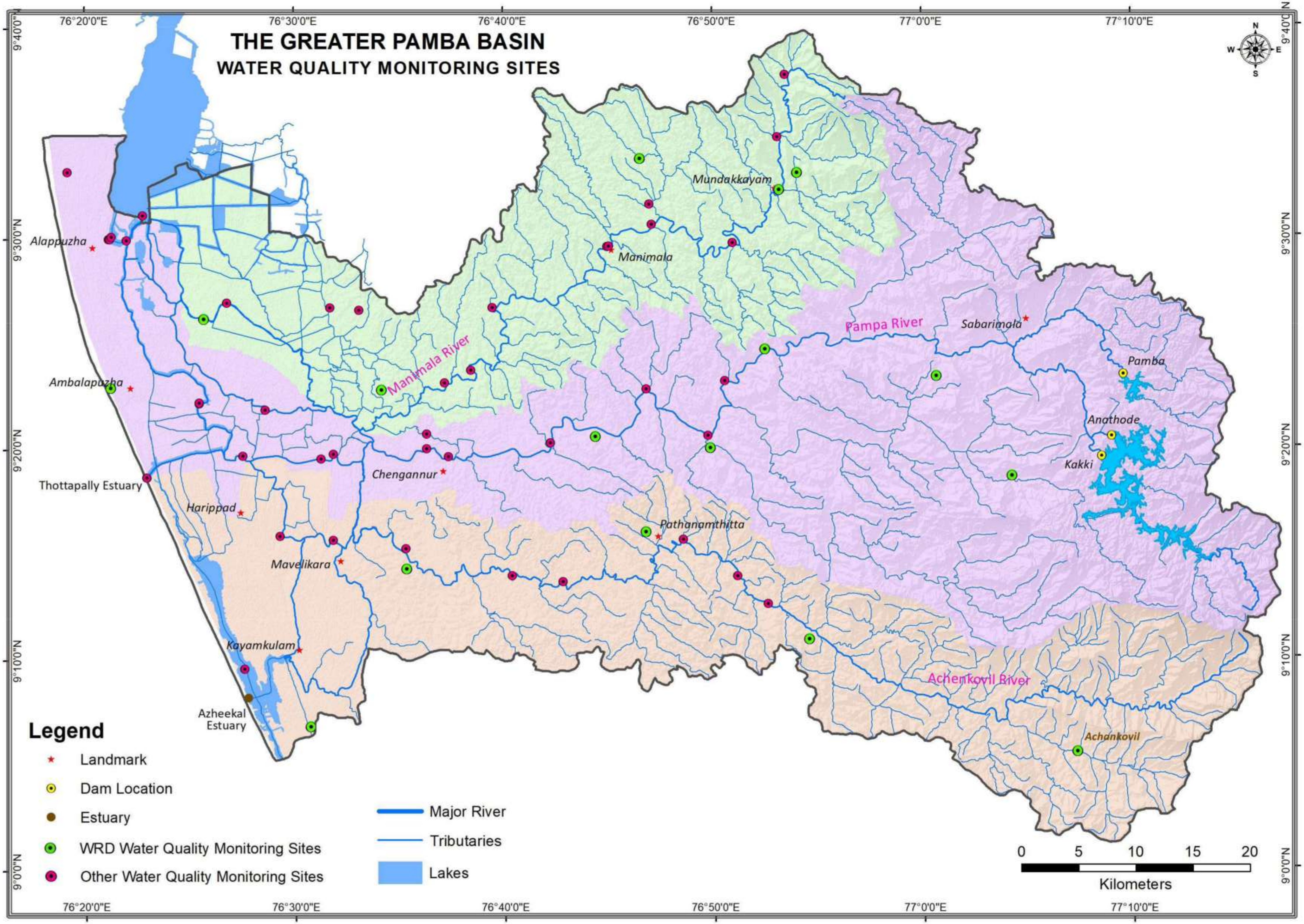
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WATER QUALITY MONITORING SITES
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Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala
Manimala River
Mundakkayam
Pathanamthitta
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
WRD Water Quality Monitoring Sites
Other Water Quality Monitoring Sites
Major River
Tributaries
Lakes
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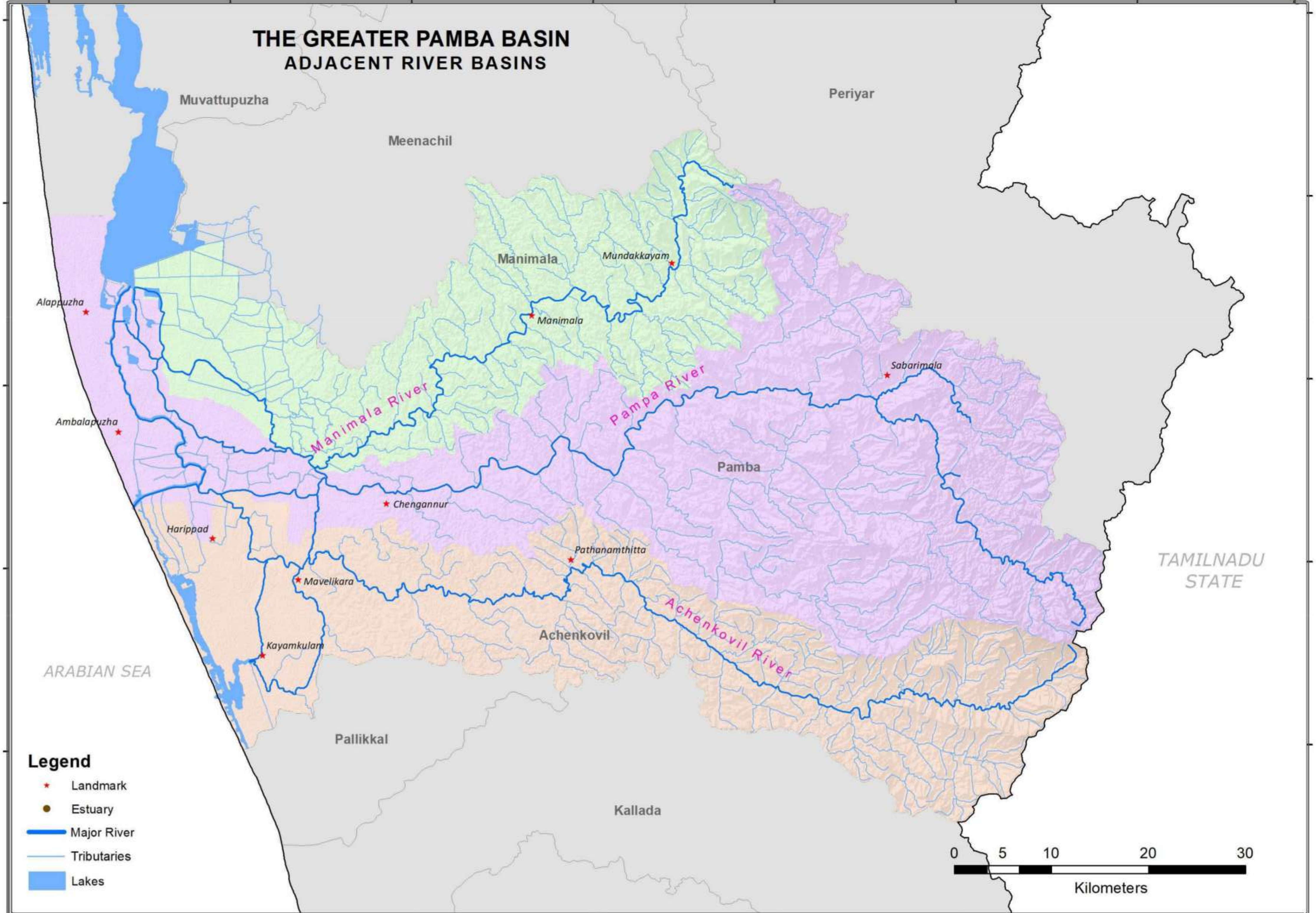
Kilometers


THE GREATER PAMBA BASIN
ADJACENT RIVER BASINS
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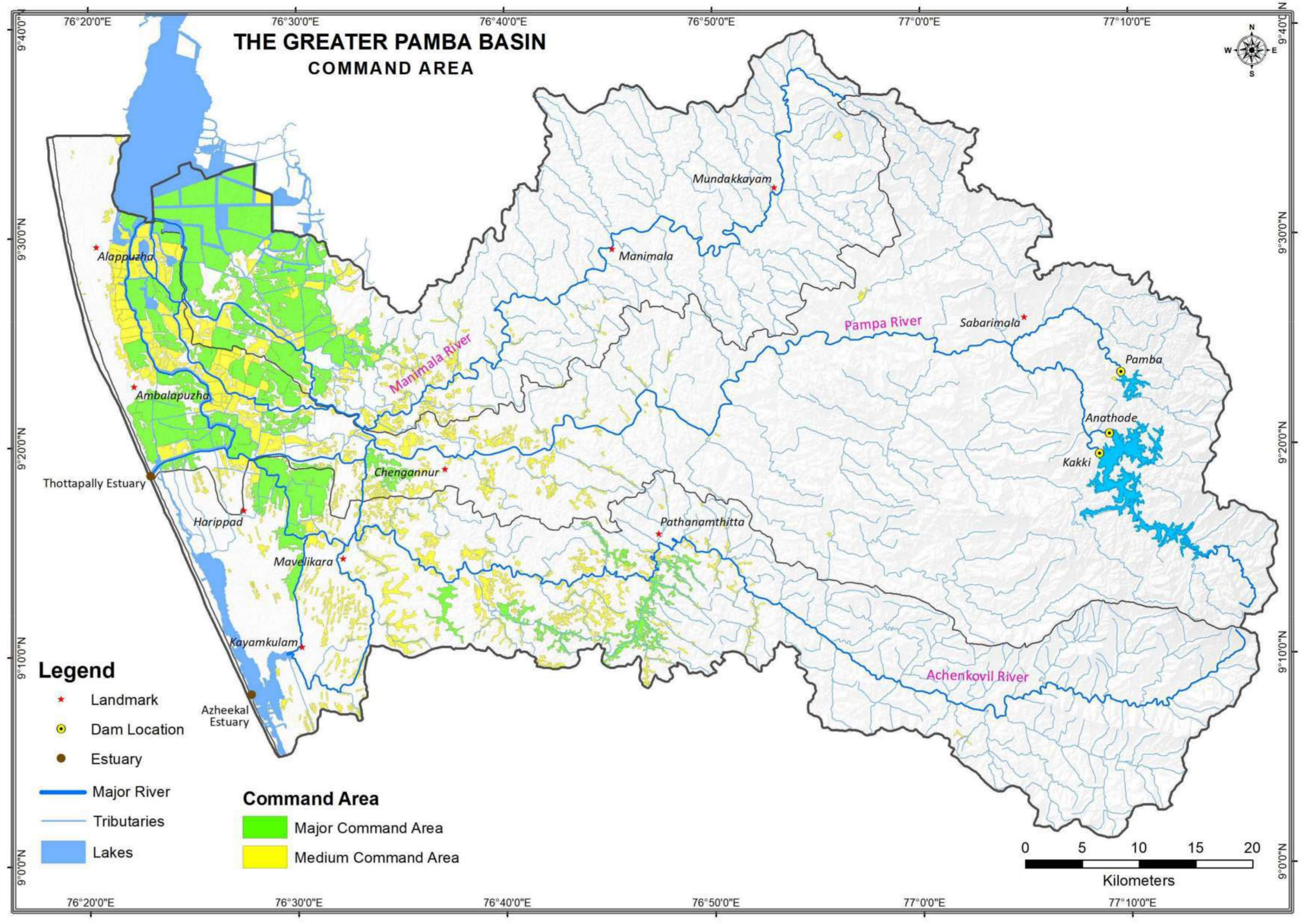
Meenachil
Periyar
Manimala
Mundakkayam
Manimala
Alappuzha
Sabarimala
Pampa River
Manimala River
Ambalapuzha
Pamba
Chengannur
Harippad
Pathanamthitta
TAMILNADU STATE
Mavelikara
Achenkovil
Achenkovil River
Kayamkulam
ARABIAN SEA
Pallikkal
Kallada
Legend
Landmark
Estuary
Major River
Tributaries
Lakes
0 5 10 20 30
Kilometers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COMMAND AREA
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S
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9°10'0"N
9°0'0"N
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala
Mundakkayam
Pathanamthitta
Sabarimala
Pamba
Anathode
Kakki
Manimala River
Pampa River
Achenkovil River
Legend
Landmark
Dam Location
Estuary
Major River
Tributaries
Lakes
Command Area
Major Command Area
Medium Command Area
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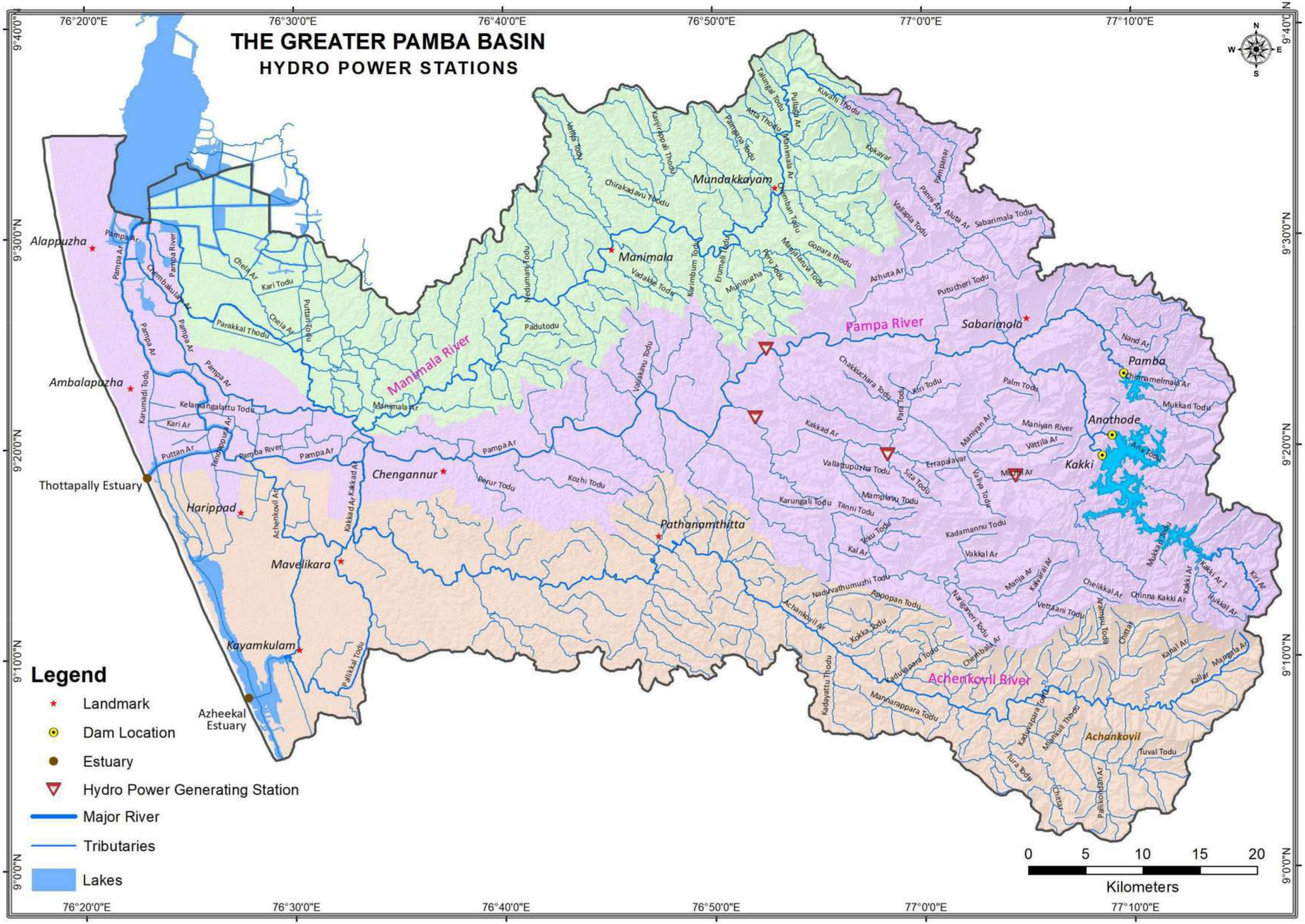
5
10
15
20
Kilometers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HYDRO POWER STATIONS
Legend
Landmark
Dam Location
Estuary
Hydro Power Generating Station
Major River
Tributaries
Lakes
0 5 10 15 20
Kilometers
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Pathanamthitta
Manimala
Mundakkayam
Sabarimala
Pamba
Anathode
Kakki
Achankovil
Pampa River
Manimala River
Achenkovil River
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76°40'0"E
76°50'0"E
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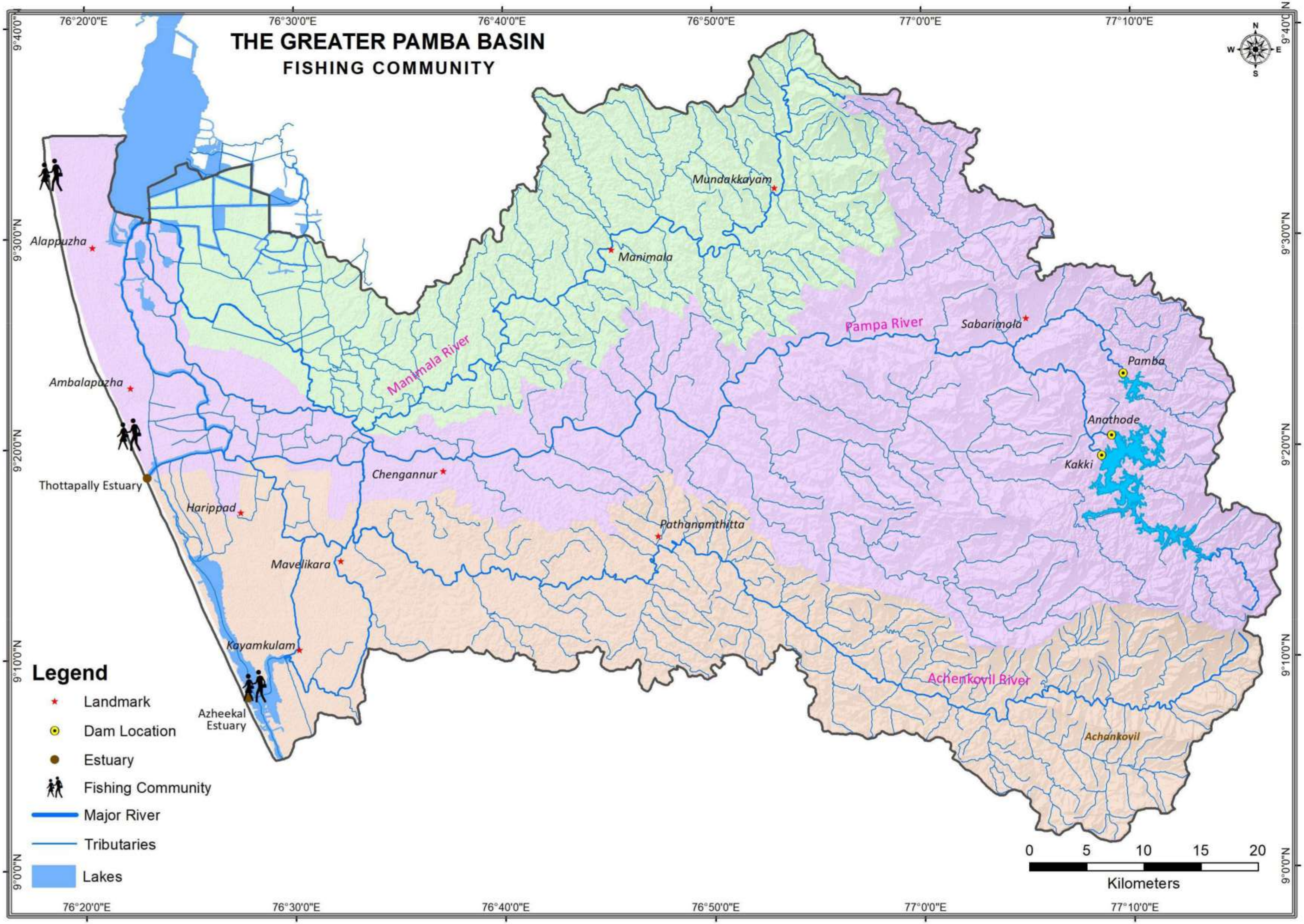
THE GREATER PAMBA BASIN
FISHING COMMUNITY
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Pathanamthitta
Manimala
Mundakkayam
Manimala River
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Fishing Community
Major River
Tributaries
Lakes
0 5 10 15 20
Kilometers
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76°50'0"E
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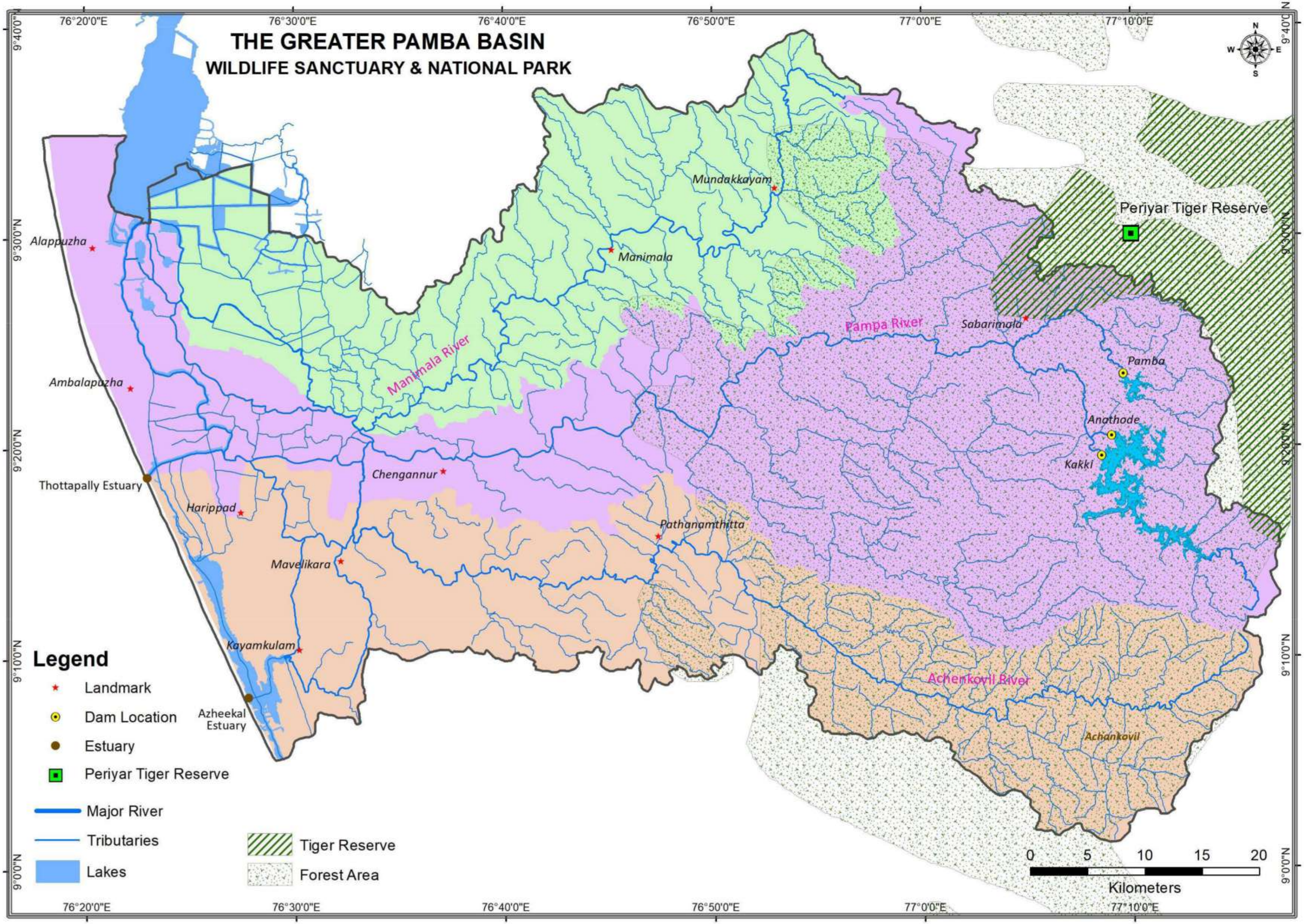
THE GREATER PAMBA BASIN
WILDLIFE SANCTUARY & NATIONAL PARK
Periyar Tiger Reserve
Mundakkayam
Manimala
Alappuzha
Ambalapuzha
Manimala River
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Chengannur
Thottapally Estuary
Harippad
Pathanamthitta
Mavelikara
Kayamkulam
Azheekal Estuary
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Periyar Tiger Reserve
Major River
Tributaries
Lakes
Tiger Reserve
Forest Area
0 5 10 15 20
Kilometers
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76°30'0"E
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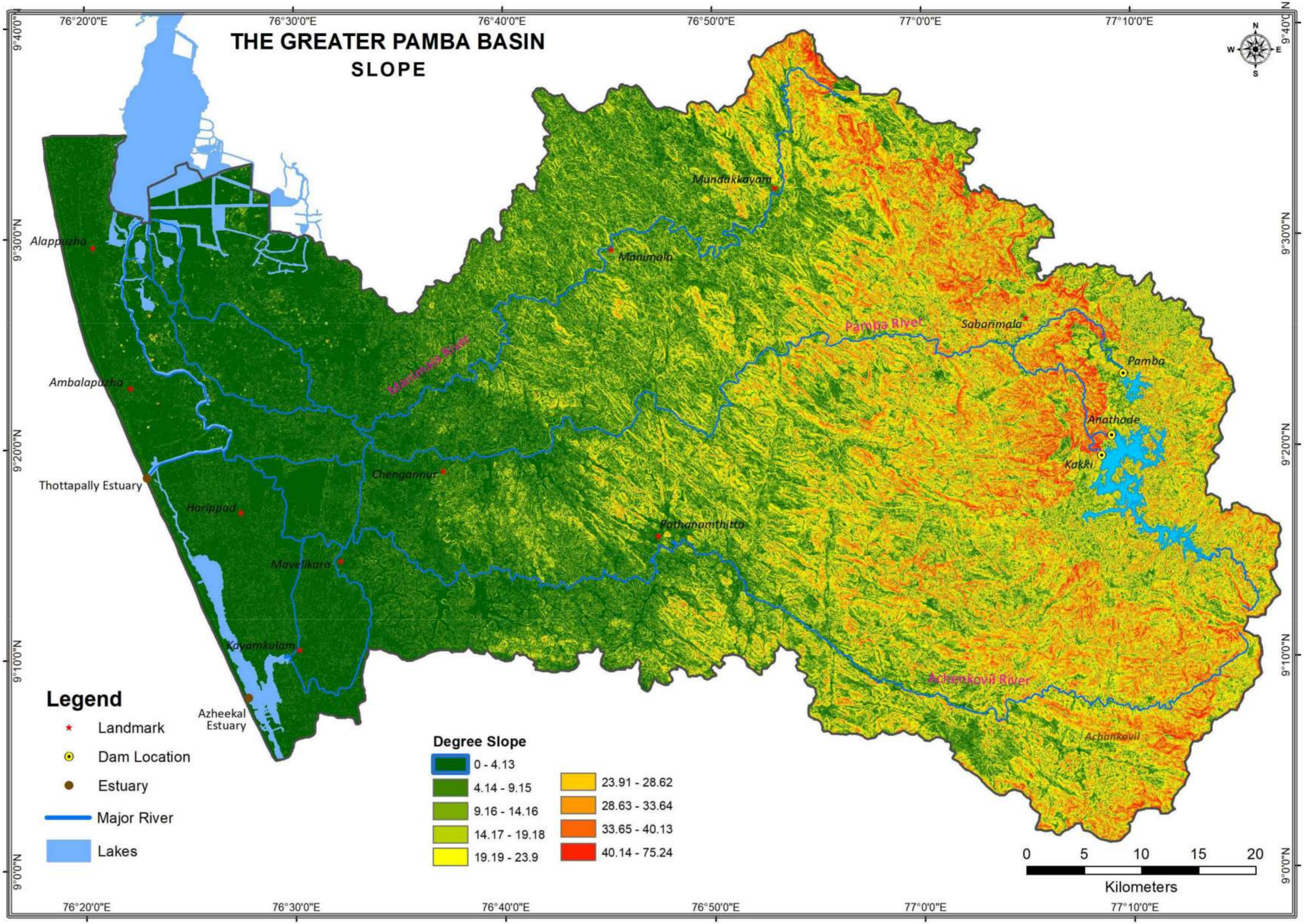

THE GREATER PAMBA BASIN
SLOPE
N
S
E
W
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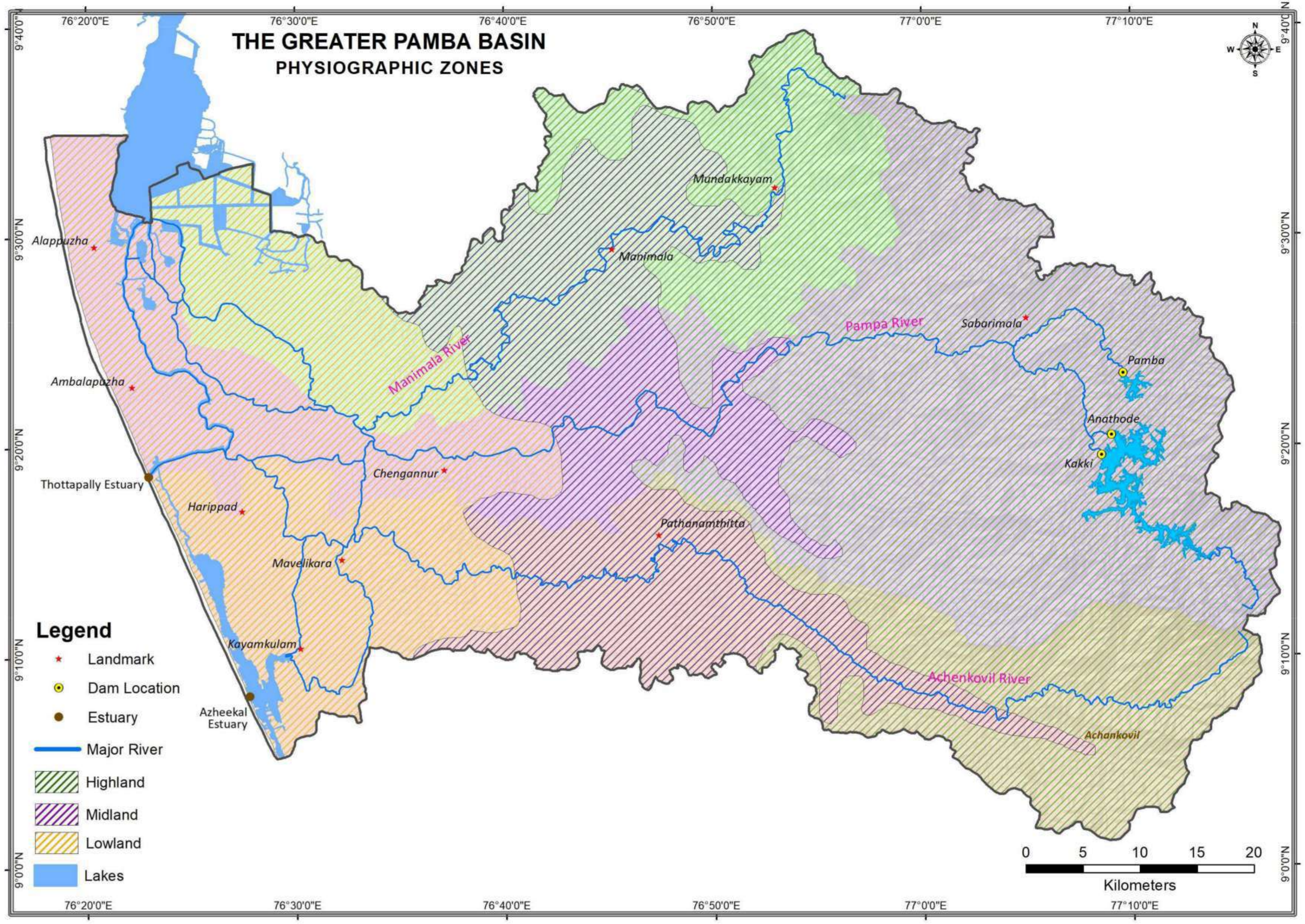
76°30'0"E
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
9°40'0"N
9°30'0"N
9°20'0"N
9°10'0"N
9°0'0"N
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala River
Manimala
Mundakkayam
Pathanamthitta
Pamba River
Sabarimala
Pamba
Anathode
Kakki
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Major River
Lakes
Degree Slope
0 - 4.13
4.14 - 9.15
9.16 - 14.16
14.17 - 19.18
19.19 - 23.9
23.91 - 28.62
28.63 - 33.64
33.65 - 40.13
40.14 - 75.24
0
5
10
15
20
Kilometers


THE GREATER PAMBA BASIN
PHYSIOGRAPHIC ZONES
Alappuzha
Ambalapuzha
Thottapally Estuary
Harippad
Mavelikara
Kayamkulam
Azheekal Estuary
Chengannur
Manimala River
Manimala
Mundakkayam
Pathanamthitta
Pampa River
Sabarimala
Pamba
Anathode
Kakki
Achenkovil River
Achankovil
Legend
Landmark
Dam Location
Estuary
Major River
Highland
Midland
Lowland
Lakes
0 5 10 15 20
Kilometers
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N
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S
W

INTEGRATED RIVER BASIN MANAGEMENT PLAN FOR

THE GREATER PAMBA BASIN

(Pamba River, Achankovil and Manimala River)

APPENDIX II -
DETAILS OF INTERVENTIONS UNDER GREATER PAMBA BASIN (PAMBA, ACHANKOVIL, MANIMALA KUTTANAD REGION AND ITS TRIBUTARIES)

Prepared by
Irrigation Department
Government of Kerala

APPENDIX II

Details of interventions under Greater Pamba Basin (Pamba, Achankovil, Manimala Kuttanad Region and its Tributaries)

MUST DO PROJECTS

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
1	Reiuvenation of pampa river - restoration of the left bank of pampa river d/s of Elamkavilkadavu near MSTTI in Ranni panchayath.	Pamba	38.13	Restoration of eroded embankment
2	Emergency Clearance of vent ways of cross structures including bridges and causeways etc. in Manimala River and its tribütraies consequent to the flood 2021	Manimala	72.7	Flood mitigation work
3	Providing temporary barricade and warning boards in various kadavus and embankment protection in Srampickal kadavu near Pandalam Palace in Pandalam muncipality.	Achenkovil	18.8	Construction of a Retaining Wall, Development of a Flood-Resistant Bathing Ghat, Reconstruction of Damaged Sidewalls, Installation of Seasonal Fencing and Barricades.
4	Restoration of eroded embankment on the left bank of Achenkovil river near Ambazhavelil bhagom in ward no 19 of Pramadam Panchayath	Achenkovil	25	Restoration of eroded embankment
5	Restoring the left bank of Pampa River near M.T.L.P.S. Mepadam in ward No.4 of Veeyapurampanchayth in Kuttanad constituency.	Pamba	30	Restoration of eroded embankment
6	Restoration of eroded embankment on the left bank of Achenkovil river near KWA pump house near Kottarathilkadavubhagam in ward no. 11 of Konni panchayat in Konni constituency	Achenkovil	18.55	Restoration of eroded embankment
7	Restoration of eroded embankment on the left bank of Achenkovil river and urgent stabilization of footbridge near Valachuzhy temple in Pramadam panchayat	Achenkovil	33.2	Restoration of eroded embankment
8	Urgent removal of deposited silt and debris from the periphery of water authority intake well to ensure sufficient water collection and rectification of the kadavu and protection wall in Ranni-Angadi Panchayat of Ranni Constituency.	Manimala	46.6	Restoration of eroded embankment
9	Desiltation of Pamba-Topographical Investigation and Soil investigation	Pamba	14.7	Topographical & Soil Investigation
10	Desiltation of Manimala river - Topographical investigation and soil investigation	Manimala	16.1	Topographical & Soil Investigation
11	Desiltation of Achankovilar - Topographical Investigation and soil investigation	Achankovil	4.65	Topographical & Soil Investigation
12	Side protection work and steps at Kunnathupuzha in Manimala River	Manimala	20	Restoration of eroded embankment
13	Side Protection works to Right Bank of Manimala River near Karimbukayam Bhagom	Manimala	97.8	Restoration of eroded embankment
14	Karimbukayam walkway - Side protection work to the right bank of the Manimala river near Karimbukayam causeway and construction of walkway	Manimala	50	Restoration of eroded embankment
15	Side protection -Side protection work of left bank of Manimala near Manimalakavu temple	Manimala	8	Restoration of eroded embankment
16	Improvement of the connection canal between Muttom Chanaganachery canal and Muttar Neelamperoor canal near Kochithra kadavu in Vazhapally panchayath	Manimala	30	Restoration of eroded embankment
17	Protection works to the left bank of the Pamba River in Mannar Panchayathu	Pamba	7.7	Restoration of eroded embankment
18	Urgent Protection Work to the Right Bank of Achenkovil River near Kottarathil Kadavu in Venmony Panchayath	Achankovil	21.5	Restoration of eroded embankment
19	Urgent Protection Work to the Left Bank of Varattar in Chengannur Municipality	Varattar	17.2	Restoration of eroded embankment
20	Rectification to the protection work to the left bank of Pamba River near South of Illimala Bridge (North side of Illimala Kadavu) in Pandanad Panchayath	Pamba	10	Restoration of eroded embankment
21	Urgent repair works- Strengthening of Kolamukkam chira to the left bank of Pamba river in the Chengannur municipality	Pamba	45	Restoration of eroded embankment
22	Protection work to the right bank of the Kuttamperoor River in Budhanoor panchayath in Chengannur LAC	Kuttamperoor	70	Restoration of eroded embankment
23	Protection work on the right bank of Pamba River in Thiruvanvandur panchayath	Pamba	15	Restoration of eroded embankment
24	Protection of Pamba River- Protection to the right bank of Pamba river in Pandanad panchayath of Chengannur LAC.	Pamba	50	Restoration of eroded embankment
25	Protection Work to the Left Bank of Pamba River in Mannar Grama Panchayath.	Pamba	15	Restoration of eroded embankment
26	Protection work to the right bank of the Pamba river in the Thiruvanvandur panchayath of Chengannur LAC. -Reach I	Pamba	32	Restoration of eroded embankment
27	Achenkovil River-Urgent protection of the eroded abutment of Irupathettil kadavu bridge in Pallippad panchayath	Achankovil	17	Restoration of eroded embankment
28	Rectification work to the right bank of Achenkovil River near Ayaparamp, north kadvu in Cheruthana Panchayath in Haripad LAC	Achankovil	15	Restoration of eroded embankment

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
29	Protection of the bund road to the right bank of Pamba river near Perumankara bridge in Cheruthana panchayath in Harippad LAC.	Pamba	40	Restoration of eroded embankment
30	Protection work to the bund road in left bank of Achenkovil river near cheruthana kadavu in Cheruthana panchayath in Haripad LAC (Phase II)	Achenkovil	36.4	Restoration of eroded embankment
31	Protecting the right bank of Achenkovil river near Salem Marthoma church in Chennithala Thriperumthura Panchayath	Achenkovil	18.7	Restoration of eroded embankment
32	Protecting the right bank of Achenkovil river in Chengannoor constituency.	Achenkovil	20.4	Restoration of eroded embankment
33	Protecting the eroded right bank of Komaramchirapally Thodu D/S of Pulukkikkalam ambulance bridge in Muttar Grama panchayat in Kuttanad constituency.	Pamba	22.4	Restoration of eroded embankment
34	Protecting the eroded right bank of Pamba river at Kattum bhagam bund in ward no.5 of Edathua panchayath in Kuttanad constituency.	Pamba	26.2	Restoration of eroded embankment
35	Restoring the right bank of Pamba river at Pullepady junction in Thalavady grama panchayath in Kuttanad constituency	Pamba	13	Restoration of eroded embankment
36	Protecting the left bank of Thalavady river from Kaithavanapady to Pullamthara bhagom in Thalavady Grama Panchayath in Kuttanad Constituency.	Pamba	22	Restoration of eroded embankment
37	Protecting the left bank of Kaitha thodu U/S of Kaitha thodu palam in Thalavady Grama Panchayath in Kuttanad constituency	Pamba	19.2	Restoration of eroded embankment
38	Restoring the L/B of Pamba river near M.T.L.P.S Melpadam in Veeyapuram panchayath in Kuttanad constituency -Phase II	Pamba	80	Restoration of eroded embankment
39	Restoring the left bank of Pamba River near M.T.L.P.S. Mepadam in Veeyapuram Panchayth in Kuttanad constituency.	Pamba	30	Restoration of eroded embankment
40	Urgent protection work using contiguous piles to the eroded bank of Manimala River from Thombilpady to Mulaykkalpady near Neerettupuram NSS Karayogam in Thalavady Grama Panchayath	Pamba	100	Restoration of eroded embankment
41	Repairs to various kadavu along Achenkovil River in Nooranad panchayath-phase 2	Achenkovil River	10	Restoration of eroded embankment
42	Kadavu at Konathukadav in Thazhakkara Panchayath in Mavelikkara constituency.	Achenkovil River	24	Restoration of eroded embankment
43	Strengthening of protection wall of Achenkovil River at Ellamkavu Mahadeva Kshethram near Venpalapady in Aruvapulam Panchayath	Achankovil	12	Restoration of eroded embankment
44	Restoration of erroded embankment on the left bank of Pamba river near Panchayat kadavu, Idayaranmula in Aranmula panchayat	Pamba	20	Restoration of eroded embankment
45	Restoration of eroded embankment on the left bank of Achenkovil River near Kochupura Kadavu in Pandalam Municipality	Achankovil	24	Restoration of eroded embankment
46	Restoration of Thayyilkadavu and eroded embankment of the right bank of the Kallada river near the Mannadi temple in Kadambanadu Panchayat in Adoor constituency	Kallada	20	Restoration of eroded embankment
47	Restoration of eroded embankment on the left bank of the Pamba river in Kozhencherry panchayat	Pamba	15	Restoration of eroded embankment
48	Restoration of erroded embankment on the left bank of Achenkovil river D/S of Kaippattur Bridge in Vallikodu Panchayath	Achankovil	32	Restoration of eroded embankment
49	Urgent rectification and allied works of Kadavu's in Vallikodu and Kulanada Panchayath	Achankovil	7.6	Restoration of eroded embankment
50	Urgent rectification and allied works of kadavus in Kozhencherry panchayat.	Pamba	10.6	Restoration of eroded embankment
51	Flood Mitigation works of Kadavu on the left bank of Achencovil river near Forest Division and Konnithazham SC colony in Konni Panchayath	Achankovil	19.6	Restoration of eroded embankment
52	Flood Mitigation works of Mallelil mannil Kadavu on the right bank of Achencovil river in Konni Panchayath	Achankovil	14.9	Restoration of eroded embankment
53	Flood mitigation works on the left bank of Achenkovil River near Kumpazha Bridge in Pramatam Panchayath	Achankovil	20	Restoration of eroded embankment
54	Flood mittigation works on the left bank of Achencovil river in between Kurunthottathil kadavu and Aythala kadavu and protection works between Mannarathara kadavu and Aythala kadavu and rectification of kadavu in Konni Village of Konni Constituency.	Achankovil	22.6	Restoration of eroded embankment
55	Flood Mitigation works of semi-permanent check dam across Achencovil river downstream of multi B.G Jalanidhi,and near kadavus in Muringamangalam in Konni panchayath	Achankovil	25	Infrastructure restoration

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
56	Flood mitigation works at the right bank of Achenkovil river d/s of Kallarakadavu Check dam near KWA pump house in Pathanamthitta municipality in Aranmula constituency.	Achankovil	23.5	Restoration of eroded embankment
57	Flood mitigation works of check dam and embankment protection at Valiyakoickal Sastha temple in Pandalam Municipality	Achankovil	30	Infrastructure restoration
58	Flood mitigation works at the right bank of Achenkovil river near Uzhuvathu temple in Omallur panchayat in Aranmula constituency.	Achankovil	20	Restoration of eroded embankment
59	Flood mitigation works on the left bank of Achenkovil river between Moothedathu Kadavu to Illathu Kadavu and Palappamannil Bhagam in Omallur panchayat in Aranmula constituency.	Achankovil	29	Restoration of eroded embankment
60	Restoration of eroded embankment on the right bank of Achenkovil river d/s of Thottathil Kadavu in Omallur Grama Panchayath	Achankovil	28	Restoration of eroded embankment
61	Flood Mitigation works on the left bank of the Achenkovil River in the upstream of Swamipady Kadavu in Pramadam Grama Panchayath in Konni Constituency	Achankovil	25	Restoration of eroded embankment
62	Flood mitigation works at the left bank of the Pamba river near Thundil Kadavu in Kozhencherry panchayat.	Pamba	24	Restoration of eroded embankment
63	Flood mitigation works on the left bank of the Achenkovil river near Karippoor Devi temple, Thottakkonam, and renovation of Ambala Kadavu in Kulanada panchayat and Pandalam municipality.	Achankovil	40	Restoration of eroded embankment
64	Flood Mitigation works on the left bank of Achenkovil River in Pallavazhi bhagom in Thumpamon Panchayath	Achankovil	24	Restoration of eroded embankment
65	Construction of Bathing ghat at Ambala Kadavu in Aranmula constituency	Pamba	16.7	Restoration of eroded embankment
66	Providing temporary barricade and warning boards in various kadavus in Achenkovil river and maintenance of Muttathu Kadavu in Pandalam Municipality	Achankovil	15	Infrastructure restoration, Providing Temporary barricade and warning boards
67	Restoration of eroded embankment on the left bank of the Achenkovil river near Kavumpattu Bhagam in Vallikodu Panchayath	Achankovil	19	Restoration work
68	Providing temporary barricade and warning boards on various kadavus of Achenkovil river and maintenance of Plakkottu kadavu in Pandalam Municipality.	Achankovil	15	Infrastructure restoration, Providing Temporary barricade and warning boards
69	Restoration of eroded embankment on the left bank of Pamba river U/S of Maruthoor kadavu in Mallappuzhassery panchayath.	Pamba	25	Restoration of eroded embankment
70	Restoration of eroded embankment on the left bank of the Achenkovl river near Valanchuzhy temple in Pramadam panchayath.	Achankovil	33	Restoration of eroded embankment
71	Rectification and allied works of various kadavus in Aranmula Constituency	Pamba	40	Restoration of eroded embankment
72	Flood damage Restoration of eroded embankment on the right bank of the Pamba River in Aranmula panchayat.	Pamba	27.7	Restoration of eroded embankment
73	Restoration of eroded bank on the left bank of the Achenkovil river in Muttam bhagam in Pramatam panchayath	Achankovil	22.5	Restoration of eroded embankment
74	Restoration of eroded embankment on the left bank of the Achenkovil river in Pramadam Panchayath	Achankovil	25	Restoration of eroded embankment
75	Rectification and allied works of Thadathil kadavu in Kulanada Panchayath	Achankovil	6.9	Restoration of eroded embankment
76	Rectification and allied works of Azhoor Velampady Kadavu in Pathanamthitta Municipality	Achankovil	7.4	Restoration of eroded embankment
77	Rectification and allied works of Mannil kadavu in Kulanada Panchayath	Pamba	7.4	Restoration of eroded embankment
78	Rectification and allied works of Velampady kadavu in Pramadom Panchayath.	Achankovil	7.1	Restoration of eroded embankment
79	Rectfcation and allied works of Manthrayil kadavu in Pandalam Municipality.	Achankovil	9	Restoration of eroded embankment
80	Rectification and allied works of Kottinattethu kadavu in Pandalam Municipality.	Achankovil	7.5	Restoration of eroded embankment
81	Rectification of Varappuzha Kadavu and Koledathu Kadavu in Koipuram Panchayath and Road kadavu in Kozhencherry Panchayath	Pamba	10	Restoration of eroded embankment
82	Sabarimala Pilgrimage 2021- Providing temporary barricades and warning boards in various kadavus and embankment protection in Srampickal Kadavu near Pandalam Palace in Pandalam muncipality.	Pamba	18	Infrastructure restoration, Providing Temporary barricade and warning boards
83	Restoration of eroded embankment on the right bank of the Achenkovil river near Thevarthottathil kadavu and rectification of kadavu in Kulanada panchayath	Achankovil	32	Restoration of eroded embankment

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84	Restoration of erroded embankment on the left bank of Achenkovil river near Vadakke Kottara Kadavu in pandalam Municipality	Achankovil	14	Restoration of eroded embankment
85	Providing temporary barricadesing boards at various kadavus of Achenkovil river and construction of bathing ghat d/s of checkdam near Pandalam Valiyakoickal temple	Achankovil	23	Infrastructure restoration, Providing Temporary barricade and warning boards
86	Restoration of eroded embankment on the left bank of Achenkovil river upstream of Muttam bhagam in Pramatam panchayath	Achankovil	9	Restoration of eroded embankment
87	Restoration of eroded embankment on the left bank of the Achenkovil river near Nariyapuram Mahadeva temple in vallikkodu panchayat	Achankovil	30	Restoration of eroded embankment
88	Restoration of eroded embankment on the right bank of the Pamba River near Cheppallil Kadavu and Mukkarnethu kadavu in Thottappuzhassery Panchayath	Pamba	32	Restoration of eroded embankment
89	Rectification of Ambalakadavu at Northside of Aranmula Parthasarathy Temple	Pamba	6	Restoration of eroded embankment
90	Urgent rectification and allied works of kadavus in Pamba river in Ranni panchayath	Pamba	14.2	Restoration of eroded embankment
91	Repairs and allied works of various kadavus in Ayroor panchayath	Pamba	18.6	Restoration of eroded embankment
92	Repairs and allied works of Panavamthara kadvu, Kailathu kadavu,Puthoor kadavu, Para kadavu, Pulikkal kadavu, and Puthiyakacavu temple kadavu in Ayroor panchayath	Pamba	14.9	Restoration of eroded embankment
93	Restoration works to the Edappavoor Churulithodu at the mouth of the river in Ayroor panchayath in Ranni constituency.	Pamba	17.1	Restoration of eroded embankment
94	Restoration works to the right bank of Pamba river and repair works to the Kadavu near Vallachi Kadavu in Ranni Gramapanchayath in Ranni constituency	Pamba	17.3	Restoration of eroded embankment
95	Restoration works to the right bank of Kakkadu river downstream of Boys highschool perunadu in Ranni constituency	Pamba	23	Restoration of eroded embankment
96	Restoration works to the left bank of the Kakkadu river near Poovathummoodu bridge in Ranni Perunadu panchayath	Pamba	9.6	Restoration of eroded embankment
97	Restoration works to the right bank of Pamba river in Ranni Angadi panchayath in Ranni constituency	Pamba	9.2	Restoration of eroded embankment
98	Restoration works to the right bank of Pamba river near Chempon thuruthu bhagam in Ayroor panchayath	Pamba	30	Restoration of eroded embankment
99	Restoration works on the left bank of Pamba River and repair works to the Kadavu in Kochumadathil Kadavu near Kattoor temple in the Cherukole Panchayath in Ranni Constituency	Pamba	23.6	Restoration of eroded embankment
100	Restoration works to the left bank of Koonamkara Valiya Thodu and repair works to the Kadavu at Swamippadi in Ranni perunadu Panchayath	Pamba	7.9	Restoration of eroded embankment
101	Restoration works to the left bank of the Pamba river and repair works to the Illathu Kadavu U/S of the Kattoor temple in Cherukole panchayath in Ranni constituency.	Pamba	20	Restoration of eroded embankment
102	Restoration of Embankment protection on the left bank of the Pamba river at the downstream of the foot bridge at Pamba Thriveni.	Pamba	386	Restoration of eroded embankment
103	. Restoration of Arattukadavu VCB across the Pamba river in Pamba Thriveni.	Pamba	31.8	Infrastructure restoration
104	Rebuild Kerala Initiative--Restoration of bathing ghat on the left bank of the Kakki river at balitharpanam area in Pamba Triveni	Pamba	73	Restoration of eroded embankment
105	Restoration of bathing ghat and pathway on the left bank of Pamba river between foot bridge and Arattukadavu VCB in Pamba Thriveni.	Pamba	67.5	Restoration of eroded embankment
106	Restoration of Pandarakkayam VCB across Pamba River in Pamba Thriveni.	Pamba	30	Infrastructure restoration
107	- Restoration of bathing ghat on the Right bank of the Pamba river between footbridge and Arattukadavu at Pamba Thriveni	Pamba	38.3	Restoration of eroded embankment
108	. Restoration of Sreeramapadam VCB across Pamba River in Pamba Thriveni.	Pamba	19.88	Infrastructure restoration
109	Removing silts, slurry & cloths before and after pilgrimage season	Pamba	6.1	cleaning work
110	Sabarimala pilgrimage 2019-20 Annual maintenance of irrigation structures like Check dams, Office building etc.	Pamba	14.9	Infrastructure restoration
111	Restoration of the protection wall on the left bank of Pamba river between Vehicular bridge and foot bridge in Pamba-Triveni	Pamba	29.2	Restoration of eroded embankment

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112	Providing temporary barricade and warning board at various kadavus of Pamba and Kakkadu river and seasonal fencing at Pamba triveni	Pamba	20	Infrastructure restoration, Providing Temporary barricade and warning boards
113	Removing silt and debris on the upstream and downstream of VCB near KWA intake well and its allied works in Pamba Thriveni	Pamba	30.43	Infrastructure restoration
114	Improvements to the Pamba Thriveni Road	Pamba	18.2	Infrastructure restoration
115	Urgent rectification works and allied works of Kattoor Kadavu in Cherukole panchayath in Ranni constituency	Pamba	10.92	Infrastructure restoration
116	Urgent Cleaning works on both banks of Pamba River in the Convention Nagar in Ayroor and Cherukol Panchayath in Ranni	Pamba	4.6	Cleaning work
117	Construction of a Ramp on the right bank of Pamba river at Cherukolpuzha in Ayroor Panchayath of Ranni constituency	Pamba	20	Infrastructure restoration
118	Improvements to the Ramapuram Temple kadavu and embankment protection on the left bank of Pamba river in Ranni Panchayath of Ranni Constituency	Pamba	25	Infrastructure restoration
119	Restoration works to the right bank of Pamba river in Madathil vallakkadavu in Ranni Angadi panchayath	Pamba	21.3	Restoration of eroded embankment
120	Repair works for the Pamba Thriveni road and Ramp towards Balitharpanam area at Pamba Thriveni	Pamba	5.39	Infrastructure restoration
121	Extension of the existing drain on the left side of Pamba - Thriveni road	Pamba	21.27	Infrastructure restoration
122	Restoration of KSRTC VCB across Kakki River and store shed at chakkupalam near Pamba thriven	Pamba	22	Infrastructure restoration
123	Restoration work on the left bank of the Pamba River and repair to the Kadavu in Peruchal kadavu in Cherukole anchayath of Ranni constituency.	Pamba	13.23	Restoration of eroded embankment
124	Urgent Rectification and allied works of Kailathu Kadavu in Ayroor Panchayath.	Pamba	12.45	Restoration of eroded embankment
125	Urgent Rectification and allied works of Delta Kadavu in Ranni panchayath	Pamba	7.49	Restoration of eroded embankment
126	Removal of deposited silt and debris to maintain the River flow in the Pamba river at Cherukolpuzha in Ayroor Panchayath.	Pamba	15	Desilting work
127	Restoration of right bank of the Pamba river downstream side of cherukolppuzha bridge in Ayroor panchayath	Pamba	21	Restoration of eroded embankment
128	Urgent cleaning works on both banks of Pamba River in the convention Nagar in Ayroor and cherukole Panchayath in Ranni Constituency.	Pamba	6.05	Cleaning work
129	Restoration of the Right bank of the kakkadu River D/S of Perunadu Power house in Ranni Perunadu Panchayath of Ranni constituency.	Pamba	18	Restoration of eroded embankment
130	Urgent rectification works to the Elamkavil Kadavu in Ranni panchayath of Ranni Constituency.	Pamba	10	Restoration of eroded embankment
131	Rectification works to the Mattappally kadavu in Ranni Panchayath.	Pamba	10.78	Restoration of eroded embankment
132	Urgent rectification works to the Konamala kadavu in Ranni Pazhavangadi Panchayath of Ranni constituency.	Pamba	10.79	Restoration of eroded embankment
133	Restoration of the left bank of the Kakkadu River Down stream side of Maniyar barriage in perunadu Panchayath of Ranni constituency.	Pamba	10.2	Restoration of eroded embankment
134	--Restoration works to the left bank of the pamba river Near parakkadavu in cherukol panchayath.	Pamba	11.2	Restoration of eroded embankment
135	Maintenance of Pamba water stadium at Neerettupuram from the starting point to Finishing point for "Uthradam thirunal Pamba boat race Neerettupuram"	Pamba	2.8	Infrastructure restoration
136	Protecting the right bank of Manimala River opposite side of Veliyam kadavu in Thiruvalla Municipality of Thiruvalla constituency	Manimala	17	Restoration of eroded embankment
137	Maintenance of approach road and allied works of Alathu Kadavu Bridge at Kadapra Grama Panchayat in Thiruvalla constituency.	Pamba	6.3	Restoration of eroded embankment
138	Urgent Temporary protection works to the eroded right bank of the Kadalimangalam river at Iruvellitthara near Thirumoolapuram in Thiruvalla Municipality	Manimala	1.75	Restoration of eroded embankment
139	Protecting the right bank of the Manimala river near Ammantrakadavu in Kuttoor GP in Thiruvalla constituencty.	Manimala	21.4	Restoration of eroded embankment
140	Protection works for the public stadium Mallappally on the right bank of Manimala river in Mallappally Gramapanchayath.	Manimala	37	Infrastructure restoration
141	Protection works and approach road works to the left bank of the Varattar river in Thiruvanvandoor Panchayath in Chengannur constituency.	Varattar	6.88	Restoration of eroded embankment

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142	Providing protection works to the left bank of Manimala river in Kuttoor grama Panchayath	Manimala	14.3	Restoration of eroded embankment
143	Protecting the left bank of the Kolarayar river near Thullakalathil Kadavu in Kadapra Panchayath in Thiruvalla constituency.	KOLARAYAR	8.4	Restoration of eroded embankment
144	Maintenance of Pamba water stadium at Neerettupuram from starting point to finishing point for Uthradam thirunal pamba boat race Neerettupuram.	Manimala	1.5	Infrastructure restoration
145	Rectification works to the kadavu on the Right bank of Pamba River D/S of the Vehicular bridge at Pamba Thriveni	Pamba	9.69	Restoration of eroded embankment
146	SABARIMALA PILGRIMAGE 2022-2023-Construction of cross drainage work in Thiruvabharanapatha near Aayikkal thiruvabharana para in Cherukole Panchayath of Ranni Constituency.	Pamba	19.13	Restoration of eroded embankment
147	Urgent removal of deposited silt and debris from Kakkadu river near Kandamkulam and restoration of the Left bank in Ranni Perunadu Panchayath.	KAKKADU	20	Restoration of eroded embankment
148	Restoration of Left bank of Pamba River u/s of Footbridge at Pamba Thriveni in Ranni Perunadu Panchayath of Ranni Constituency.	Pamba	10.67	Restoration of eroded embankment
149	Restoration of Right bank of Pamba River Near NSS Karayogam Varavoor in Ranni Angadi Panchayath of Ranni Constituency.	Pamba	20.8	Restoration of eroded embankment
150	Rectification of the ramp towards the Edappavur Perur palliyodakadavu in the Ayroor panchayath of the Ranni Constituency.	Pamba	8.2	Restoration of eroded embankment
151	Restoration Works to the left bank of Pamba River at varavoor near Thuthi moothedath kadavu in Ranni Panchayath.	Pamba	32.45	Restoration of eroded embankment
152	Providing Ramp and protection work d/s of the foot bridge near Arattukadavu VCB in Pamba Thriveni in Ranni Perunadu panchayath.	Pamba	11.24	Restoration of eroded embankment
153	Cleaning and desilting of Kuratheri Akkanadi thodu in Neelamperoor panchayath in Kuttanad thaluk	Manimala	50	Restoration of eroded embankment
154	Rectification of VCB across Uravantekadavu thodu and Improvments of irrigation facilities in Edappara vayal ela in Thumpamon Panchayath in Adoor Constituency	Achenkovil	17	Restoration of eroded embankment
155	Protection of damaged side bund of Paranthal Valiya thodu near St.George Orthodox Aramanapally at Kalarikkal Jn. Paranthal in Pnadalam Thekkekara Panchayath	Achenkovil	15	Restoration of eroded embankment
156	Providing irrigation facilities to the upstream side padasekharams of Punnon in Naranganam Panchayath in Aranmula Constituency.	Pamba	28.25	Infrastructure restoration
157	Kattoor vayal Attutheram thode -Urgent rectification of Kattoor vayal Attutheram thode in Cherukole Panchayath	Pamba	17.5	Restoration of eroded embankment
158	Providing irrigation facilities to Aanappara Mannathupara ela in Elanthoor pyt Aranmula constituency	Pamba	40	Infrastructure restoration
159	Pathanamthitta Urgent rectification of breached bund of Chamathakkal Veeramala thodu in Cherukole panchayath	Pamba	3.6	Restoration of eroded embankment
160	Protecting the side bund of Thottumadom Thodu in Kozhencherry Panchayath.	Pamba	15	Restoration of eroded embankment
161	Improvements of Irrigation Facilities to Mundakathu Ela and Allied works in Omalloor Grama Panchayat	Achenkovil	16.43	Infrastructure restoration
162	Urgent desiltation and protection works to ponganamthode peechanaducolony in Kozhencherry Panchayath	Pamba	20	Restoration of eroded embankment
163	Thanungattil Valiyathodu at Tholuparampil puncha in Kozhencherry Panchayath in Aranmula constituency	Pamba	25	Infrastructure restoration
164	Rectification of breached bund of Konnammoodu thodu near Mundukottakkal Jn in ward 5 of Pathanamthitta Municipality	Achenkovil	5.3	Restoration of eroded embankment
165	Urgent Rectification of breached bund of Kannankarathodu thodu upstream of Parakkadavu near Azhoor in Pathanamthitta Municipality in Aranmula Constituency	Achenkovil	9.87	Restoration of eroded embankment
166	Renovation of Potholi Punja thodu in Kozhencherry Panchayath	Pamba	1.76	Flood mitigation work
167	Clearing and de silting of Pattathil Kuzhimannil kadavu in PTA Municipality	Achenkovil	0.53	Flood mitigation work
168	Clearing and desilting of Kodumthara ela thodu in PTA Municipality	Achenkovil	0.84	Flood mitigation work
169	Clearing and desilting of Ponganamthodu near Keezhuvara peechanadu colony in Kozhencherry Panchayath	Pamba	1.37	Flood mitigation work
170	Clearing and desilting of Kottanthodu near StPeters Junction in Pathanamthitta Municipality	Achenkovil	0.62	Flood mitigation work
171	Kannankara thode-Clearing and desilting ofKannankara thode between Municipal bus stand and kallarakadavu in Pathanamthittamunicipality	Achenkovil	1.5	Flood mitigation work

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172	Urgent desiltation of Punnapadam ela thodu in ward 27 of Pathanamthitta Mmunicipality	Achenkovil	1.58	Flood mitigation work
173	Vettipuram thode- Emergency desiltation of Vettipuram thode up to Changethu hospital in Pathanamthitta municipality	Achenkovil	2.33	Flood mitigation work
174	Kannankara thode-Emergency desiltation of downstream of Kannankara thode near SP office at Pathanamthitta municipality	Achenkovil	2.01	Flood mitigation work
175	Urgent Rectification of breached portion of Chittar Valiyathod, Puthupparambil Thundiyl bhagam in chittar Gramapanchayath in Konni Constituency	Pamba	8.4	Restoration of eroded embankment
176	Urgent rectification of breached portion of Kochkoikkal thodu in Seethathod Grama Panchayat, Konni constituency	Pamba	8.4	Restoration of eroded embankment
177	Side protection work of Mundakathil pady ela thodu and construction of a culvurt near SC School, Chellakkadu in Ranni - Pazhavangadi Panchayath in Ranni constituency,	Pamba	30	Infrastructure restoration
178	Urgent rectification of breached portion of side bund of seethakuzhi thodu in ward no.10 seethathod panchayth in konni constituency	Pamba	9.6	Restoration of eroded embankment
179	Clearing the mouth of Kakkad cross way In chittar Gramapanchayth Konni constituency	Pamba	0.67	Flood mitigation work
180	Desilting of poovan mala thodu near poovan mala ela bhagam in ward no.10 Ranni Angadi Gramapanchayth Ranni constituenc	Pamba	0.9	Flood mitigation work
181	Desilting of ranni valiyathod near Manjanm Kuzhi Bhagam opp bethel church in Ranni Angadi Gramapanchayath Ranni constituency	Pamba	0.85	Flood mitigation work
182	Urgent rectification breached portion side bund of ranni valyathodu near upasanakadvu in Angadi Grama panchayth in Ranni constituency	Pamba	4.016	Restoration of eroded embankment
183	Rejuvenation of Ranni Valiyathodu in U/S side of Mamukku bridge in Ranni Angadi Grama Panchayth Ranni Constituency	Pamba	6.172	Flood mitigation work
184	Urgent rectification of side bund of Villoonni para thodu near Pulayanpara Juma-Masjid in chittar Gramapanchayth in konni constituency	Pamba	4.8	Restoration of eroded embankment
185	Urgent rectification of the breached portion therattamon thodu in chittar gramapanchayth Konni constituency	Pamba	4.8	Restoration of eroded embankment
186	Urgent rectification of side bund of Valiyakavu Manjanam Kuzhi Thodu near valiya kavu in Ranni Angadi Gramapanchayath Ranni constituency	Pamba	16.8	Restoration of eroded embankment
187	Urgent rectification of the side bund of up streamside of Eettichuvad checkdam in Chittar Gramapanchayth in Konni Constituency	Pamba	16.8	Restoration of eroded embankment
188	Urgent rectification of a breached portion of Vayaranmaruthi thodu in Ranni-Perunad Grama Panchayath Ranni constituency	Pamba	8.4	Restoration of eroded embankment
189	Urgent rectification of side bund of Koodathu Padi Thodu in Ranni Angadi Gramapanchayth Ranni	Pamba	4.8	Restoration of eroded embankment
190	Urgent Rectification of the side bund of Thodu near manpilav in Chittar Grama Panchayath Konni constitency	Pamba	10.8	Restoration of eroded embankment
191	Urgent rectificatin of the breached portion of Kulangaravalley - Vayyattupuzha Thodu in Chittar Gramapanchayath in Konni constituency.	Pamba	9.6	Restoration of eroded embankment
192	Urgent rectification of the side bund breached portion of the mambara thodu in Ranni Perunad Gramapanchyath Ranni constituency	Pamba	3.6	Restoration of eroded embankment
193	Urgent rectification of the breached portion of the side bund of Pazhoor Padi thodu Ranni-Perunad grama Panchayath Konni Constituency	Pamba	4.8	Restoration of eroded embankment
194	Urgent rectification of venkurinji thodu in Ranni-Perunad Grama Panchayath Konni constituency	Pamba	4.8	Restoration of eroded embankment
195	Urgent rectification of side bund of thodu near govt.U.P. School madamon in Perunad Grama Panchayath in Ranni constituency	Pamba	2.4	Restoration of eroded embankment
196	Urgent rectification of the side bund of Chettikunnu thodu in Ranni Angadi Gramapanchayath Ranni constituency	Pamba	2.4	Restoration of eroded embankment
197	Desilting of Kurumban moozhi thodu in Naranamoozhi grama panchayath in Ranni Constituency	Pamba	0.4	Flood mitigation work
198	Desilting of Vayyattupuzha -Pulayanpara thodu in ward no.8 in Chittar Grama Panchayath Konni constituency	Pamba	0.4	Flood mitigation work
199	Restoration of diverted Chirakkal thodu path near Model Residential School in Vadaserikkara Grama Panchayth Ranni constituency	Pamba	50	Restoration of eroded embankment

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
200	Urgent rectification of the side bund of Neeliplavuthodu in Chittar Gramapanchayth Konni Constituency	Pamba	15	Restoration of eroded embankment
201	Kavu mannil thodu - Ranni Angadi-urgent rectification of kavi mannil thodu in Ranni Angadi Grama Panchayath Ranni constituency	Pamba	7.5	Restoration of eroded embankment
202	Pre-monsoon-Deepening of Madathumoozhi thodu(river mouth) in Ranni Perunad Grama Panchayath	Pamba	0.7	Flood mitigation work
203	Renovation of Kattottu chal in Aranmula Panchayath in Aranmula constituency	Pamba	40	Flood mitigation work
204	Providing Irrigation Facilities to Mukkuzhy Alakkodu Padasekharam in Mezhuveli Panchayath in Aranmula Constituency	Pamba	43	Infrastructure restoration
205	Construction of New motor thara and installation of Motor at memana thodu for Nedumpana Thanappally in Eraviperoor panchayath	Manimala	34	Infrastructure restoration
206	Constuction of New motor thara and installation of motor at middle of Puthenthodu for Narayankally padashekaram in Eraviperoor panchayath	Manimala	30	Infrastructure restoration
207	Providing irrigation infrastructure facilities to Pulleli padashekharam in Puramattom panchayath	Manimala	40	Infrastructure restoration
208	Desiltation of Thazhakulam thodu near Thazhakulam padashekharam in puramattom panchayath	Manimala	0.75	Flood mitigation work
209	Desiltation of thettupara thodu in Koipuram panchayath in aranmula constituancy	Pamba	0.5	Flood mitigation work
210	Annual Clearance of waste from trash rack near Erappen Thodu PIP RBC crossing during monsoon in Koippuram Panchayath	Pamba	0.5	Clearance of waste from trash rack
211	Desiltation of mundodathilpadi thodu in Ayroor panchayath of Ranni constiuancy	Pamba	0.7	Flood mitigation work
212	Desiltation of Erappen thodu at the upstreem and down streem of PIP RBC crossing in koippuram panchayath	Pamba	1.15	Flood mitigation work
213	Desiltation of Erappen thodu near PIP RBC crossing in koippuram panchayath in Aranmula constituency	Pamba	1.5	Flood mitigation work
214	Desiltation cheruvi thodu near cheruvil padashekram of puramattom panchayath of thiruvalla constituancy	Manimala	0.7	Flood mitigation work
215	Desiltation kadamala thodu in puramattom panchayath in thiruvalla constituancy	Manimala	0.9	Flood mitigation work
216	Desiltation of Chelaykkal thodu in puramattom panchayath in thiruvalla constituancy	Manimala	0.9	Flood mitigation work
217	Cleaning and desilting of varous thodu in koipuram block in Aranmula,Ranni and Thiruvalla constuency	Pamba	2.85	Flood mitigation work
218	Cleaning and desilting of thodu in Thottapuzhasserry,Ayroor and Ezhumattoor panchayath	Pamba	3.319	Flood mitigation work
219	Cleaning of Erappenthodu at Chirayirambu Ela in Thottapuzhassery panchayath	Pamba	1.19	Flood mitigation work
220	Cleaning and deepening of Naduthodu of Palavayal padashekharam in puramattom panchayath	Pamba	0.6	Flood mitigation work
221	Cleaning and desilting of thodu in Puramattom panchayath	Manimala	1.75	Flood mitigation work
222	Cleaning and desilting of thodu in Koipuram and Eraviperoor panchayath	Pamba	1.77	Flood mitigation work
223	Renovation of Kulanilam chal in Kulanada Panchayath in Aranmula Constituency	Achankovil	55	Infrastructure restoration
224	Providing Irrigation facilities to Kidangannur puncha in Aranmula Panchayath in Aranmula Constituency	Pamba	76	Infrastructure restoration
225	Construction of access culvert across Vaipinary thodu for Chathenkery padashekharam near Cherupperi Jn in Peringara Panchayat	Manimala	55	Infrastructure restoration
226	Replacement of irrigation shutter near Kattodu bridge accross Kattodu valiyathodu in Thiruvalla constituency	Manimala	45	Infrastructure restoration
227	Construction of Triple box culvert across Thiruvambadi Thodu at Maroothrakadavu in Peringara Panchayath in Thiruvalla Assembly Constituency	Manimala	75	Infrastructure restoration
228	Providing Irrigation Facilities to Manikkathakidy Padashekharam in Peringara Panchayat of Thiruvalla Constituency.	Manimala	46.25	Infrastructure restoration
229	Rehabilitation of Nedumpuram West LI Scheme in Nedumpuram Panchayat of Thiruvalla Constituency (Phase -II)	Manimala	82	Infrastructure restoration
230	Rehabilitation Of Li Scheme For Nedumpuram West Padasekharam In Thiruvalla Constituency	Manimala	40	Infrastructure restoration
231	Providing a motor shed and allied works of Ayyamkonary Padasekharam in Niranam Panchayath	Pamba	28	Infrastructure restoration
232	Improvements to the bund road at Kelamparambilpadi to Rakshasainyam Pallipadi in Peringara Panchayath of Thiruvalla Constituency	Manimala	29	Infrastructure restoration

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
233	Providing irrigation facilities to Kaipala west Padashekharam in Peringara Panchayat of Thiruvalla constituency	Manimala	25	Infrastructure restoration
234	Restoration of thodu between Panikkottilpady to Alummoottilpady and construction of Box culvert and RCC slab in ward no.10 of Peringara Panchayath in Thiruvalla Assembly Constituency	Manimala	50	Infrastructure restoration
235	Providing irrigation facilities to Manjathanam puncha in Mallappally Panchayath in Thiruvalla Constituency	Manimala	64.38	Infrastructure restoration
236	Providing irrigation facility to Kaviyoor puncha in Kaviyoor & Kunnathanam panchayath under Harithakeralam	Manimala	80	Infrastructure restoration
237	Protection of side bund of Thalayara thodu at Viriyankuzhy in ward no.9 of Vallicode Grama Panchayath.	Achankovil	2.97	Restoration of eroded embankment
238	Improving irrigation facilities of Erappanal Ela in Aruvappulam Panchayath.	Achankovil	11	Restoration of eroded embankment
239	Poovanpara-Maroor thodu-FD- Side protection works of Poovanpara- Maroor thodu near Snehabhavan at Eliyarakkal in Konni Panchayath.	Achankovil	5	Restoration of eroded embankment
240	Urgent removal of silt and debris from Manjadi thodu in ward no.10 of Konni Grama Panchayath.	Achankovil	0.5	Flood mitigation work
241	Thanugadu ela thodu-Urgent removal of silt and debris from Thanungadu ela thodu in Pramadam Gramapanchayath	Achankovil	0.8	Flood mitigation work
242	Desilting of Kodumon Valiyathodu Urgent removal of silt and debris from KodumonValiyathodu in Vallicodu Grama Panchayath.	Achankovil	3.46	Flood mitigation work
243	Urgent removal of silt and debris from Kaaruvelil Ela Kai thodu in Vallicodu Grama Panchayath.	Achankovil	0.8	Flood mitigation work
244	Urgent removal of silt and debris from Kuthiravattam Ela Thodu in Pramadam Grama Panchayath.-	Achankovil	0.9	Flood mitigation work
245	Repairing of VCB at Pulinchani kadavu and improvements of Radhappadi- Pulinchani thodu and construction of Tractor Bridge at Pulinchani kadavu in Aruvapulam Panchayath	Achankovil	25	Infrastructure restoration
246	Side Protection works of Mallasserry ela thodu at Indiralinkal bhagam in Pramadom Panchayath.	Achankovil	6	Restoration of eroded embankment
247	Maintenance work of side bund of Erappenkuzhi Thanungadu ela in Pramadom Panchayath	Achankovil	12	Restoration of eroded embankment
248	De-silting of Kodumon Valiyathodu near Pulayanchira VCB in Vallicodu Panchayath.	Achankovil	1.8	Flood mitigation work
249	Repairs to the side bund of Manakkuppathodu in ward No.8 of Vallicodu Panchayath.	Achankovil	6	Restoration of eroded embankment
250	Improving irrigation facilities to Mallassery Vadake ela in Pramadom panchayath	Achankovil	25	Restoration of eroded embankment
251	Repairs to the side bund of Ammoommathodu Kanjirapparathodu near Petrol pump at Poonkavu in Pramadom/Vllicodu Panchayath	Achankovil	10	Restoration of eroded embankment
252	Repairs to side bund of Lakkoor thodu in Pramadom panchayath.	Achankovil	10	Restoration of eroded embankment
253	Side protection works of Vellappara-Cheeppupadi thodu at Vellappara Vattakkavu in ward No.8 & 9 of Pramadom Panchayath	Achankovil	8	Restoration of eroded embankment
254	Strengthening of side bund of Kodumon valiyathodu in Vallikkodu panchayath	Achankovil	0.33	Restoration of eroded embankment
255	Strengthening of side bund of Attachakkal valiya thodu at Kizhakkumpuram ela bhagam in Konni panchayath	Achankovil	0.43	Restoration of eroded embankment
256	Urgent removal of silt and debris from Vakayar ela thodu near market at Vakayar in Pramadom Panchayath	Achankovil	0.4	Flood mitigation work
257	Rectification of damaged bund of Maroor thodu in Konni Panchayath	Achankovil	8.4	Rectification of damaged bund
258	Construction of VCB and side protection of Attachakkal Ela thodu in Konni Panchayath	Achankovil	25	Restoration of eroded embankment
259	Maintenance of Kodinjimoola check dam across Achenkovil river in Konni panchayath	Achankovil	5	Infrastructure restoration
260	Clearing Flood deposited Boulders and earth from D/S of Maniyar Barrage -1	Pamba basin	11.2	Flood mitigation work
261	Reconstruction of Thottankarapadi Thoomugham road cada canal	Pamba basin	17.82	Infrastructure restoration
262	Restoration Of Nunungar Bridge in Pamba Triveni	Pamba	139	Restoration work

LIGHT TOUCH PROJECTS

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
1	Constructing Aqueduct in place of collapsed Varayannur Aqueduct of Poovathoor East Branch Canal at ch. 1000 m.	Pamba	190	Construction of aqueduct and land barrel for a length of 236m, rectification of existing canals etc.
2	Construction of Sasthampadi- Paruthiyathonnu cada canal	Pamba	29.99	Construction of Sasthampadi- Paruthiyathoonnu CADA canal – construction of 435m long canal in CC 1:3:6 walls over a rubble making portion and a CC bed of 10cm thick.
3	Renovation of Kulanilam chal in Kulanada Panchayath in Aranmula Constituency	Achenkovil	55	Desiltation of kulanilam chal thereby the reclaimation of the storage capacity of kulanilam chal, Restoration of the protection walls of the inlet thodu, The side stabilisation of the thodu, construction of pump house, Supply and erection of pump set and accessories,
4	Repair and maintenance of checkdam near 35th mile in peruvanthanam panchayat.		18	Silt and Debris Removal, Structural Repairs. Creation of Additional Vents, Construction of Protection Wall, civil works, such as earthwork excavation, installation of dowel bars, dismantling and rebuilding masonry walls, and laying cement concrete for the apron and lining.
5	Mitigation of flood in Neelamperoor Pallippadam Padasekharam in Neelamperoor Panchayath	Manimala	180	Retaining wall construction and restoration of outer bunds., Construction of Motor thara (Floor), Construction of Motor Shed, Excavation of clay for outer bund, Excavation of clay for outer bund.
6	Mitigation of flood in Padinjare 40 Thazhathu 40 Padasekharam of Ramankary Panchayath in Kuttanadu LA Constituency	Manimala	150	DR and RR masonry protection wall construction, Raising and strengthening the outer bund surrounding padasekharams, Construction of Motorthara Petti mukham.
7	Mitigation of flood in Kaniyankadavu padashekaram in Edathua Gramapanchayath	Pamba	146	Retaining wall construction and restoration of outer bunds., Excavation of clay for outer bund,
8	Restoring outer bund of Vettithuruth padashekaram in Edathua Gramapanchayat	Pamba	105.4	Increasing the height of the bunds to protect against water levels rising up to 1 m above the normal water surface is a proactive approach to safeguarding the padasekharam. This intervention should help mitigate the risk of flooding and ensure better protection for the area.
9	improving infastructural facilities of Kollamparambu Padasekharam in Thakazhy Panchayath	Pamba	150	Raising the bund height to ensure that it can withstand floodwaters up to +1.25 meters above mean sea level (MSL), constructing a walkway or road along its length, construction of 17 kadavu along the bund.,
10	Mitigation of Flood in padasekharams of Kuttanad taluk- Mitigation of flood in Enpathumpadompadasekharam in Pulincunnu panchayath.	Manimala	158	construction of a rubble retaining wall for the outer bund, Construction of Clay bund Formation,
11	Mitigation of flood in Moolapongapra Padashekaram in Champakulam Panchayat.	Manimala	480	Potection of the outer bunds of Padasekharam. Execution of his work is aim to reduce the risk of flooding significantly by constructing protective bunds surrounding the padasekharam. This intervention is designed to enabling protection for padasekharam against floodwater, A walkway using clay extracted from nearby canals.
12	Flood Mitigation works for Kattakkuzhy Padasekharam in Chaganassery Muncipality in Changanassery LA Constituency	Manimala	49	Deepening of Vachal (length=1100m), construction of protection wall of Vachal and main Thodu (Length =256 m) and bund formation (Length=1100m) and a walkway
13	Infrastructural Development works for Kadampadam Cherikkalakam Padasekharam in Vazhappally Panchayath	Manimala	42	Constructing protective bunds surrounding the padasekharam, constructing a walkway along the length of bund, using clay extracted from nearby Streams, Construction of the Retaining wall and Outer bund,
14	Flood Mitigation Programme-Outer bund protection works of Devaswamkari padashekharam in Alappuzha Municipality	Pamba	200	Construction of a new rubble retaining wall on the sides of Ramapuram Thodu on the north side of Padashekharam (Length = 1000 m), Construction of pile & slab retaining wall on the sides of Pampa River on the east side of Padashekharam (Length= 165 m)., Construction of clay bund throughout the length of new rubble retaining wall and pile & slab retaining wall for protection (Length = 1400 m).
15	Providing Irrigation facilities to Manjathanam Puncha in Mallappally Panchayath in Thiruvalla Assembly Constituency	Manimala	64.38	Desiltation of Mallappally Valiyathodu and its vachals, Construction of protection wall of Main thodu and Vachal in DR masonry. Construction of 4 ramps using DR foundation and RR Superstructure,
16	Flood Mitigation Programme and Improving the Infrastructure Facilities of Pathum Padasekharam in Thakazhy Panchayath		105.3	Retaining wall construction and restoration of outer bunds., Construction of Motor thara (Floor), Construction of Motor Shed, Excavation of clay for outer bund, Excavation of clay for outer bund.
17	Mitigation of flood in padashekharams of Kuttanad thaluk- Mitigation of flood in Kattathara kadavu padashekharam in Thakazhy panchayath		165	Retaining wall construction and restoration of outer bunds, Side protection (DR and RR) of padashekharam near areethodu, Clay bund formation
18	Rejuvanation of Ranni Valiyathodu In Ranni Angadi Grama Panchayth Ranni Constituency Pathanamthitta District	Manimala	100	Desilting and Deepening, Side Protection, Beautification and Footpath Construction, Pollutant Removal, Vegetation Management
19	Renovation to group of Padashekharams (Nadayil Kizhakkuvasham, Palliyeckal Mulleymoola, Manackattu Kizhakku) in Pallippad Panchayath of Haripad constituency.	Achenkovil	541	Raising and strengthening the outer bunds with Dry Rubble (DR) and Random Rubble (RR) masonry for padashekharams, forming bund roads using quarry muck, gravel, locally available earth, and geotextiles, construction of ramps for vehicle passage and culverts to enhance both irrigation potential and flood mitigation,

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
20	Improvements to Karippuzha river and its tributaries and providing irrigation facilities to Ullittapuncha Padashekharam in Cheppad and Chettikulangara Panchayaths of Alappuzha district. (Reach 1)	Achenkovil	200	Right and Left Bank Sidebunds and Desilting Works, Right and Left Bank Sidebunds and Chungumadam Thodu Sidebunds, Right and Left Bank Sidebunds and Aavanakkan Thodu Sidebunds, Rectification to Right and Left Bank Sidebunds and Pulinthara Thodu Sidebunds, Sidebund construction and restoration of outer bunds., Excavation of clay for outer bund, Desiltation of Thodu
21	Improvements to Karippuzha river and its tributaries and providing irrigation facilities to Ullittapuncha Padashekharam in Cheppad and Chettikulangara Panchayaths of Alappuzha district. (Reach 2)	Achenkovil	200	
22	Improvements to Karippuzha river and its tributaries and providing irrigation facilities to Ullittapuncha Padashekharam in Pathiyoor and Chettikulangara Panchayaths of Alappuzha district. (Reach 3)	Achenkovil	200	
23	Improvements to Karippuzha river and its tributaries and providing irrigation facilities to Ullittapuncha Padashekharam in Pathiyoor Panchayaths of Alappuzha district. (Reach 4)	Achenkovil	200	
24	Desilting the Areethodu from Thottadi to Vattadi in Thalavady and Edathua panchayath	Pamba	83.7	To regain the natural flow of river
25	Desilting -Desilting of Attukadavu & Rationkada thodu in Champakulam Panchayath	Pamba	10.42	To regain the natural flow of river
26	Desilting of Manathrakkad Meppuram thodu in Nedumudy panchayath	Pamba	45.69	To regain the natural flow of river
27	Desilting the Areethodu in Thalavady Panchayath-	Pamba	85.13	To regain the natural flow of river
28	Desilting the branch thodus of Areethodu in Thalavady and Edathua Panchayath	Pamba	20.76	To regain the natural flow of river
29	Mitigation of flood damages Desilting and cleaning of Karipozhi in Mararikkulam south Panchayath.	Pamba	5.6	To regain the natural flow of river
30	Repair works of vachal near Parakuzhy in Thayyil Kayal Padashekharam in Alappuzha municipality	Pamba	6.3	Repair works in Padashekharam
31	Mitigation of flood damages, desilting and cleaning of Theeyasery Pozhi and branch thodu in Aryad Panchayath and Mararikkulam South Panchayath.	Pamba	28.4	Desilting and Cleaning of streams
32	Improvement works to Edavazhikal Padashekharam in Alappuzha Municipality	Pamba	35	Repair works in Padashekharam
33	Improvements to Kattakkuzhy Padasekharam-Infrastructural Development works for Kattakkuzhy Padasekharam in Chaganassery Muncipality	Manimala	49	Repair works in Padashekharam
34	De-Silting of Feeder Canals of National Waterways- De-silting of Ambalappuzha Canal in Ambalapuzha South Grama Panchayath of Ambalapuzha L.A. Constituency.Reach-1	Pamba	64.2	Desiltation
35	Improvements of Feeder canal (National water way 3) from Vysyam bhagom bridge to Thakazhy bridge in Ambalappuzha south Panchayath in Ambalappuzha L.A.C - Poleppadam Pacha Feeder canal	Pamba	75	Repair and maintenance
36	Improvements of Feeder canal(National water way 3)from Karumady vilakkumaram to karumadi bridge in Ambalappuzha south Panchayath in Ambalappuzha L.A.C	Pamba	60	Repair and maintenance
37	Desilting of Feeder canal to National water way 3- Chanthayil thodu from south of St. Marys Chappel in Purakkad Grama panchayath towards Kunnumna in Ambalappuzha L.A.Constituency.	Pamba	52	Desiltation
38	Desilting of Feeder canal to National water way 3 - Naluchira Canal towards Korankuzhy Canal in Purakkad Grama panchayath in Ambalappuzha L.A.Constituency.	Pamba	56	Desiltation
39	Improvements to branch thodu of Ambalappuzha canal near old boat jetty at East Gate of Ambalapuzha temple in Ambalappuzha South Panchayat in Ambalappuzha LAC.	Pamba	10.8	Desiltation
40	Improvements of Feeder canal (National water way 3) - Ambalappuzha Canal connecting Pookaitha river and TS canal-(Reach 2) from near RSS Karyalayam to TS Canal in Ambalappuzha south Panchayath in Ambalappuzha L.A.C	Pamba	96.7	Desiltation
41	Improvements of Feeder canal (National water way 3) - connecting kariyar thodu to Pamba river in Purakkad Panchayath in Kuttanad L.A.C	Pamba	91.66	Desiltation
42	Improvements of Feeder canal (National water way 3) - Ambalappuzha Canal connecting Pookaitha river and TS canal-(Reach 2) from near RSS Karyalayam to TS Canal in Ambalappuzha south Panchayath in Ambalappuzha L.A.C	Pamba	96.7	Desiltation
43	Aranmula Destination Development Project .	Pamba	90	Desiltation
44	Construction of VCB in Tholuparampil padi Thanungattil padi thodu in Kozhencherry Panchayath	Pamba	20	Providing adequate irrigation facilities to the ela.
45	Constructing Aqueduct in place of collapsed Varayannur Aqueduct of Poovathoor East Branch Canal at ch. 1000 m.	Pamba basin	190	Construction of aqueduct for distributing irrigation water to Vellangoor, Thrikkannapuram, Nellickal padasekharams and to provide well recharging in draught season.

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
46	Providing Irrigation Infrastructure facilities to Punnackadu Ela in Aranmula Constituency	Pamba	138	Construction of Tractor slab, farm road,VCB,side protection of thodu, desiltation of thodu etc
47	Renovation of Kuppannur chal in Kulanada Panchayath in Aranmula Constituency	Achankovil	218	Desilting of inlet thodu,outlet thodu, chal and bund fomation around chal, construction of culvert etc
48	Flood Mitigation Programme - Outer bund protection works of Devaswamkari padashekharam in Alappuzha Municipality	Pamba	200	Rectification work

HEAVY TOUCH - PROJECTS

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
1	TSM - Pampa - Proposal for improving the efficiency of the existing Sewage Treatment Plant (STP) at Cheriyanavattom, Pampa	Pamba	83.65	Infrastructure Development
2	Construction of a bridge at Puthukulangara across Varattar in Aranmula and Chengannur Constituencies.	Varattar	465	Infrastructure Development
3	Construction of a bridge at Trikkayil Kadavu across Varattar in Thiruvalla and Chengannur Constituencies	Varattar	425	Infrastructure Development
4	Rejuvenation of Varattar - Construction of bridge at Anayar across Varattar in Thiruvalla and Chengannur Constituencies	Varattar	526	Infrastructure Development
5	Protection work to the left and right banks of Pamba River in Veeyapuram panchayath in Kuttanad LAC-Reach I	Pamba	250	Restoration of embankment
6	Protection work to the Left and right banks of the Pamba River Upstream of the Leading Channel from downstream of Veeyapuram bridge to Prayatteri Padasekharam in Veeyapuram Panchayath in Kuttand LAC-Reach II	Pamba	250	Restoration of embankment
7	Protection work to the left and right banks of Pamba River and Leading Channel from Veeyapuram to Kurichikkal towards Thottapally Pozhi passing through Veeyapuram,Cheruthana and karuvatta panchayaths	Pamba	3330	Restoration of embankment
8	Protection work to the Left and Right Banks of Pamba river (Leading Channel to the Thottappally Spillway) from Kurichikkal to Thottappally Spillway and downstream to the Pozhy mouth in Purakkad Gramapanchayath in Ambalappuzha LAC	Pamba	3700	Restoration of embankment
9	Desilting & Side Stabilization Work-Deepening, formation of bund and stabilization by using Geotextile in Achenkovil river from Thuruthel bridge to Mundattinkara thodu of Veeyapuram panchayath in Kuttanad LAC	Achenkovil	600	Desiltation and Side protection work
10	Desilting & Side Stabilization Work- Deepening, formation of bund and stabilization by using Geotextile in Mangotta - Pamba river from Forest depot to Pachapally in Veeyapuram panchayath and Edathua panchayth in Kuttanad LAC	Pamba	500	Desiltation and Side protection work
11	Desilting & Side Stabilization work-Deepening ,formation of bund and stabilization using Geotextile and granite stone in Pamba river from Melpadom to D/S of Veeyapuram bridge in Veeyapuram panchayath of Kuttanad LAC.	Pamba	1600	Desiltation and Side protection work
12	Desilting & Side Stabilization work-Deepening ,formation of bund in Achenkovil river using Geotextile from kuthukuzhy to mundattinkarathodu at chettykulangara panchayath and pallippad panchayath of kayamkulam and harippad lac	Pamba	900	Desiltation and Side protection work
13	Protection Work-Construction of Public kadavu and Protecting left bank of AchenKovil river in Thazhakkara panchayth in Mavelikkara constituency	Achenkovil	300	Desiltation and Side protection work
14	Improvements In Waterways And Flood Protecting Works Related With Rejuvenation Of Kuttamperoor River-Phase - II	Kuttamperoor	1170	Flood mitigation work
15	Thottappally Spillway Shutter Maintenance for Flood Management in Kuttanad Region	Pamba		Maintenance Work
16	Increasing carrying capacity of the Thottapally leading channel	Pamba		Maintenance Work
17	Construction of flood regulators at Karumadi, Thakazhy, Cheruthana, and Kuthiyathodu	Pamba		Flood mitigation work
18	Rejuvenation of network of water bodies from Narivapuram to Kannamaly connecting Thalavady river to Mangotta Pampa river in Edathua Panchayath of Kuttanad LAC	Pamba	775	Flood mitigation work
19	Rejuvenation of tributary of Pamba river from Nakkada to the confluence point of Kuttamperoor River in Budhanur and Pandanad Panchayaths of Chengannur LAC	Pamba	300	Flood mitigation work
20	Rejuvenation of network of water bodies of Pamba river from Nedumudy bridge to Kidangara bridge in Kuttanadu LAC	Pamba	500	Flood mitigation work

Sl No.	Name of Work	Name of River Basin (Pamba, Achankovil, Manimala, Kuttanad Region and its Tributaries)	AS Amount (in Lakhs)	Objective of the work
21	Restoration of Ecosystems - Rejuvenation of Karlyar and its tributaries connecting Achenkovil river in Harippad Municipality of Harippad LAC	Pamba	490	Flood mitigation work
22	Rejuvenation of Nadubhagam thodu and its major tributories from Nadubhagam to Ponga bhagam in Nedumudy Panchayath of Kuttanadu LAC	Pamba	450	Flood mitigation work
23	Rejuvenation of network of water bodies from Thuruthintemoole pady to Pally thodu connecting Thalavady river in Edathua Panchayath of Kuttanad LAC	Pamba	650	Flood mitigation work
24	Rejuvenation of Puthanar in Chenithala – Thriprumthura Panchayath of Chengannur LAC	Pamba	670	Flood mitigation work
25	Rejuvenation of tributaries of Leading channel of Pamba to Pamba River in Cheruthana Panchayath of Harippad LAC	Pamba	280	Flood mitigation work
26	Rejuvenation of Chithirappally thodu and its major tributaries in Kuttanadu LAC	Pamba	475	Flood mitigation work
27	Removal of deposited silt and stablisation of the river banks at Punchappidaram bhagam, Thuruthel chira bhagam in Manimala River in Veliyanadu panchayath of Kuttanadu LAC	Pamba	75	Flood mitigation work
28	Rejuvenation of network of water bodies connecting TS canal and Pamba river in Amabalappuzha and Kuttanad LAC	Pamba	210	Flood mitigation work
29	Rejuvenation of tributaries connecting Pamba and Achenkovil rivers in Cheruthana Panchayath of Harippad LAC	Pamba	160	Flood mitigation work
30	Rejuvenation of Chekkidikkad tributary of Pamba river in Thakazhy Panchayath of Kuttanad LAC	Pamba	90	Flood mitigation work
31	Reclamation of Kakkathuruthu Island in Vembanad Kayal in Ezhupunna Panchayath of Aroor LAC	Pamba	500	Flood mitigation work
32	Deepening, construction of retaining wall and formation of bund using Geo textile in Pampa river from Melpadom to upstream of Perumankkara bridge in veeyapuram panchayath in Kuttanad constituency	Pamba	1600	Flood mitigation work
33	Deepening and formation of bund using Geo Textile in Achenkovil river from Kariyar to Thuruthel bridge of Veeyapuram Grama panchayath in Kuttanad constituency	Pamba	600	Flood mitigation work
34	Deepening and formation of bund using Geo Textile in Mangotta- Pampa River from Forest depot to Pachappally in Veeyapuram panchayath and Edathuva panchayath in Kuttanad constituency	Pamba	500	Flood mitigation work
35	Deepening and formation of bund using Geo Textile from Kuthukuzhi to confluence point of Kariyar at Chettikulangara panchayath and Pallipadpanchayath of Kayamkulam and Harippad	Pamba	900	Flood mitigation work
36	Deepening, construction of retaining wall and formation of bund using Geo textile in Pampa river from Melpadom to upstream of Perumankkara bridge in veeyapuram panchayath in Kuttanad constituency	Pamba	1600	Flood mitigation work
37	Deepening and formation of bund using Geo Textile in Achenkovil river from Kariyar to Thuruthel bridge of Veeyapuram Grama panchayath in Kuttanad constituency	Pamba	600	Flood mitigation work
38	Deepening and formation of bund using Geo Textile in Mangotta- Pampa River from Forest depot to Pachappally in Veeyapuram panchayath and Edathuva panchayath in Kuttanad constituency	Pamba	500	Flood mitigation work
39	Deepening and formation of bund using Geo Textile from Kuthukuzhi to confluence point of Kariyar at Chettikulangara panchayath and Pallipadpanchayath of Kayamkulam and Harippad	Pamba	900	Flood mitigation work
40	Reconstruction of Bridge at Perumankara in Cheruthana Panchayath of Harippad LAC	Pamba	1400	Flood mitigation work
41	Reconstruction of Bridge at Pandy in Cheruthana Panchayath of Harippad LAC	Pamba	1600	Flood mitigation work
42	Reconstruction of Bridge at Irupethettil kadavu in Harippad LAC	Pamba	2000	Flood mitigation work