

Preface

In an era of unprecedented environmental change, understanding our rivers and their ecosystems has never been more critical. This report aims to provide a comprehensive overview of our rivers, highlighting their importance, current health, and the challenges they face. As we explore the various facets of river systems, we aim to equip readers with the knowledge necessary to appreciate and protect these vital waterways.

Throughout the following pages, you will find an in-depth analysis of the principles and practices that support healthy river ecosystems. Our team of experts has meticulously compiled data, case studies, and testimonials to illustrate the significant impact of rivers on both natural environments and human communities. By sharing these insights, we hope to inspire and empower our readers to engage in river conservation efforts.

This report is not merely a collection of statistics and theories; it is a call to action. We urge all stakeholders to recognize the value of our rivers and to take proactive steps to ensure their preservation. Whether you are an environmental professional, a policy maker, or simply someone who cares about our planet, this guide is designed to support you in your efforts to protect our rivers.

We extend our heartfelt gratitude to the numerous contributors who have generously shared their stories and expertise. Their invaluable input has enriched this report, making it a beacon of knowledge and a practical resource for all who read it. It is our hope that this report will serve as a catalyst for positive environmental action, fostering a culture of stewardship that benefits both current and future generations.

As you delve into this overview of our rivers, we invite you to embrace the opportunities and challenges that lie ahead. Together, we can ensure that our rivers continue to thrive and sustain life for generations to come.

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List of Abbreviation

MSL	Mean Sea Level
GIS	Geographic Information Systems
MSI	Multi-Spectral Instrument
SWIR	Short-Wave Infrared
MNDWI	Modified Normalized Difference Water Index
TOA	Top of The Atmosphere
SAR	Synthetic Aperture Radar
DEM	Digital Elevation Models
LULC	Land Use Land Cover
GEE	Google Earth Engine

1. Geomorphology of the Periyar River Basin

The river basin exhibits a diverse range of physiographic features, with elevations varying from 1830 m in the east to sea level in the west. The topography is highly undulating, featuring steep hill ranges, meadows, valleys, and plains. A significant portion of the basin is situated in the hilly terrain of the Western Ghats, with slopes that range from nearly flat to steep. Based on elevation and terrain characteristics, the basin is divided into five physiographic units: lowlands, midlands, foothills, plateaus, and highlands.

The lowlands form a narrow belt along the shoreline, with elevations below 7.6 m above mean sea level (MSL). This area includes broad valleys, submerged lands with swamps and marshes, and sand dunes. The coastal belt hosts several islands, including the large Vypin Island, stretching 27 km, as well as smaller islands such as Mulavukad and Vallarpadam. Vypin is home to Cherai Beach, the longest beach in Kochi, and Munambam, which houses the largest fishing harbour in Kochi, the Munambam Fishing Harbor. The area is also notable for harbour-related industries, including the SPM project of Kochi Refineries and the Puthuvype LNG Terminal. To the east of the lowlands lies the midland, a region with elevations ranging from 7.6 to 76 m above mean sea level (MSL) and characterized by undulating terrain with small hills and valleys. This area generally slopes westward, creating a distinct transition zone. Beyond the midlands are the foothills, where elevations exceed 76 m above MSL and slopes range steeply from 30% to 50%. The plateau region follows, featuring moderately sloping land with gradients below 30% and elevations under 1500 m, marked by deep-cut streams. Further east, the highlands form part of the Western Ghats, distinguished by ridges and high ranges. This area includes elevations exceeding 1500 m, with the highest point being Anamudi, reaching 2700 m in the central basin region.

Figure 1 illustrates the general geomorphological features present in the basin (<https://bhukosh.gsi.gov.in/Bhukosh/Public>). The major geomorphological units include plateau, coastal plain, Pedi plain, denudational structural hill, residual hill, floodplain, marshy area, mudflats, and backwaters.

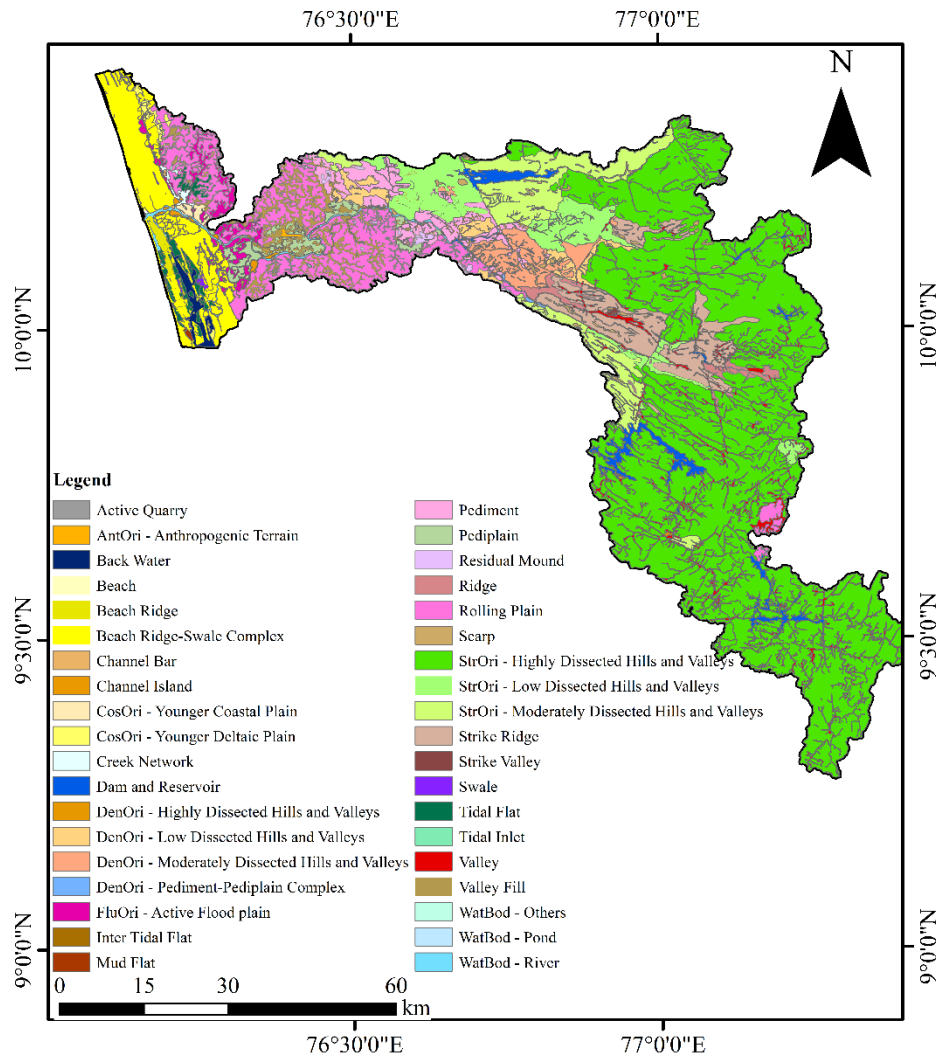


Fig. 1 Geomorphological Map of Periyar River Basin

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2. River Island

2.1 Introduction

River island mapping plays a crucial role in fluvial geomorphology by enhancing our understanding of the formation, evolution, and dynamics of islands within river systems. These islands are shaped by processes such as sediment deposition, erosion, and channel bifurcation, serving as indicators of river behavior. The mapping process uses advanced tools like Geographic Information Systems (GIS), remote sensing, and hydrological modeling to identify and document these features. By combining remote sensing, GIS, field surveys, and soil analyses, researchers can track land loss, assess erosion levels, and study the sedimentary nature of the islands (Singh et al., 2011). This information offers valuable insights into sediment transport, biodiversity patterns, and river changes, which are essential for effective river basin management, ecological conservation, and flood mitigation.

The Periyar River basin, located in Kerala, India, exhibits a dynamic geomorphology characterized by rugged highlands, undulating midlands, and a flat coastal plain. The basin is shaped by tectonic influences, intense rainfall, and the interplay of erosional and depositional processes. Sediment supply in the river system is driven by weathering of the Western Ghats, contributing to the formation of features such as floodplains and river islands. These islands, primarily formed by sediment deposition, indicate channel dynamics and sediment transport, reflecting seasonal flow variations and geomorphic processes in the basin.

2.2 River Islands and their Significance

A river island is a vegetated mid-channel bar that emerges during the bank full stage, typically elongated and aligned with the river's flow direction (Brierley, G. J., et al., 2005). These islands are compound structures, comprising smaller geomorphic units, and often extend one or more channel widths in length. Their formation begins around a bar core stabilized by vegetation, which encourages further sediment deposition and contributes to the island's development. River islands are distinguished from smaller bar forms by their larger size, greater stability, and enhanced capacity to store instream sediments. The internal arrangement of smaller geomorphic units within the island provides insights into its formation history, shaped by flood events and the dynamic processes that rework and sustain it over time.

River islands hold significant geomorphological, ecological, and socio-economic roles within river systems. Geomorphologically, they are essential for understanding river dynamics,

sediment transport, and deposition processes. They form because of complex interactions between hydrological conditions, flood events, and channel morphology (Gurnell et al., 2001). These islands are often created around bar cores that become stabilized by vegetation, which then facilitates further sediment deposition and island growth (Ashworth, 1996). Ecologically, river islands provide critical habitats for various plant and animal species, contributing to biodiversity within riverine ecosystems. They support a range of vegetation types that help prevent soil erosion, regulate sedimentation, and provide refuge for wildlife. In addition, river islands often serve as natural flood buffers, absorbing floodwaters and mitigating the impact of floods on surrounding areas (Gurnell et al., 2001). Socio-economically, these islands are valuable for agricultural production, fisheries, and tourism, especially due to their fertile soils and unique landscapes, which attract recreational and ecotourism activities (Singh et al., 2011). Understanding the multifaceted significance of river islands is crucial for effective river basin management and the preservation of ecological and cultural heritage.

2.3 River Island Mapping and Analysis

2.3.1 Data used and Methodology

2.3.1.1 Sentinel-2 MSI with a 10–60 m resolution and 13 spectral bands.

The mapping of river islands in the Periyar River basin was carried out using advanced remote sensing techniques, utilizing Sentinel-2 satellite imagery due to its high spatial resolution and multispectral capabilities. This imagery was particularly effective in delineating land-water boundaries, facilitating the accurate identification and analysis of river islands. Cloud-free satellite imagery from 2024 was selected and processed in ArcMap 10.8 to extract the spatial extent of river islands within the basin (Figure 3). Appropriate band combinations were applied to enhance the precision of island delineation (Table 1). The analysis revealed that most of these islands are concentrated in the downstream section of the Periyar River basin.

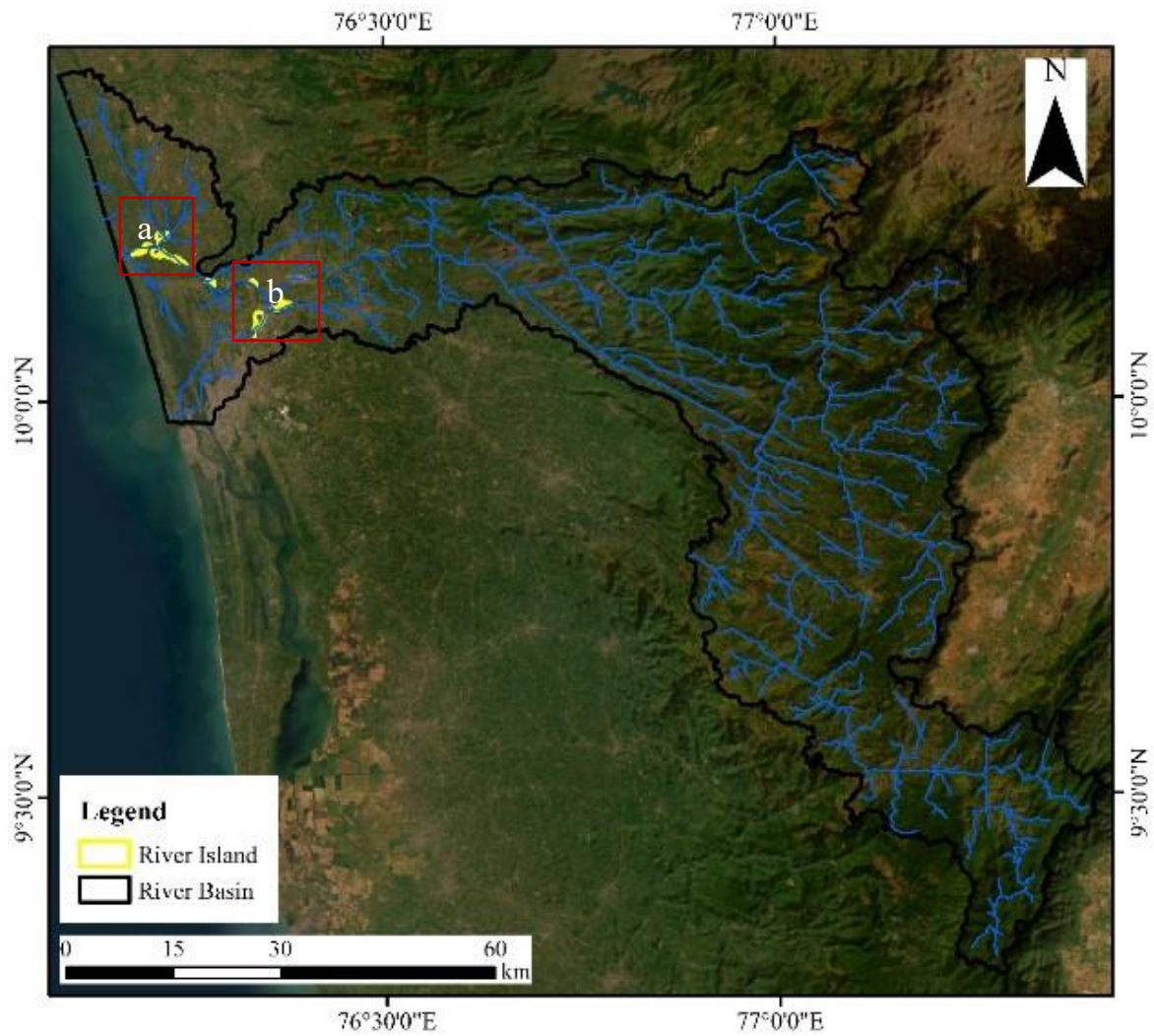


Fig. 2 Map of River Islands in the Periyar River Basin

Table 1: Sentinel-2 Band Combinations for Enhanced Image Interpretation.

Combination	Red (R)	Green (G)	Blue (B)
Natural Colours	B4	B3	B2
False Colour Infrared	B8	B4	B3
False Colour Urban	B12	B11	B4
Land/Water	B8	B11	B4

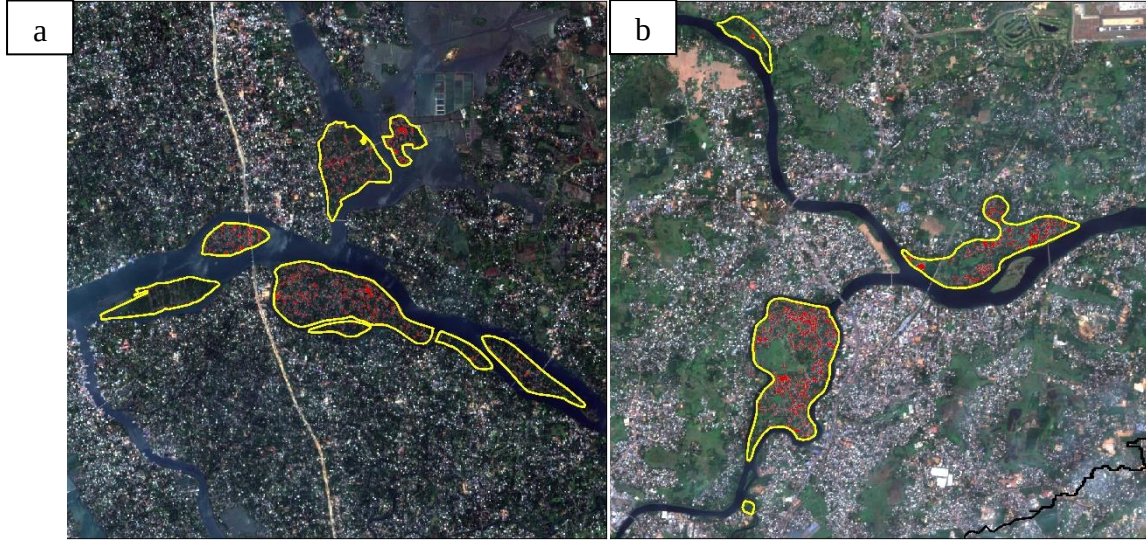


Fig. 3 Sentinel-2 Satellite Images depicting River Islands at (a) Near Munambam, (b) Aluva.

Additionally, the Sentinel-2A Multi-Spectral Instrument (MSI), equipped with 13 spectral bands spanning from visible (VIS) to short-wave infrared (SWIR) wavelengths, offers diverse spatial resolutions that enable the precise delineation of water bodies and land by applying water indices. The VIS and near-infrared (NIR) bands are available at a high resolution of 10 m, while three vegetation red-edge bands, two SWIR bands, and a narrow NIR band are provided at a 20 m resolution. The combination of SWIR and VIS bands makes Sentinel-2A an exceptional tool for mapping water bodies (Du et al., 2016). The water and non-water bodies were extracted using the Modified Normalized Difference Water Index (MNDWI) (Xu, 2006). The MNDWI was calculated using Equation (1), with the 10 m green band upsampled to 20 m.

$$MNDWI_{20m} = \frac{\rho_3^{20m} - \rho_{11}}{\rho_3^{20m} + \rho_{11}} \quad (1)$$

In Equation (1), ρ_{11} represents the top of the atmosphere (TOA) reflectance of band 11 (SWIR) from Sentinel-2A, while ρ_3^{20m} is the TOA reflectance of the 20 m upsampled band 3 from the Sentinel-2A dataset. The value of ρ_3^{20m} is derived as the average of the corresponding 2×2 values. This method effectively delineated river islands from satellite imagery, as illustrated in Figure 4.

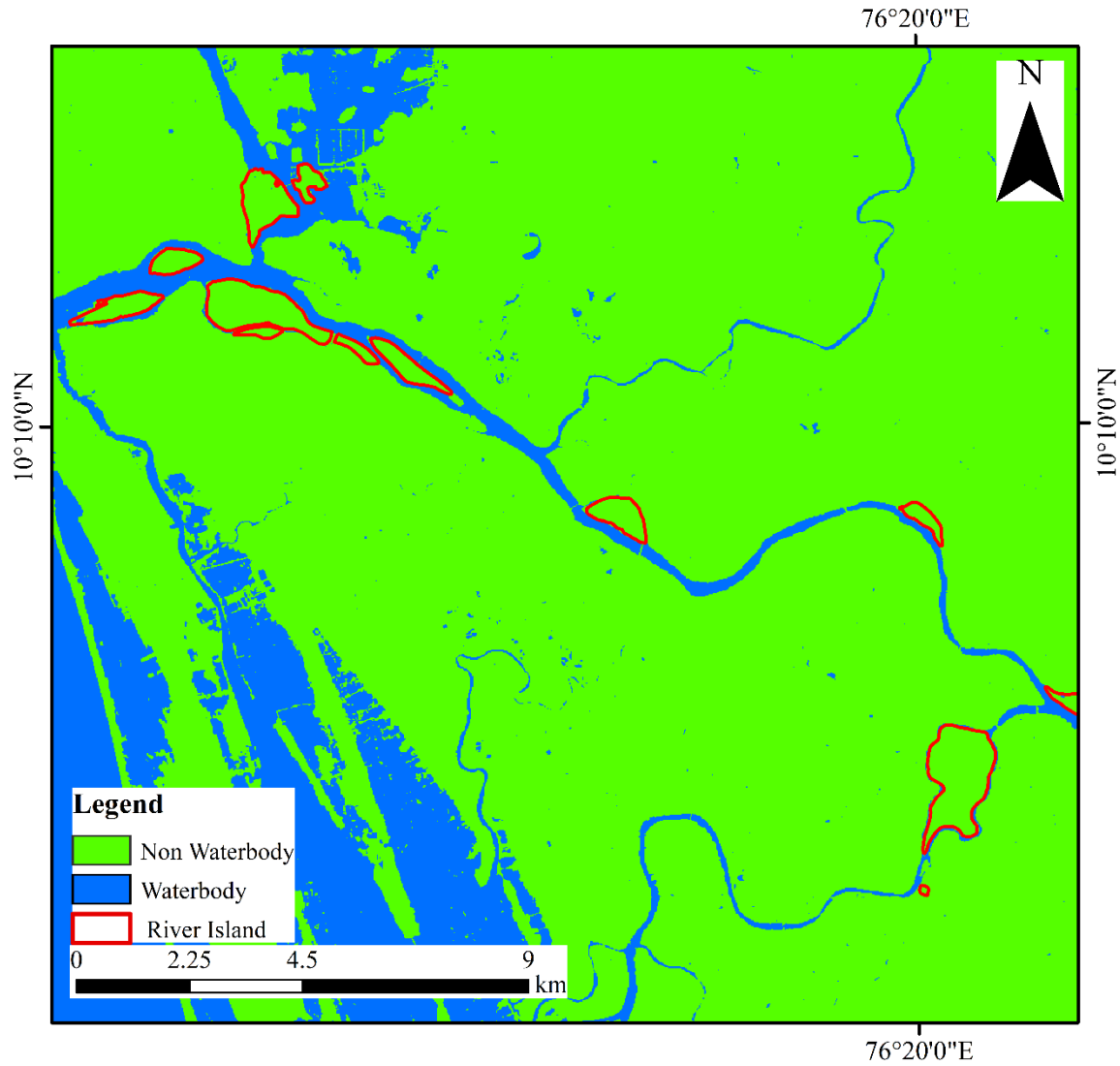


Fig. 4 Modified Normalized Difference Water Index (MNDWI) Map

2.3.1.2 Sentinel-1 SAR imagery of 10 m resolution with dual-polarization (VV, VH) in the C-band

To complement the optical data, Sentinel-1 Synthetic Aperture Radar (SAR) data was integrated into the analysis to further enhance the reliability of the mapping process. SAR data offers the distinct advantage of being unaffected by atmospheric conditions or lighting, thereby ensuring reliable detection of surface features even in the presence of cloud cover or during low-light conditions.

The Sentinel-1 SAR data processing was carried out using the ESA SNAP 10.8 software. The image was first calibrated and then filtered to remove noise using a speckle filtering process. Subsequently, the calibrated and noise-free product was subjected to binarization by applying a specified threshold value, which was determined from the data

histogram. A band math operation was used to isolate all pixels below this threshold (Smith, 1997; Mason et al., 2007). During binarization, the image was classified into a binary representation of water and non-water pixels. Due to the specular reflection characteristics of water in response to microwave signals, water pixels displayed a low backscatter coefficient and appeared significantly darker.

The resulting binary image was then imported into ArcGIS 10.8 for further analysis. Figure 5 depicts River Island Mapping in the Periyar River Basin Using Sentinel-1 SAR Imagery.

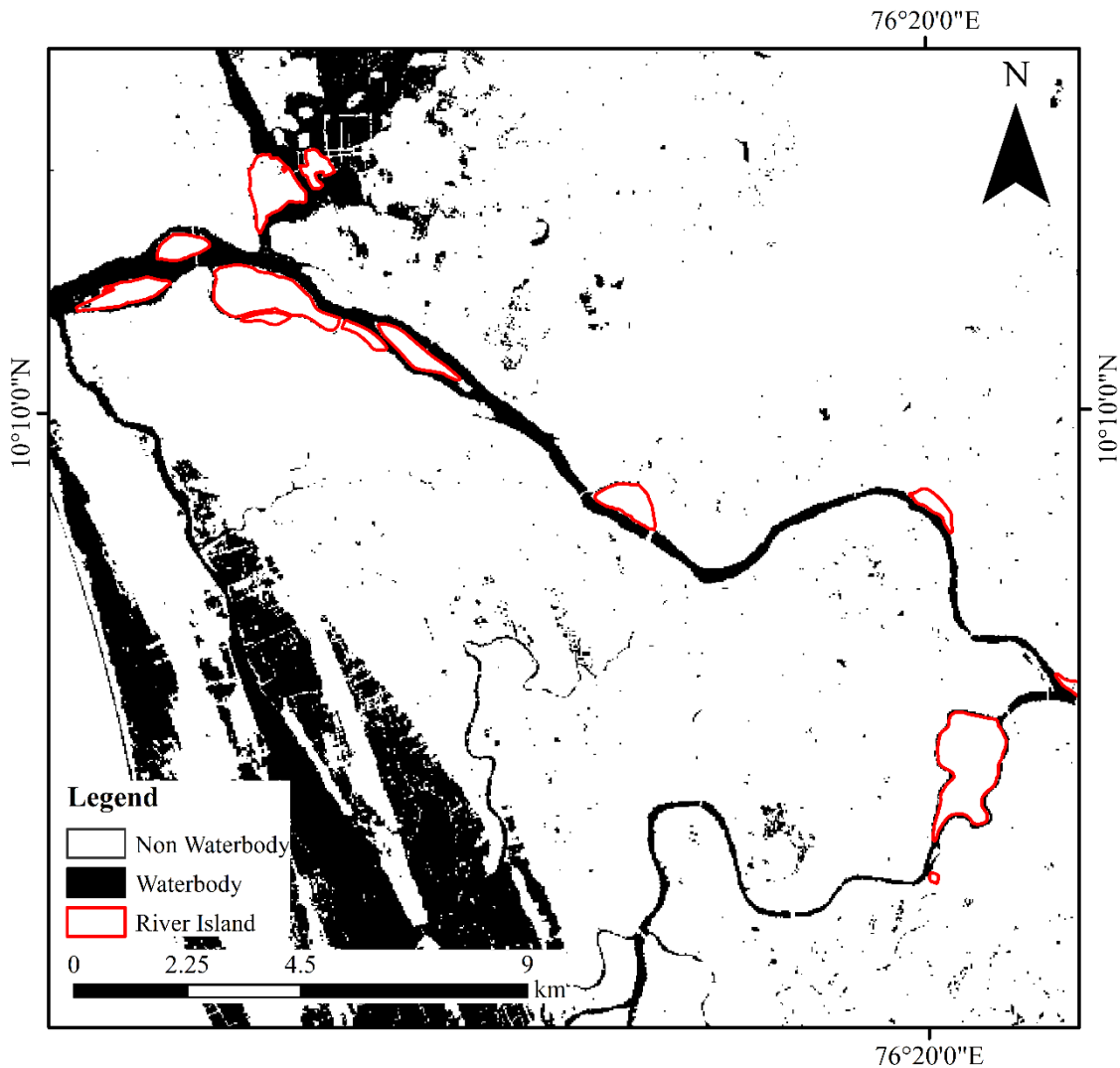


Fig. 5 River Island Mapping in the Periyar River Basin Using Sentinel-1 SAR Imagery

2.4. Geomorphological data from the Bhukosh website

The National Remote Sensing Centre (NRSC), Hyderabad, played a pivotal role in the preparation of geomorphological maps for the region. The original source of data used for this mapping was multi-temporal satellite imagery from Resourcesat-1 LISS III, acquired during three distinct seasons of 2005-06. These data sets correspond to the following seasons: the

Monsoon Season (Kharif) from August to October, the Post-Monsoon (Rabi) from December to March, and the Pre-Monsoon (Zaid) from April to May. The seasonal variations captured through this imagery were essential for identifying and analysing geomorphological features over time. The geomorphological mapping was carried out in collaboration with the Geological Survey of India (GSI) under the National Natural Resources Management System (NNRMS) Standing Committee on Geology Activities. Satellite data, combined with other collateral data sources such as Digital Elevation Models (DEM) and topographic sheets, was utilized to enhance the accuracy and interpretation of geomorphological features. Figure 1 shows the Geomorphological map of the Periyar River Basin. Since geomorphological boundaries are often gradational in nature, these supplementary data sources helped to refine the delineation of landforms, improving the confidence level of the resulting maps. The mapping process was supported by limited field verification to validate the interpretations from the satellite data, ensuring the reliability and accuracy of the geomorphological boundaries identified. The geomorphological data can be downloaded from the Bhukosh website (<https://bhukosh.gsi.gov.in/Bhukosh/Public>), which provides access to geospatial data sets related to landforms and other natural resources.

2.4.1 LULC Analysis of River Islands in the Periyar River Basin.

The total area of the river islands in the study region is approximately 9 square kilometres. According to the Land Use Land Cover (LULC) map generated using Sentinel-2 MSI (10m resolution), the islands show a varied distribution of land cover types (Figure 6).

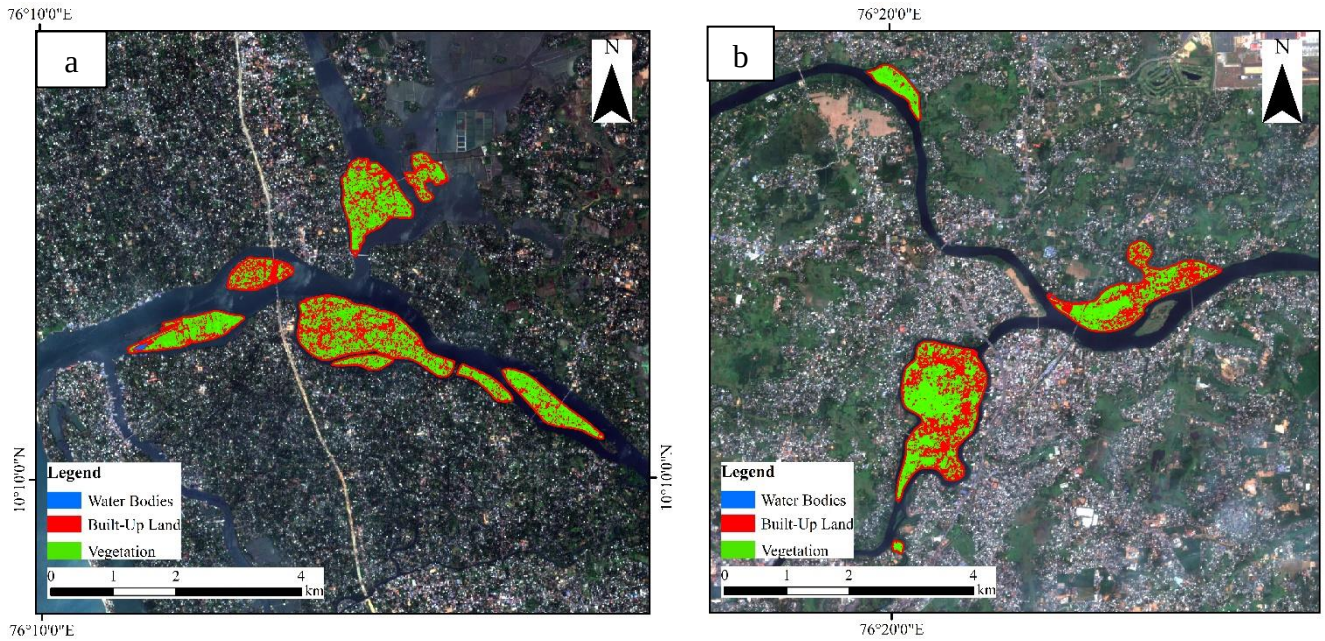


Fig. 6 LULC Map (a) Near Munambam, (b) Aluva

A small portion, 0.48%, is covered by water bodies, indicating the presence of small streams, ponds, or waterlogged areas. Built-up land comprises 34.07% of the total area, reflecting significant human settlements and infrastructure on the islands. Most of the area, 65.45%, is covered by vegetation, highlighting the prevalence of natural or cultivated green cover, which plays a vital role in maintaining the ecological balance of the riverine system.

2.4.2 Analysis of Temporal Changes in the River Islands

The analysis of multispectral LANDSAT imagery from 1973 (Landsat 1 MSS), 1988 (Landsat 5 TM), 2001 (Landsat 5 TM), and 2017 (Landsat 8 OLI/TIRS) indicates no significant temporal changes in the morphology of river islands within the Periyar River. The River Island boundaries, delineated using Sentinel-2 imagery, were overlaid on the Landsat images, confirming the absence of notable morphological changes over time (Figure 7).

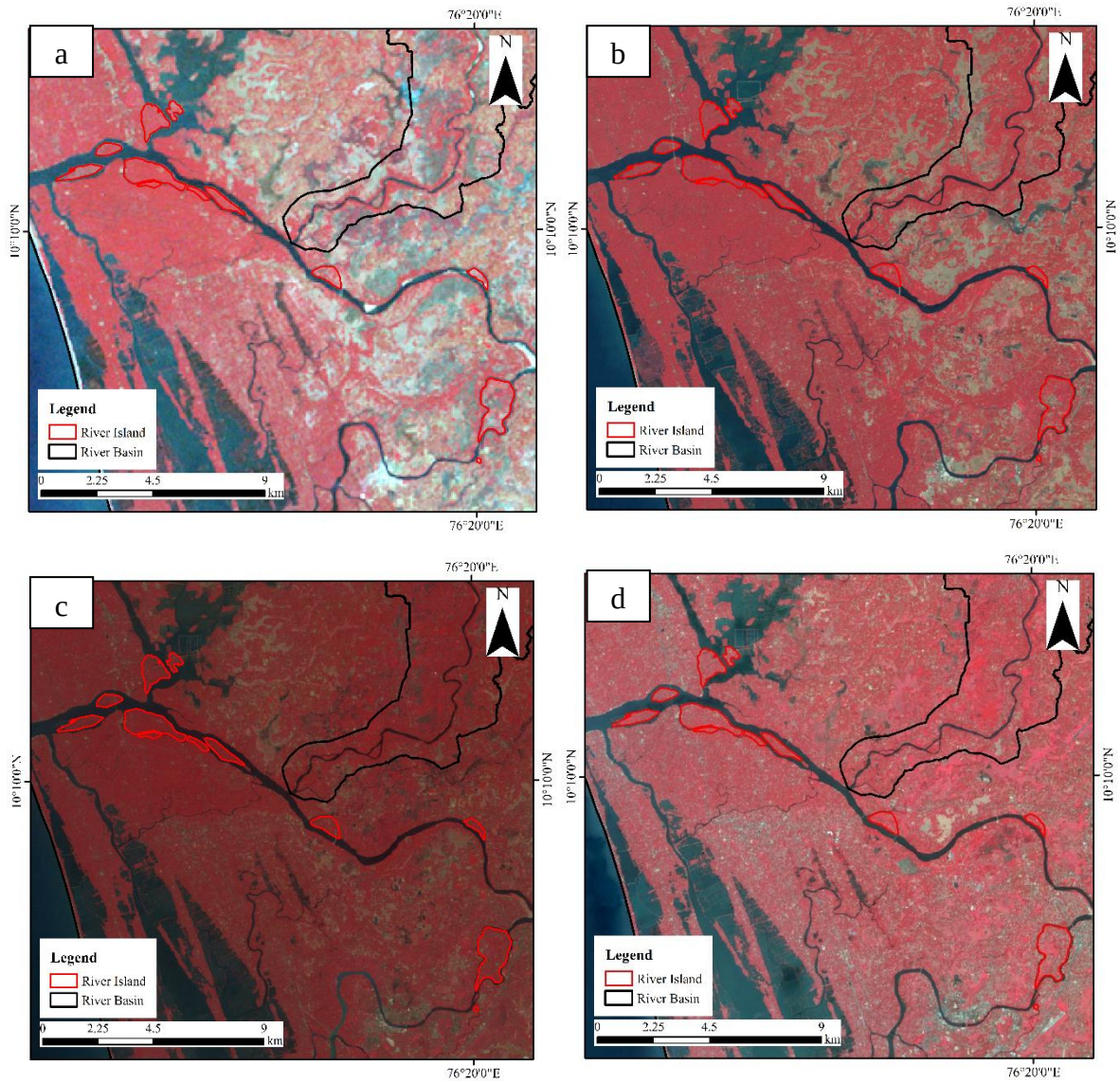


Fig. 7 Landsat Satellite images of (a) 1973 (b) 1988 (c) 2001 (d)2017

However, distinct morphological transformations were noted at the Periyar River mouth and Cochin inlet over the periods (Narayana et al., 2006). At the Periyar River mouth, key changes include the narrowing of the river inlet, the extension of a spit on the northern bank, and modifications in the shape and size of the braided riverbed.

In the Cochin inlet area, significant changes involve the expansion of coastal land and spit formation. Additionally, Vallarpadam Island exhibited significant growth, reflecting ongoing sediment deposition and the dynamic evolution of its landforms.

2.5 Conclusion

River island mapping is a very important for understanding fluvial geomorphology, as it provides insights into sediment dynamics, river behaviour, and ecological balance, while also supporting sustainable river basin management. The study of the Periyar River basin in Kerala emphasizes this importance, utilizing satellite imageries, such as Sentinel-2 MSI and Sentinel-1 SAR (with a resolution of 10 meters), to precisely map and analyse river islands. The mapping shows that most of the islands are located in the downstream section of the basin. The analysis further indicates that these islands are predominantly covered by vegetation and human settlements, highlighting their ecological and socio-economic significance. Temporal studies indicate that the morphology of these islands has remained largely stable over time.

3. Flood Plain Mapping

3.1. Introduction

India, as an agrarian economy, remains highly vulnerable to climatic fluctuations, with its economic growth significantly influenced by extreme weather events (De et al., 2005). Flooding is a natural and recurring event for a river. Floods are the most frequent calamity in the world; they occur frequently, cause significant damage, and are expensive. Flooding is a transient phenomenon that results in total flooding when unexpected water builds up from inland or tidal sources or from quick runoff from rain. Bangladesh is the nation most afflicted by flooding worldwide, followed by India, where flooding accounts for one-fifth of all fatalities worldwide. Twenty-three states in the country are vulnerable to flooding, and around 40 million hectares, or one-eighth of the country's topography, are at risk of flooding. Nearly one-fifth of all deaths globally are attributed to floods in India. Approximately one-eighth of India's topography, or four lakh square kilometers, is prone to flooding (Joy et al. 2019). Floodplains are land areas adjacent to rivers and streams that are subject to recurring inundation.

The process of flooding is a result of heavy or continuous rainfall exceeding the absorptive capacity of soil and the flow capacity of rivers, streams, and coastal areas. This causes a watercourse to overflow its banks onto adjacent lands. During droughts, floodplains slowly release stored water, reducing the impact of dry seasons. The soil in these areas usually consists of clays, silts, sands, and gravels deposited during floods. The frequency of flood inundation depends on a combination of climatic, hydrological, and geographical factors, as well as human interventions. Floods are usually described in terms of their statistical frequency. A "100-year flood" or "100-year floodplain" describes an event or an area subject to a 1% probability of a certain size flood occurring in any given year. Active and Passive Floodplains are two distinct types of floodplains that differ in terms of their flood dynamics and interaction with the river system. Active floodplains are areas that are regularly inundated by floodwaters and actively shaped by the river's flow. These floodplains experience frequent flooding, typically during seasonal events like monsoons or heavy rains. Passive floodplains are areas that were once regularly flooded but have become less affected by river dynamics due to human interventions or natural changes. The primary goal of flood plain mapping is to provide a visual representation of the flood hazard areas, which enables communities to make informed decisions about land use, development, and flood risk management. The availability of synoptic and repetitive coverage through satellite remote sensing makes it an indispensable tool in

disaster management. Active radar sensors operating in the microwave region are particularly valuable for flood mapping, as they function effectively even under cloud cover. This study utilized Sentinel-1A radar datasets to map flood-affected areas in the Periyar River Basin. Images from peak monsoon discharge and maximum rainfall during the 2015–2024 period were analyzed to provide insights into flood dynamics and their impacts on the region.

The floodplain mapping report provides detailed information about the geographic areas at risk of flooding. The reports clearly identify and map areas prone to flooding, often categorized by flood risk levels. Additionally, the reports indicate the frequency of floods (e.g., 100-year flood, 20-year flood) to provide a probabilistic understanding of flood risks. Flood plain mapping reports delve into the hydrology and hydraulics of the area. They analyze the hydrology of the area, including stream flow patterns, drainage systems, and potential for flooding. It also assesses the potential impacts of flooding on human life, property, and infrastructure. They also provide recommendations for emergency preparation and response plans, including evacuation routes, shelters, and communication strategies. Floodplain mapping is crucial for identifying flood-prone areas, supporting sustainable land-use planning and mitigation. Advances in remote sensing, like Synthetic Aperture Radar (SAR) and optical sensors, have revolutionized flood monitoring and management. Optical remote sensing uses low reflectance in infrared bands, while SAR emits electromagnetic waves. Its high penetration capability makes it especially useful for monitoring floods in vegetated or urban areas (Mason et al., 2007). Flood plain mapping reports serve as valuable tools for land use planning, development decisions, emergency management, and overall community resilience in flood-prone areas. Recommendations for floodplain management are included, such as suggested mitigation strategies, land-use guidelines, floodproofing measures, and emergency planning.

3.2 Flood Vulnerability in the Basin Due to Climate and Geography

The impact of floods is severe in densely populated and urbanized regions, where the consequences of such disasters are magnified. Kerala, located in southwestern India with an area of 38,863 km², experiences nearly six months of rainfall annually, predominantly during the monsoon season. Unlike other Indian regions, Kerala exhibits minimal variation in annual rainfall. However, sporadic intense rainfall events, particularly in the Western Ghats, have caused reservoirs to exceed their Full Reservoir Level (FRL), resulting in controlled dam releases. The basin is prone to floods due to a combination of its geographical and climatic conditions along with rapid urbanization. The short monsoon duration of June-September

followed by smaller river stretches to the mouth of Arabian sea results in severe drainage congestion. This cumulative effect of drainage congestion and high precipitation leads to severe floods/flash floods within the basin. The devastating floods of 2018 have resulted in severe loss to human lives and property. The floods of 1924 were the most severe floods in history prior to the great floods of 2018. Additionally, urbanization and changes in land use, such as deforestation and encroachment of floodplains, have exacerbated the situation, reduced water retention and increasing runoff. These factors together make the basin highly susceptible to flooding, causing widespread damage to life, property, and infrastructure.

3.3 Basin Overview and Flooding History

Periyar is the longest river with large discharge potential in the state with a total length of approximately 244km. The Periyar river basin is the state's second-largest river basin, covering an area of 5,245 km². The river basin with stream network is shown in Figure 8. It is crucial for Kerala's water resources, supporting agriculture, industry, and drinking water supply. It consists of 17 dams of which 15 are under the control of KSEB and 2 dams are maintained by the Irrigation Department. The major dams across this river are Mullaperiyar, Idukki, Bhoothathankettu and Edamalayar, Lower Periyar, and Madupetty. The primary regions under built-up facing the flood include the taluks of Aluva, Paravoor, Kodungalloor, Perumbavoor and Kothamangalam under Ernakulam district alongwith Irinjalakuda taluk of Thrissur district. The total number of flood plain areas identified in Periyar basin are 14 in the main stream and 6 in the Right bank tributaries. Out of the 14 flood plain areas 12 come from Marthandavarma bridge to Vaduthala and 2 come from origin to Karimanal bridge. The steep slope of the Western Ghats and the gentle slope of the central area and the shore poses a major threat of floods in this region. The steep slope causes the high velocity of flood water, and the downstream areas were severely affected due to the large quantity of water from the upstream areas.

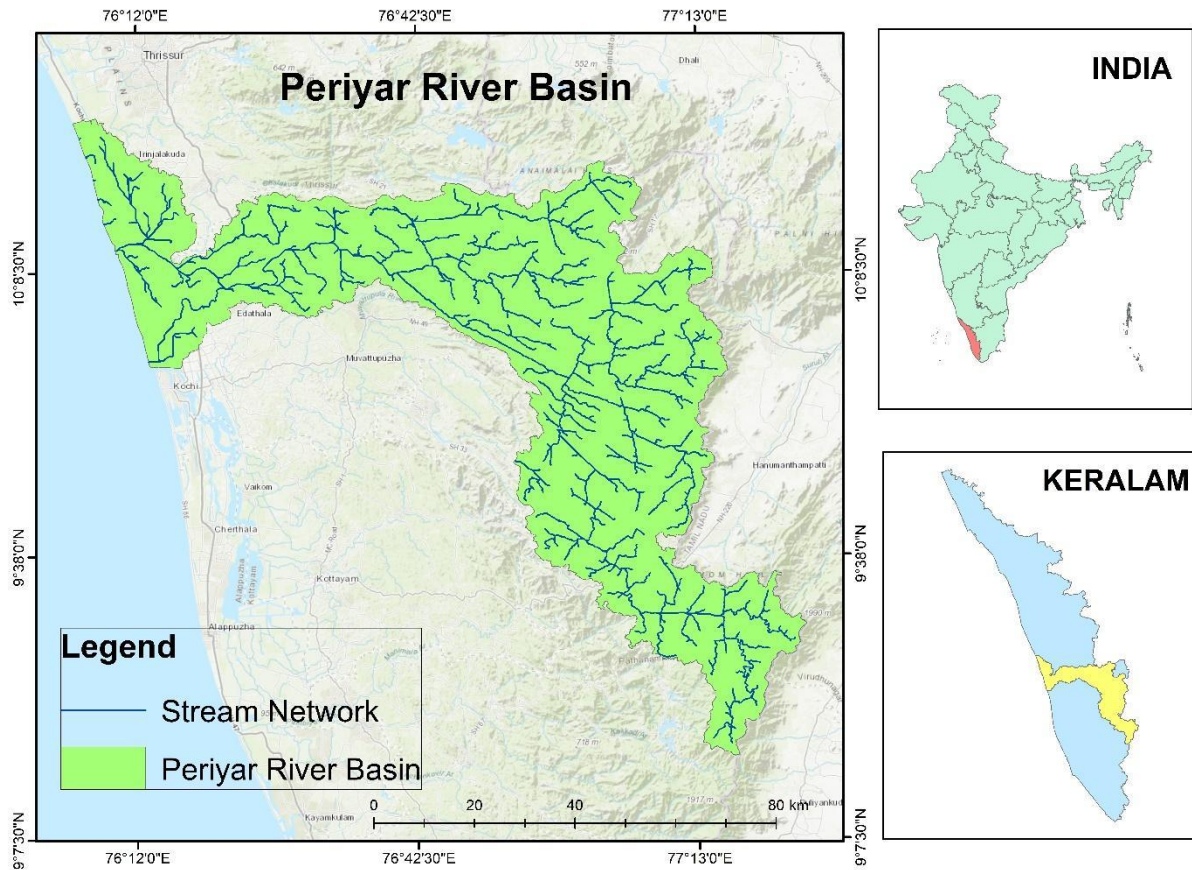


Fig. 8 Boundary of the Periyar River Basin

Flooding in the basin is primarily caused by the combination of heavy rainfall, rapid runoff from the Western Ghats, and the overflow of the Periyar River and its tributaries. The region has experienced severe flooding events in the past, including the floods of 1924, 2018, and 2020. These floods were triggered by exceptionally high rainfall, combined with the overflow of dams and rivers, leading to widespread damage to agriculture, homes, and infrastructure. Recently Kerala experienced a devastating flood during the month of August 2018. The flood caused a loss of approximately 15,800 crore rupees, injured 474 people, and affected 54 lakh people. This resulted in extensive flooding and landslides. It caused the opening of the major dams, including Idukki, Mullaperiyar and Idamalayar due to heavy downpour has led to the inundation of several low-lying areas and overflowing of rivers in the hilly region. All 5 overflow gates of the Idukki Dam were opened, for the first time in 26 years. The major bridges at Upputhara, Vandiperiyar, Chappathu have been submerged. As per CWC's Neeleswaram G&D site (Periyar sub-basin) records, the maximum discharge passed in Periyar river was 8800 cumec on 16 August 2018. The natural factors such as heavy monsoon rains and the basin's topography contribute to these events, human interventions, including unplanned urbanization and deforestation, have aggravated the problem.

3.4 Relevance of flood plain mapping

Floodplain mapping and determining the maximum floodplain extent are crucial components of assessing the condition of a river basin. For the Periyar River Basin, examining floodplain dynamics from 2015 to 2024 offers valuable insights into the basin's hydrological and ecological health. These analyses help to identify areas prone to flooding and provide a comprehensive understanding of how flood characteristics, such as frequency, severity, and extent, have evolved over the past decade. This is particularly important given the changing climatic patterns and extreme weather events that impact the basin. Floodplains are ecologically vital, contributing to groundwater recharge, nutrient cycling, and providing habitats for diverse flora and fauna. By analyzing the maximum floodplain extent, we can assess the health and resilience of these ecosystems. Moreover, understanding the spatial extent of floods enables better flood risk management, aiding policymakers and planners in identifying high-risk zones, evaluating flood protection measures, and developing sustainable disaster preparedness strategies.

3.5 Sources of Data

Floodplain mapping relies on a diverse array of data sources to accurately assess flood hazards. These sources provide crucial information about the terrain, hydrology, and historical flood events within a specific area. The integration of these diverse data sources, combined with advanced techniques, enables the creation of accurate and informative floodplain maps that are essential for effective flood risk management and mitigation. Table 1 shows the data collected and their respective sources.

Table 2: Data collected and source

Sl No.	Data Type	Source
1	Rainfall	IDRB, Kerala WRIS
2	Discharge	IDRB, Kerala WRIS
3	Sentinel Satellite Images	Copernicus Website

3.6 Methodology

Floodplain mapping is a critical tool for identifying areas prone to recurring flooding from nearby rivers, lakes, and streams, providing essential spatial data for sustainable land-use planning, habitat preservation, and flood risk mitigation. Remote sensing technologies, particularly Synthetic Aperture Radar (SAR) and optical sensors, have revolutionized flood monitoring. Optical remote sensing detects water through its low reflectance in infrared and high reflectance in blue and green bands, making it effective for dynamic flood monitoring (Twele et al., 2016). SAR datasets are very beneficial in observing flood conditions, it actively emits electromagnetic waves, which are unaffected by the weather and time of day and can be used to detect flooding in vegetated or urban areas because of its high penetration capability (Mason, et al., 2012).

The Sentinel-1 satellite system, comprising Sentinel-1A and Sentinel-1B, provides extensive high-resolution (10 m) SAR datasets for global flood monitoring (Potin et al., 2015; Torres et al., 2012). SAR imagery features polarizations like VV, HH, VH, and HV, with VV polarization being particularly effective in classifying wetlands and water bodies (Baghdadi et al., 2001; Wang et al., 2011). Thresholding-based methods, widely used for flood detection, classify flood-affected regions by isolating pixels below a specified histogram-derived threshold and applying band math operations to highlight these areas (Smith, 1997; Mason et al., 2007). These methods are efficient and reliable for near real-time flood mapping, aiding in disaster risk reduction and informed management strategies (Amitrano et al., 2018).

3.6.1 Flood Inundation Mapping (GEE)

This study used Google Earth Engine (GEE), which is a powerful cloud-based platform that allows for the analysis and processing of large geospatial datasets, including satellite imagery at no cost. GEE provides access to vast repositories of remote sensing data, such as Sentinel-1, which is particularly useful for flood inundation mapping. Sentinel-1 radar data, with its ability to capture ground surface changes under all weather conditions, is ideal for monitoring flood events, as it can detect variations in water levels and soil moisture.

Flood inundation mapping using Sentinel-1 data within GEE starts by filtering the Sentinel-1 Image Collection based on key parameters such as polarization (e.g., VH) and acquisition settings. Sentinel-1 SAR data was accessed from GEE's public archive after defining the Area of Interest (AOI). The dataset was then refined using specific criteria, including AOI boundaries, resolution, transmitter/receiver polarization, instrument mode, and orbit pass. For this analysis, SAR Ground Range images with VH polarization, acquired in Interferometric

Wide (IW) swath mode from both ascending and descending orbit passes, were selected for the defined AOI. To focus on flood events, data was further filtered for pre-flood and post-flood periods. The pre-processed datasets were mosaicked to create single images in VH polarization for both pre- and post-flood conditions and clipped to the AOI. This approach enabled the generation of detailed flood inundation maps covering the period from 2015 to 2024, supporting the assessment and analysis of flood dynamics over time.

To improve data quality, speckle noise was mitigated using a Refined Lee filter applied to both pre- and post-flood images. The filtered images were then analysed to detect flood-affected areas. Flood masks were created by comparing backscatter values: regions where pre-flood values exceeded -20 dB and post-flood values dropped below -20 dB were marked as flooded. Persistent water bodies were identified as areas with backscatter values consistently below -20 dB in both images. The resulting flood masks, water masks, and filtered images were exported for further analysis in ArcGIS 10.8 to quantify the extent of flooding across the AOI. By utilizing Sentinel-1's high-resolution, weather-independent imaging capabilities, this method successfully generated accurate flood inundation maps for the entire analysis period. Figure 9 shows a part of the flood extend map generated. Figure 10 depicts the flow chart of the methodology followed.

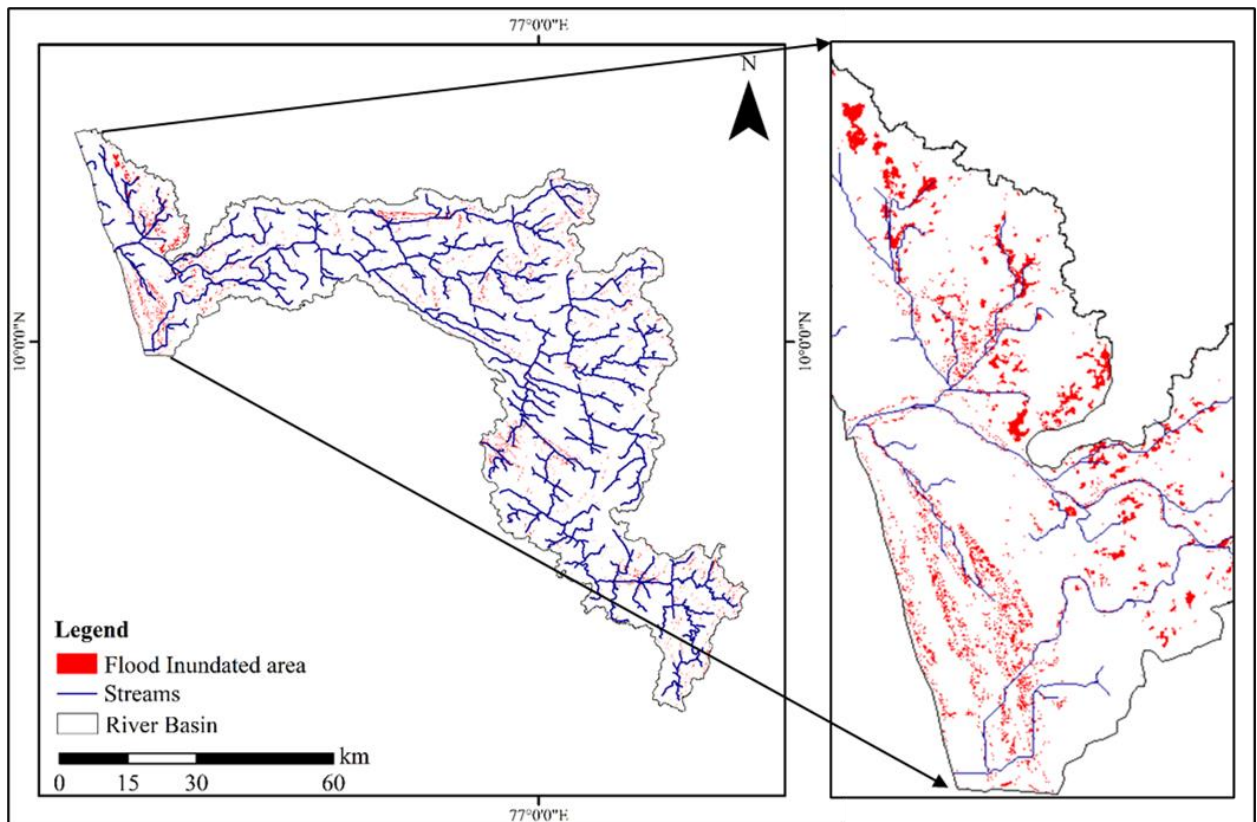


Fig 9 a) Flood Inundation Map of Periyar River Basin b) Flood inundated area at downstream

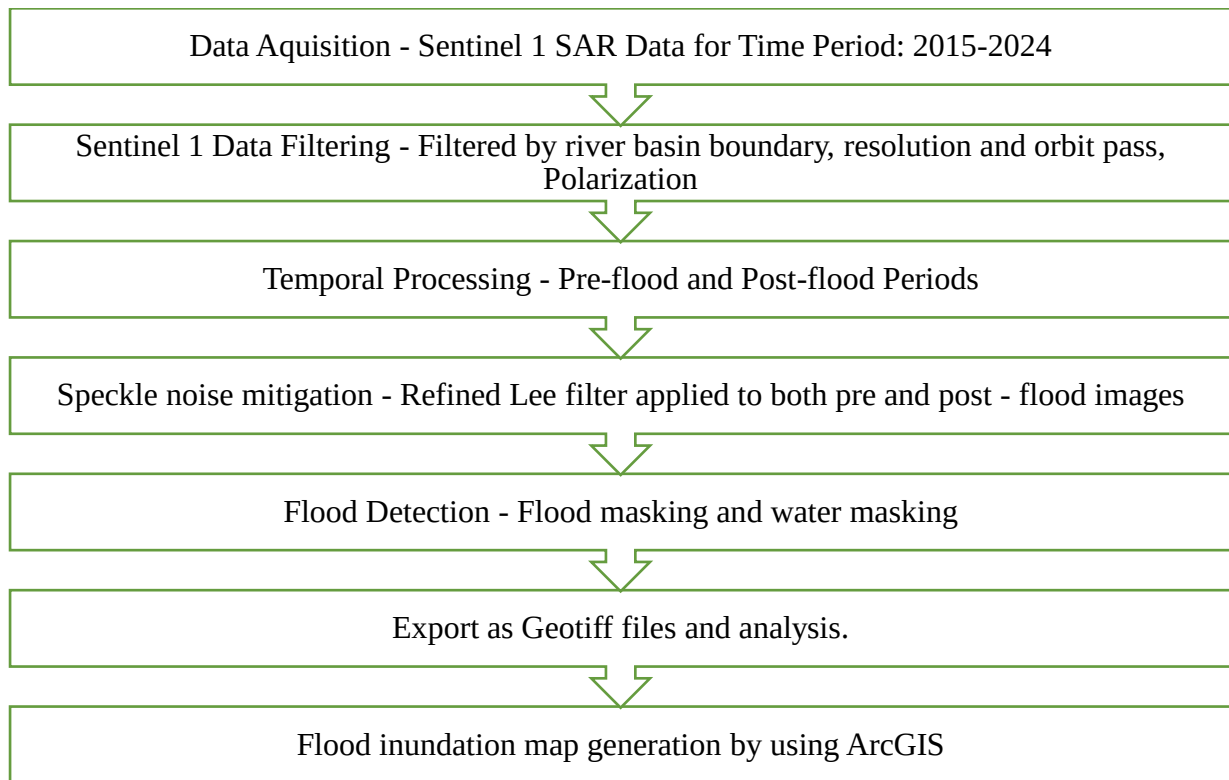


Fig. 10 Flowchart of the methodology used for preparing flood inundation map.

3.6.2 Pre- and Post-Flood Period Selection for Flood Mapping

The mapping of flood inundation, the assessment of its impact, and the accuracy of the results depend on the correct selection of the pre- and post-flood image periods. These periods are crucial for understanding how floods develop over time, as they show how rainfall and river discharge change, which influence when floods start, reach their peak, and eventually decreased. The pre-flood period refers to the time just before a flood event, characterized by increasing rainfall and rising river discharge. The post-flood period, on the other hand, refers to the period following a flood, during which rainfall levels drop, and river discharge returns to normal or subnormal levels as floodwater recedes.

The flood mapping study for Periyar river basin is carried out for the years 2015-2024. The rainfall data for the basin is taken from Kerala WRIS (Kerala Water Resource Information System). The discharge data is obtained from India WRIS (India Water Resource Information System). Table 2 represents the range of dates in which the sentinel images were used for flood map generation using google earth engine.

Table 3: Date range chosen to download sentinel images for flood mapping

Dates chosen to get sentinel images				
Year	Date_RF(max)	Date_Q(max)	Before flood	After flood
2015	18/07/2015 - 30/07/2015	22/07/2015 - 28/07/2015	01/07/2015 - 17/07/2015	18/07/2015 - 25/07/2015
2016	05/07/2016 - 25/07/2016	12/07/2016 - 25/07/2016	30/06/2016 - 08/07/2016	12/07/2016 - 25/07/2016
2017	18/08/2017 - 30/08/2017	19/08/2017 - 30/08/2017	22/07/2017 - 03/08/2017	19/08/2017 - 30/08/2017
2018	15/08/2018 - 17/08/2018	09/08/2018 - 15/08/2018	27/07/2018 - 07/08/2018	09/08/2018 - 17/08/2018
2019	06/08/2019 - 14/08/2019	08/08/2019 - 14/08/2019	27/07/2019 - 05/08/2019	08/08/2019 - 14/08/2019
2020	22/06/2020 - 30/07/2020	07/08/2020 - 09/08/2020	13/07/2020 - 29/07/2020	07/07/2020 - 11/08/2020
2021	27/08/2021 - 17/10/2021	06/10/2021 - 21/10/2021	18/09/2021 - 08/10/2021	09/10/2021 - 22/10/2021
2022	02/08/2022 - 05/08/2022	02/08/2022 - 11/08/2022	15/07/2022 - 28/07/2022	02/08/2022 - 13/08/2022
2023	06/07/2023 - 25/07/2023	05/07/2023 - 08/07/2023	20/06/2023 - 02/07/2023	05/07/2023 - 15/07/2023
2024	16/07/2024 - 30/07/2024	16/07/2024 - 17/07/2024	03/07/2024 - 12/07/2024	16/07/2024 - 30/07/2024

The post-flood dates were chosen when the rainfall as well as discharge were maximum. The gauge stations taken for each district to get the maximum discharge in the year where Arangali, Neeleswaram and Vandiperiyar for the districts Thrissur, Ernakulam and Idukki respectively. The location details of these stations are given in Table 3. The hydrographs for each of these stations with the peak discharges marked are plotted with the discharge data of every year from CWC. Figure 11(a – c) shows the hydrographs for each of the districts in the basin from the year 2015 to 2024. The rainfall trend on yearly basis from 2015 to 2024 was also taken for reference from KWRIS which is shown in Figure 12.

Table 4: Location details of River Discharge Stations

Sl no	District	Name of Station	Latitude	Longitude
1	Idukki	Vandiperiyar	10°17'9.96"N	76°19'19.20"E
2	Ernakulam	Neeleeswaram	10°11'0.96"N	76°29'44.16"E
3	Thrissur	Arangali	9°34'23.88"N	77° 5'26.16"E

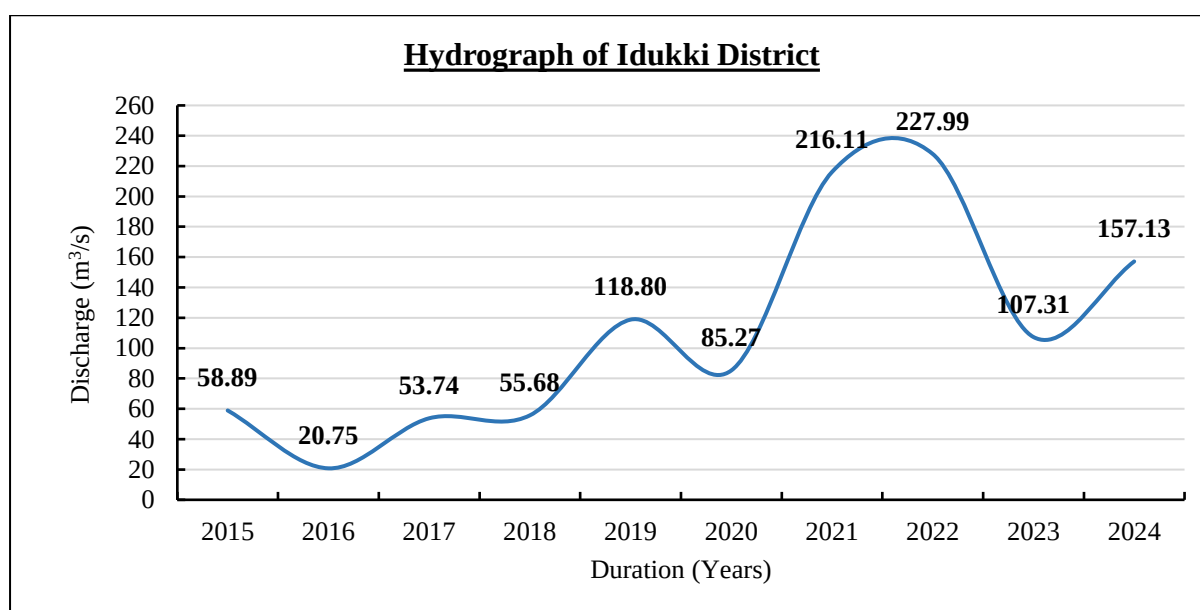


Fig. 11 Hydrograph for Idukki district

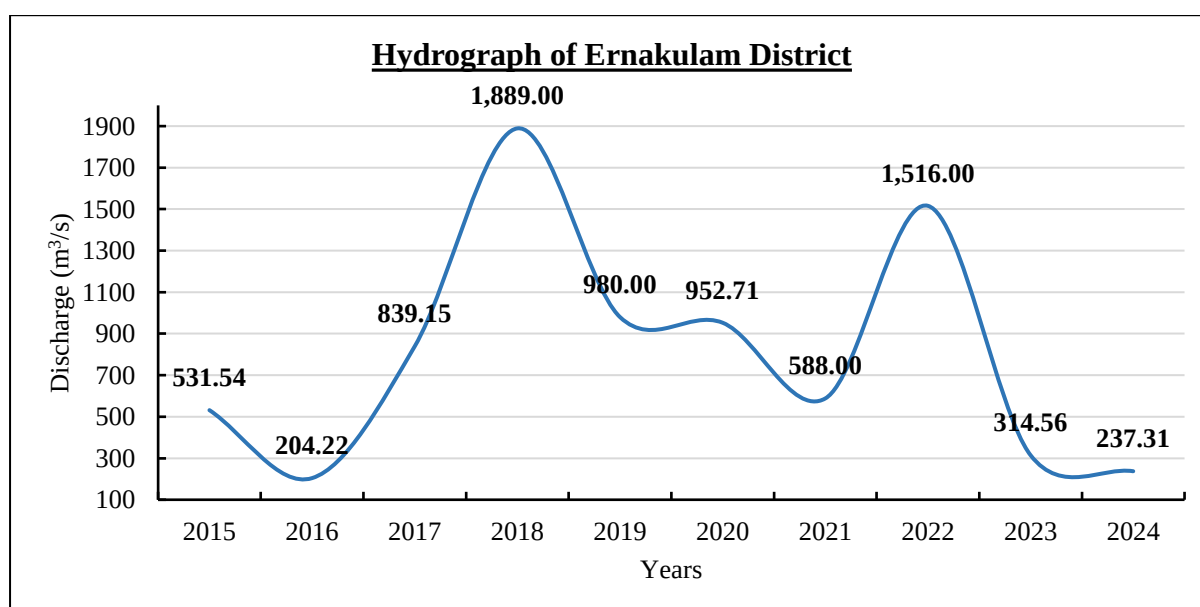


Fig. 12 Hydrograph for Ernakulam district

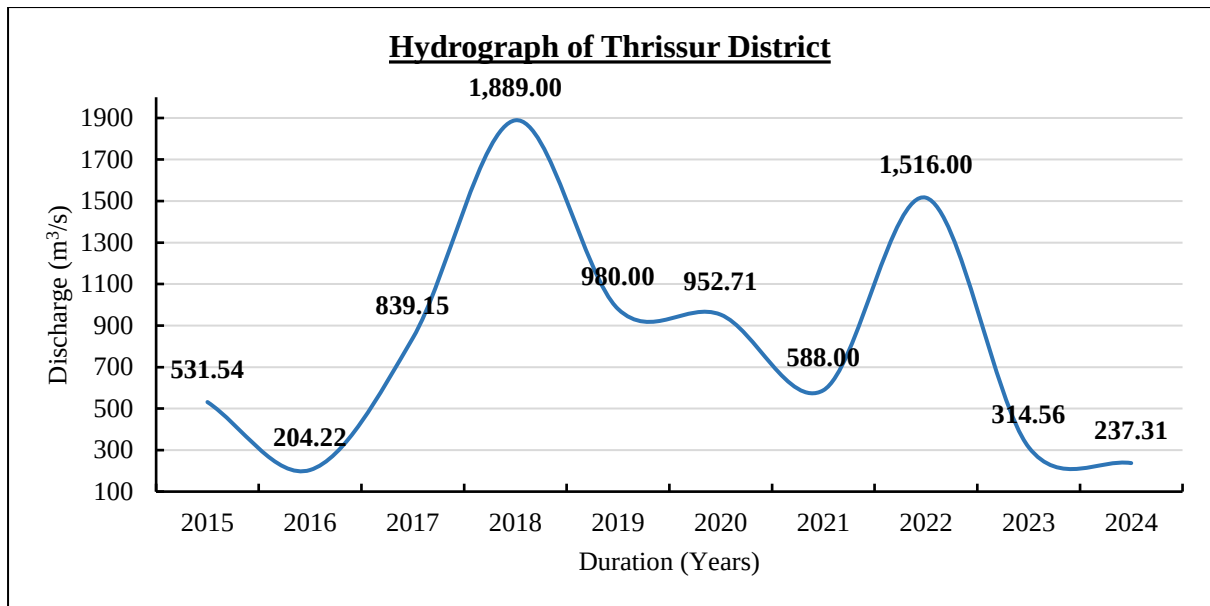


Fig. 13 Hydrograph for Ernakulam district

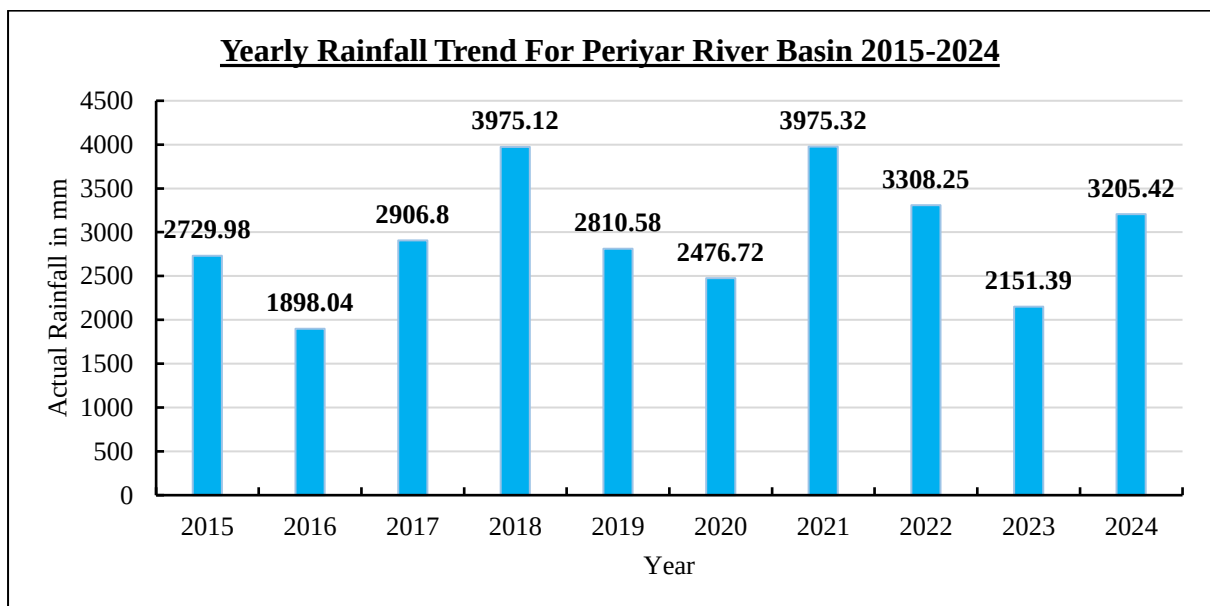


Fig. 14 Yearly Rainfall Trend for Periyar river basin during 2015-2024

3.6.3 Preparation of floodplain extent

The floodplain was effectively mapped using the exported images in ArcGIS 10.8. Flood inundation data from the years 2015 to 2024 were consolidated to create a single integrated product, facilitating the extraction of the floodplain extent. Figure 13 is the maximum flood plain extent marked adjacent to perennial stream in the region. By utilizing these images and overlaying the river shapefile, the extent of flood-affected areas was accurately quantified. The delineation of the floodplain was achieved by analysing temporal changes in the flood

inundation area, incorporating both pre-flood and post-flood conditions. This comprehensive approach ensured precise identification of flood-prone zones and supported informed decision-making for flood management. The flood extent in each subbasins is shown in Figure 14

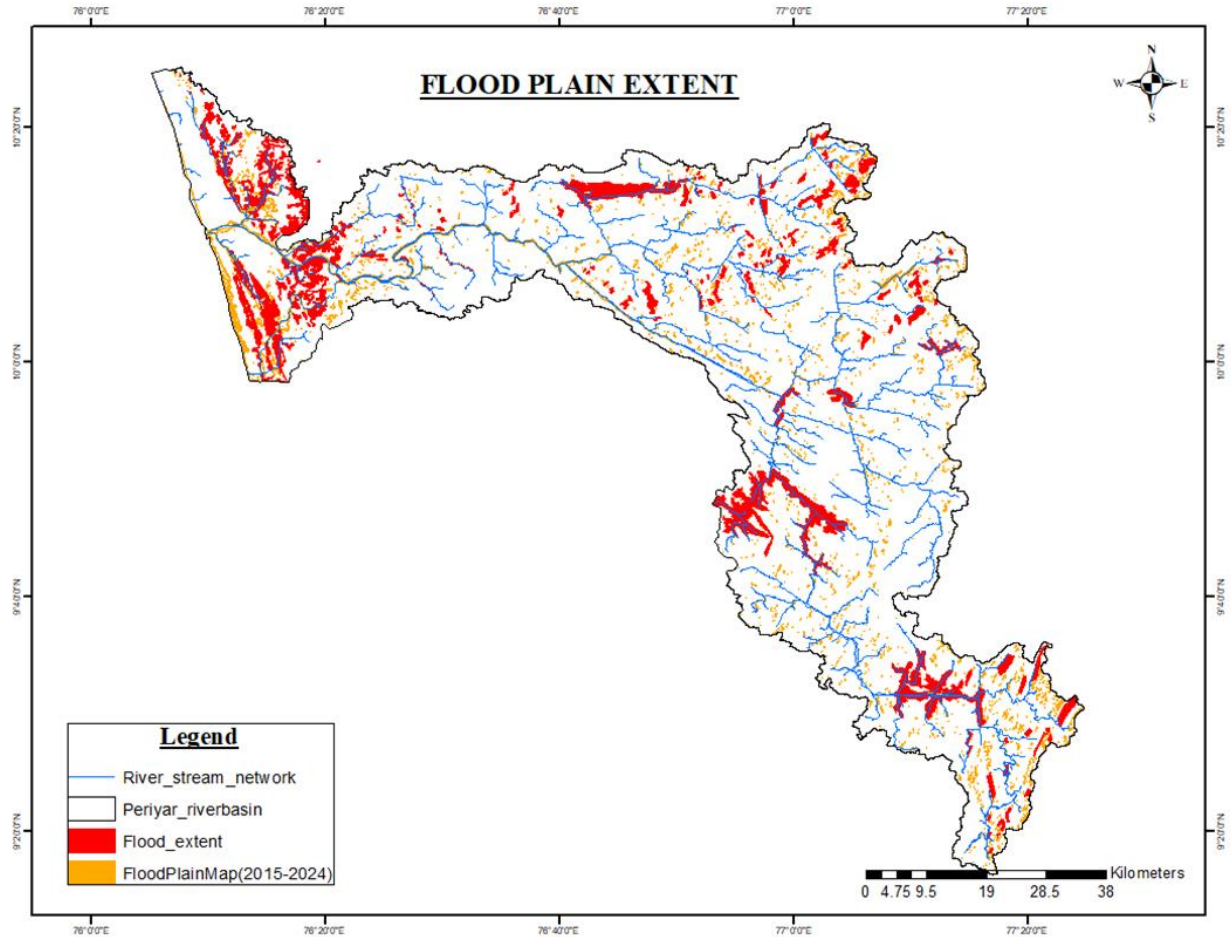


Fig. 15 Maximum Flood plain extent of Periyar River Basin

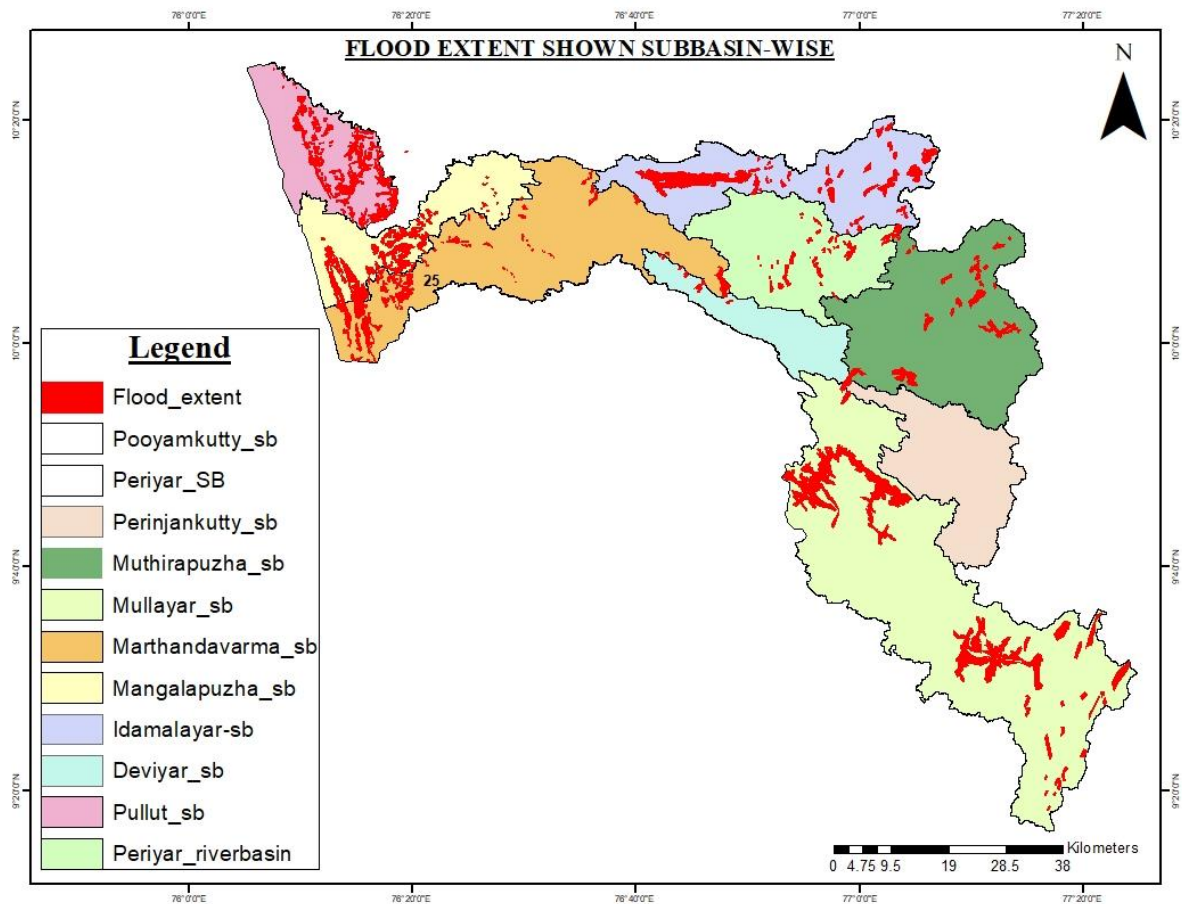


Fig. 16 Flood plain extent in each sub basin

3.6.4 Flood Plain extended within every 10 km stretch

The floodplain extent is effectively represented using a line diagram, which provides a clear and concise visualization of the spatial boundaries of the flood-affected areas. This representation delineates the edges of the floodplain, offering a straightforward method to analyze the extent and variation of the flood-prone regions across the study area. By employing a line diagram, a better understanding is obtained on which all areas the flooding is mostly affected. The Figure 14 shows the flood plain extent with the mainstream stretch being divided into segments of about 10km. The peak extend within each stretch is noted to understand the severity. Here only the flood extend adjacent to the mainstream is considered.

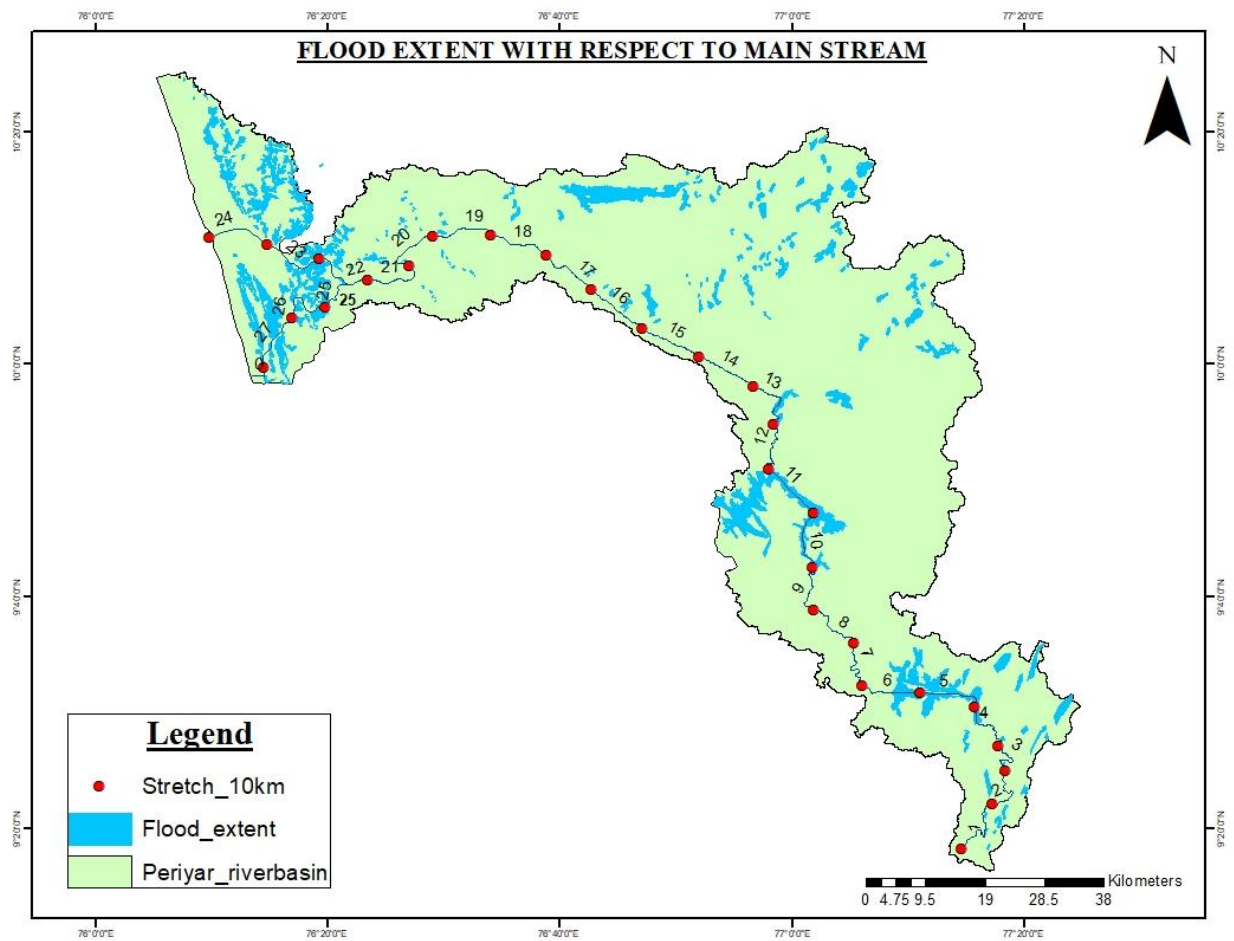


Fig. 16 Flood plain extend marked on segmented mainstream stretch

Figure 15, representing the segmented stretch of every 10 km along the entire reach, is depicted as a line diagram for improved clarity in Figure 16. Figure 16 illustrates the maximum extent of flooding within each 10 km segment on both the right bank and left bank sides of the river. By segmenting the stretch into smaller units, the diagram effectively highlights variations in flood extent, providing valuable insights into the spatial distribution of flood-prone areas along the riverbanks. This approach facilitates better interpretation of the data, enabling targeted flood management and mitigation strategies.

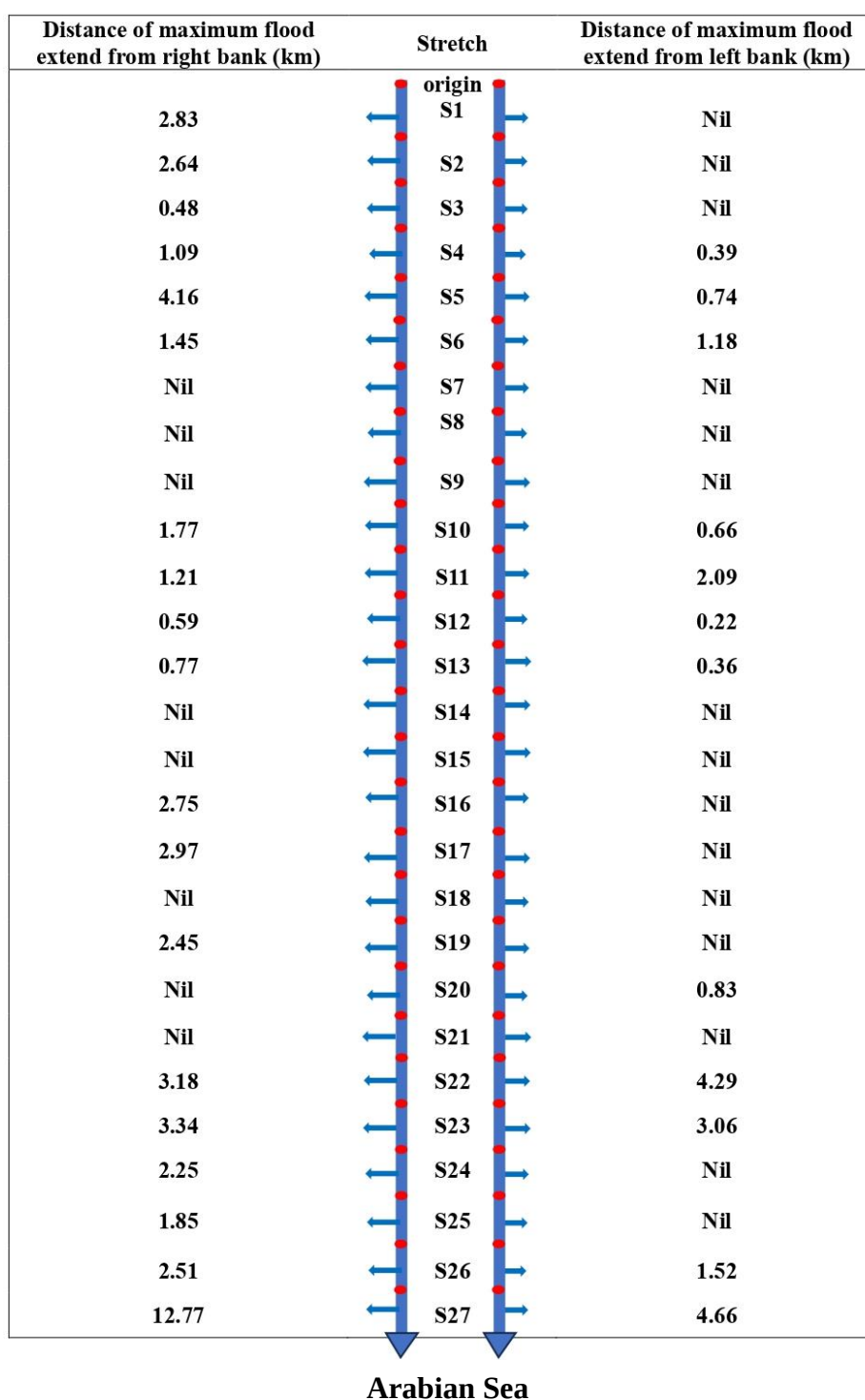


Fig. 17 Line diagram showing maximum extent of flooding within each 10km segment. From stretch 22 onwards, the stream divides into 2, towards downstream end. The flood plain is spread vastly over the downstream regions specifically in stretches 26 and 27 namely, in Pullut, Marthandavarma and Mangalampuzha sub basins.

3.7 Conclusion

Floodplain mapping for the Periyar River basin was carried out using Sentinel-1A satellite imagery from 2015 to 2024, with flood inundation maps generated selectively during key dates of the monsoon period when maximum discharge and rainfall occurred. These maps were then used to delineate the floodplains, with extensive floodplains observed in the lower stretches of the river.

The region has flood inundations spreaded mostly towards west of the basin (Arabian sea). The low-lying areas of Kadamkudi islands (spreaded over Mangalampuzha and Marthandavarma subbasins) are the major portions of flood plain in downstream region. Also, the low lying – kole lands in Pullut subbasin are also main inundation spots. Significant inundations are visible in Northern parts of the basin as well near to the tributaries namely, Idamalayar subbasin. The areas adjacent to Idamalayar Dam have been vastly inundated in this subbasin. Also, there are flood plains in upstream regions of the basin (Mullayar subbasin). Though the upstream regions are in hilly regions, the presence of Mullaperiyar and Idukki dams lead to flood plain extent in the Mullayar subbasin. More care has to be taken in the subbasins across the taluks of Paravur, Kochi, and parts of Mukundapuram, Kodungallur, Chalakudy, Aluva, Kanayannur, and Idukki.

Floodplain mapping is crucial for river conservation as it regulates water flow, supports biodiversity, mitigates flooding, and gives insights into sediment transport and habitat provision. This data aids in developing strategies to protect and restore floodplains, ensuring river system's long-term health and resilience.

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