National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Geomorphological Mapping

Periyar

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IIT PALAKKAD

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National River Conservation Directorate (NRCD)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and Ministry of Jal Shakti providing financial assistance to the State Government for conservation of rivers under the Centrally Sponsored Schemes of 'National River Conservation Plan (NRCP)'. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies.**www.nrcd.nic.in**

Centres for Periyar River Basin Management Studies (cPeriyar)

The Centers for Periyar River Basin Management Studies (cPeriyar) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by IIT Palakkad and NIT Calicut, under the supervision of cGanga at IIT Kanpur, the center serves as a knowledge wing of the National River Conservation Directorate (NRCD). cPeriyar is committed to restoring and conserving the Periyar River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.**www.cPeriyar.org**

Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India. **www.cganga.org**

Acknowledgment

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Preface

In an era of unprecedented environmental change, understanding our rivers - both as ecological systems and dynamic land-shaping forces has never been more critical. This report aims to shed light on the Periyar River Basin, a region of immense hydrological and geomorphological importance, and to highlight the evolving challenges it faces.

Despite its vital role in sustaining water resources in Kerala, a comprehensive understanding of the Periyar Basin's geomorphological characteristics has long remained limited. Fragmented studies have hindered holistic insights into its landform diversity, river islands, floodplains, and river dynamics. This report seeks to bridge that gap by presenting a detailed geomorphological mapping.

We examine the evolution and structure of the Periyar River's landscape, its islands, floodplain extents, and diverse river styles to provide a clearer picture of how the river system has developed over time. Identifying the geomorphic traits of the basin not only reveals the natural history of the river, but also informs current flood risks and future changes in its morphology.

More than just a technical document, this report is a call to action. Whether you are a researcher, policy maker, or a concerned citizen, we invite you to engage with the insights offered here. A deeper understanding of the river's physical characteristics is key to protecting its ecological integrity and the communities it supports.

We extend our heartfelt gratitude to all contributors whose insights and efforts have shaped this work. Their expertise has made this report a valuable resource, and we hope it inspires continued study, stewardship, and responsible development in the Periyar River Basin. As you explore the chapters ahead, we encourage you to reflect on both the opportunities and responsibilities that come with preserving one of Kerala's most critical river systems

Centre for Periyar River Basin
Management and Studies (cPeriyar)
IIT Palakkad & NIT Calicut

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List of Abbreviations

PRB	Periyar River Basin
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
RSF	River Styles Framework

1. Introduction of the Periyar River Basin (PRB)

Periyar is the longest river in Kerala, with large discharge potential with a total length of approximately 244km and is also the state's second-largest river basin, covering an area of 5,245 km². The river originates from the Sivagiri hills of the Western Ghats and flows through the Idukki, Ernakulam, and Thrissur districts of Kerala and joins the Arabian Sea at Cochin. The river serves as a crucial lifeline for Kerala's water resources, supporting agriculture, industry, and drinking water supply. The Periyar river also has a significant role in contributing to the state's economy. PRB has 17 dams, out of which 15 are under the control of Kerala State Electricity Board Limited (KSEB) and 2 dams are maintained by the Kerala Irrigation Department. The major dams in this river are Mullaperiyar, Idukki, Bhoothathankettu and Edamalayar, Lower Periyar, and Madupetty (Room for River 2022). Idukki Dam is one of the major sources of hydroelectric power generation for Kerala. The PRB with stream network is shown in Figure 1.

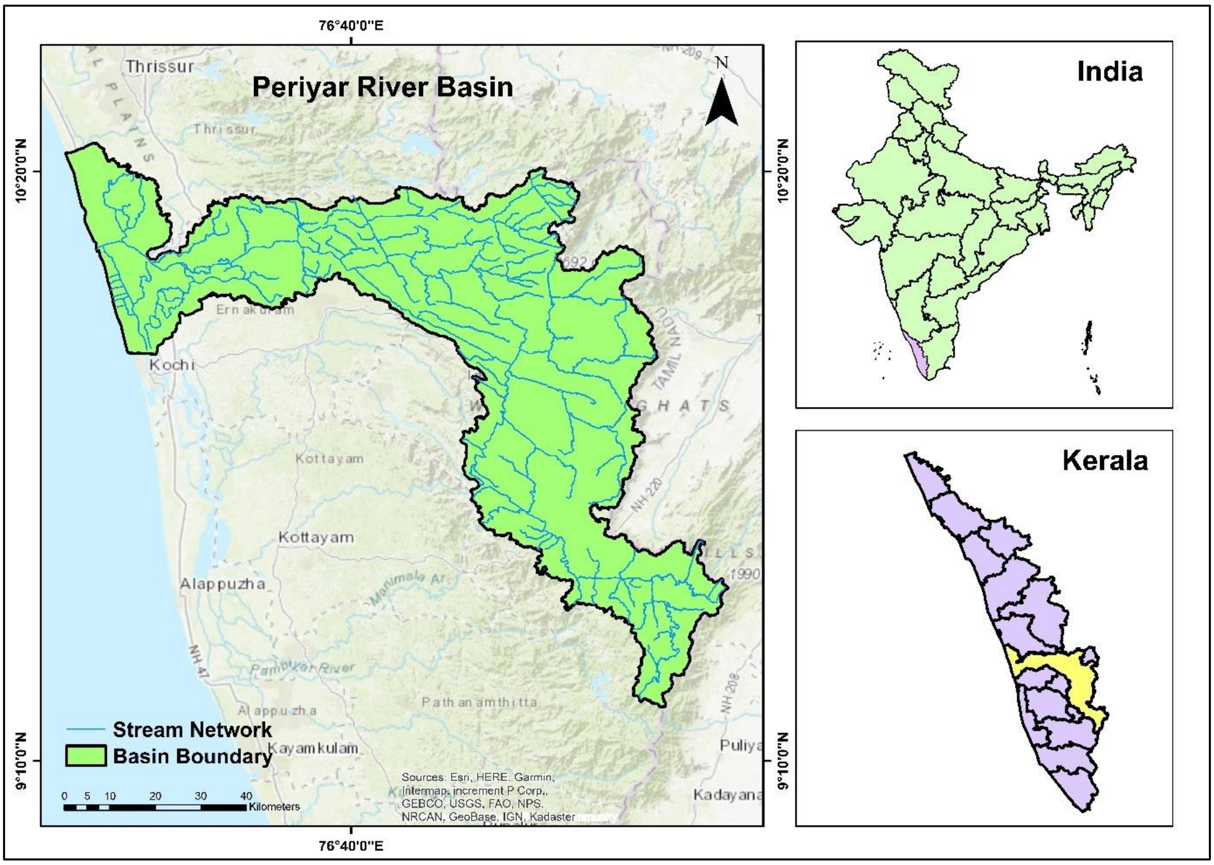

Figure 1: Boundary of the PRB

2. Geomorphological Data from the Bhukosh Website

The National Remote Sensing Centre (NRSC), in collaboration with Geological Survey of India (GSI) mapped geomorphology of India on 1:50,000 scale under the National Geomorphology and Lineament Project (NGLM) using a new classification system developed based on the landform genesis. The multi-temporal satellite imagery from Resourcesat-1 LISS III, acquired during three distinct seasons of 2005-2006 was used for this mapping. The 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 used for identifying and analysing geomorphological features over time. Satellite data, combined with other additional data sources such as Digital Elevation Models (DEM) and topographic sheets, was utilized to enhance the accuracy and interpretation of geomorphological features. Since geomorphological boundaries are often gradational, 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 was downloaded from the Bhukosh website (https://bhukosh.gsi.gov.in/Bhukosh/Public).

2.1 Geomorphology of the PRB

The PRB consists of a wide range of landforms and geological features, with elevations varying from 1830 m in the east to sea level in the west. The topography varies highly, with steep hill ranges, meadows, valleys, and plains. A major portion of the basin lies in the hilly region of the Western Ghats, with slopes that vary from flat to steep. Considering the elevation and type of terrain, the basin is divided into five units: lowlands, midlands, foothills, plateaus, and highlands (Reconnaissance Survey Report Sand Auditing of Periyar River, Ernakulam District). Figure 2 shows the Geomorphological map of the PRB. The lowlands form a thin strip along the shoreline, having elevations within a range of 7m above Mean Sea Level (MSL). This area consists of broad valleys, flooded areas with swamps and marshy lands, and sand dunes. The midland is located to the east of the lowlands, where elevations range from 7 to 76 m above Mean Sea Level (MSL) and is identified by undulating terrain with small hills and valleys sloping westwards, creating a transition zone between the landforms. Beyond the midlands are the foothills, where elevations rise 76 m above MSL, with steep slopes ranging from 30% - 50%. The plateau area has gently sloping land with gradients below 30% and elevations under 1500m. This area also consists of deep-cut streams. Further east, the highlands form part of the Western Ghats, with ridges and high mountain ranges and having altitudes 1500 m above MSL. The highest point is Anamudi which is 2700 meters high and located in the central part of the basin.

The general geomorphological features present in the basin are illustrated in figure 2, from Bhukosh website (https://bhukosh.gsi.gov.in/Bhukosh/Public). The major geomorphological units of the basin include structural and denudational hills, residual hills, pediplains, coastal plains, floodplains, marshy areas, mudflats, and backwaters. Structural and denudational hills are the most dominant features, particularly in the eastern part of the basin, which is characterized by highly dissected valleys. Coastal plains, pediplains, and floodplains are also present in significant proportions.

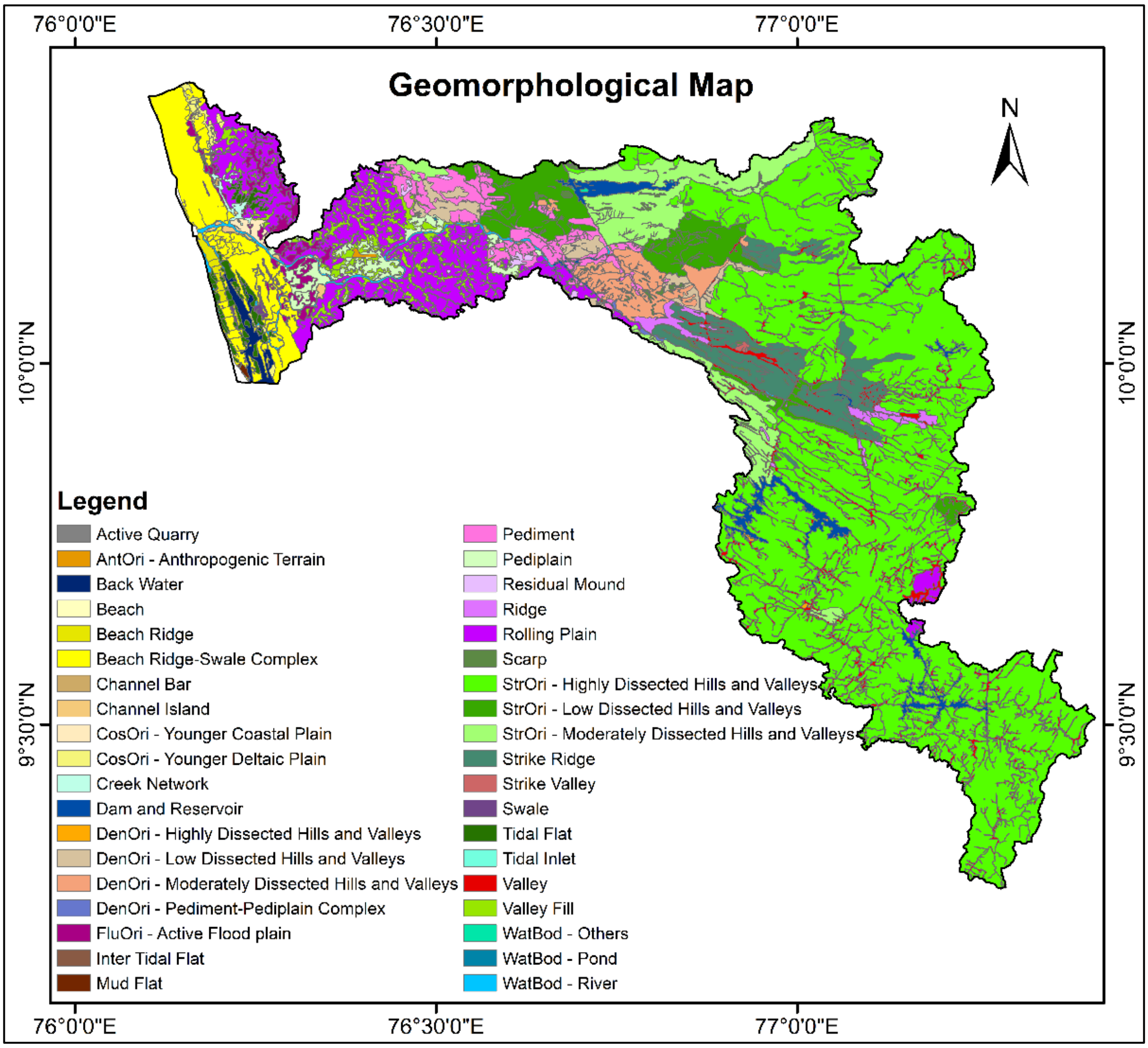

Figure 2: Geomorphological map of the PRB

3. Introduction to River Islands

A river island is a vegetated mid-channel bar that forms during the bankfull stage. The islands are mainly long and follow the flow of rivers (Brierley, G. J., et al., 2005). These islands consist of different parts, like smaller geomorphic units, and they can be very large, sometimes extending across channel widths in length (Figure 3). These islands are often created around bar cores that become stabilized by vegetation, which then facilitates further sediment deposition and island growth (Ashworth, 1996). River islands are more stable, vary in size, from smaller bar forms to larger sizes, and have a better capacity to store in stream sediments. The arrangement of smaller geomorphic units within the island provides information related to its formation, flood events, and the changing process of river over time.

River island mapping plays an important role in river basin management. It explains how islands in river systems are formed by understanding the formation, evolution, and dynamics of the islands within the river systems. The islands are formed by processes such as sediment deposition, erosion, and channel bifurcation, which shows how the river behaves.

Figure 3: Representation of river islands for illustration

Source: Wikipedia

River islands have significant geomorphological, ecological, and socio-economic roles within the river systems. Geomorphologically, they are essential for understanding river flow, sediment transport, and deposition processes. The islands are formed because of complex interactions between hydrological conditions, flood events, and channel morphology (Gurnell et al., 2001). It provides critical habitats for various plants and animal species and contributes to biodiversity within riverine ecosystems. They support a range of vegetation types that help prevent soil erosion and regulate sedimentation. 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.

3.1 Data for River Island Mapping

The mapping of river islands in the PRB was carried out by utilizing Sentinel-2 satellite imagery. It can observe every point of the earth's surface at a high spatio-temporal resolution (spatial resolutions ranging from 10-60m & ~5-day revisit). Also, it has the distinct advantage of being unaffected by atmospheric conditions or lighting, ensuring the detection of surface features even in the presence of cloud cover or during low light conditions. The multi-spectral data of Sentinel-2 satellite image with 13 spectral bands in the visible, near-infrared, and short-wave infrared parts of the spectrum have different resolutions, 10 m in the visible and the near-infrared, 20 m for the red edge and SWIR, and 60 m resolution for atmospheric bands. The imagery is particularly effective in delineating land-water boundaries, and this facilitates the accurate identification and analysis of river islands. Pre-monsoon Cloud-free satellite imagery from 2024 was selected. The data used for river island mapping are listed in Table 1.

Table 1: Data collected and their respective source for river island mapping.

Sl No.	Data type	Source	Last accessed
1	Sentinel 2 MSI	Copernicus Website (https://browser.dataspace.copernicus.eu)	07/05/2024
2	Sentinel 1 SAR	Copernicus Website (https://browser.dataspace.copernicus.eu)	25/08/2024
3	Geomorphological shapefiles	Bhukosh website (https://bhukosh.gsi.gov.in/Bhukosh/Public)	2005-2006
4	Landsat series	USGS EarthExplorer (https://earthexplorer.usgs.gov)	09/02/1973 19/01/1988 11/03/2001 18/01/2017

3.2 Methodology for River Island Mapping in PRB

The adopted methodology involved the use of spatial tools such as Geographic Information Systems (GIS), utilizing high-resolution satellite images to identify features. The Sentinel-1 SAR data of August 2024 was used, and the image 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 (-15), which was determined from the data histogram. The band math operation was used to isolate all pixels below this threshold (Smith, 1997; Mason et al., 2007). Due to the specular reflection characteristics of water in response to microwave signals, water pixels displayed a low backscatter coefficient and appeared significantly darker. In binarization, the image was classified into a binary representation of water and non-water pixels. The resulting binary image was then imported into ArcGIS 10.8 for further analysis. The satellite image was processed in ArcMap 10.8 to extract the spatial extent of river islands within river channels by manual digitization (Figure 5). The methodology of the river island mapping is shown in Figure 4.

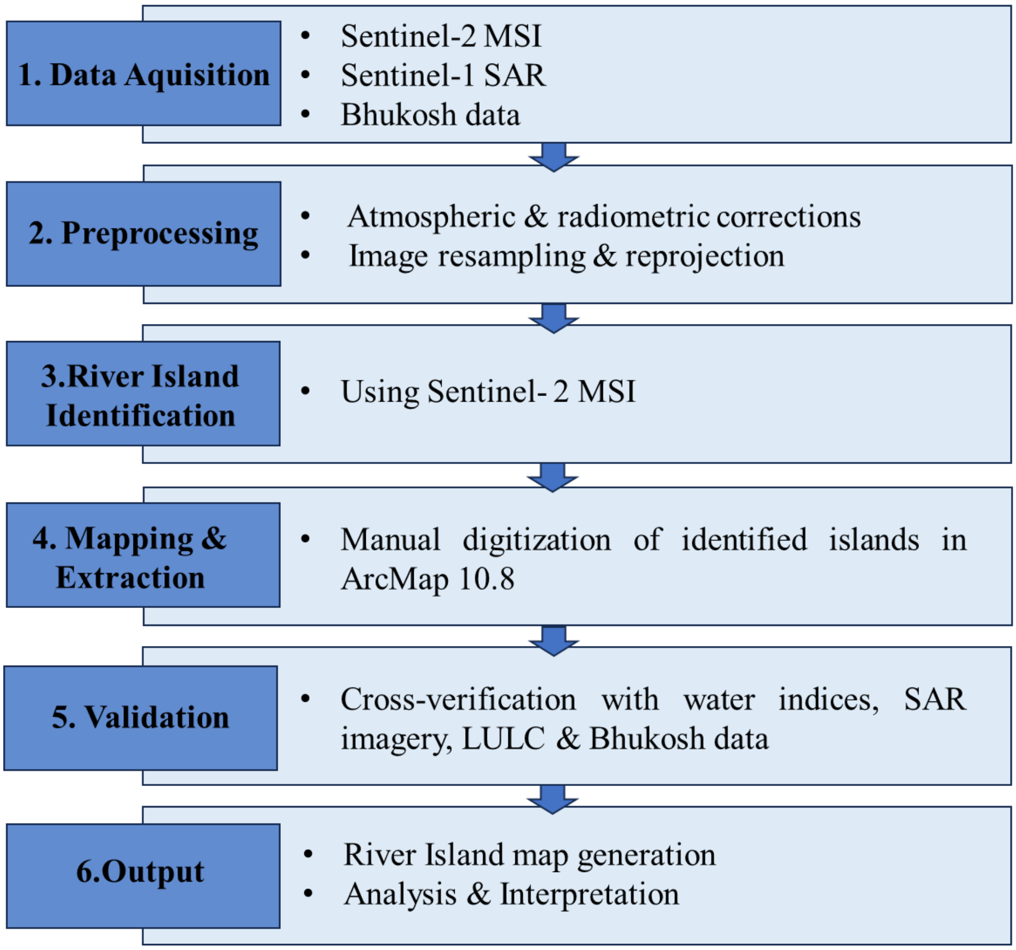

Figure 4: Flowchart of the methodology used for river island mapping

Sentinel-2 imagery contains multiple spectral bands (using different colors). Each band captures different details about the land, water, plant, and man-made structures. By mixing different bands, we can highlight specific features better than using normal color images. Appropriate color band combinations were used to enhance river island features, enabling accurate delineation of their boundaries (Table 2). The natural colour band composite uses the red (B4), green (B3), and blue (B2) spectral regions to display imagery in the same way it appears to the human eyes. False colour composite for highlighting features uses near-infrared (B8), red (B4), and green bands (B3). This helps to identify plant density, urban areas exposed grounds, and waterbodies. Denser plant growth appears in darker red, urban and exposed ground is seen in grey or tan, and water appears blue or black. Table 2 shows Sentinel-2 band combinations for enhanced image interpretation used for river island mapping.

Table 2: Sentinel-2 band combinations to identify different features

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

3.3 Mapping of river islands in the PRB

The Sentinel-2A satellite images in varying spatial resolutions, enable the delineation of water bodies and land by applying various water indices. The Periyar river confluences with the Vembanadu Lake through the Cochin estuary. Vypin Island is the largest barrier complex with beach ridge and swale complexes (Narayana A.C. And Priju C.P., 2006.) The analysis further indicates that these islands are predominantly covered by vegetation and human settlements, highlighting their ecological and socio-economic significance. Figure 5 shows the locations of river islands in the PRB. The mapping shows that most of the islands are in the downstream section of the basin. The figure a, b, and c show the enlarged images of these islands. Figure (a) shows the river islands near Munambam, (Ernakulam district), Figure (b) depicts the river islands near Aluva, (Ernakulam district) and Figure (c) shows the islands in Kalady (Ernakulam district). These islands consist of significant human settlements and infrastructure. Most of the area is covered by vegetation.

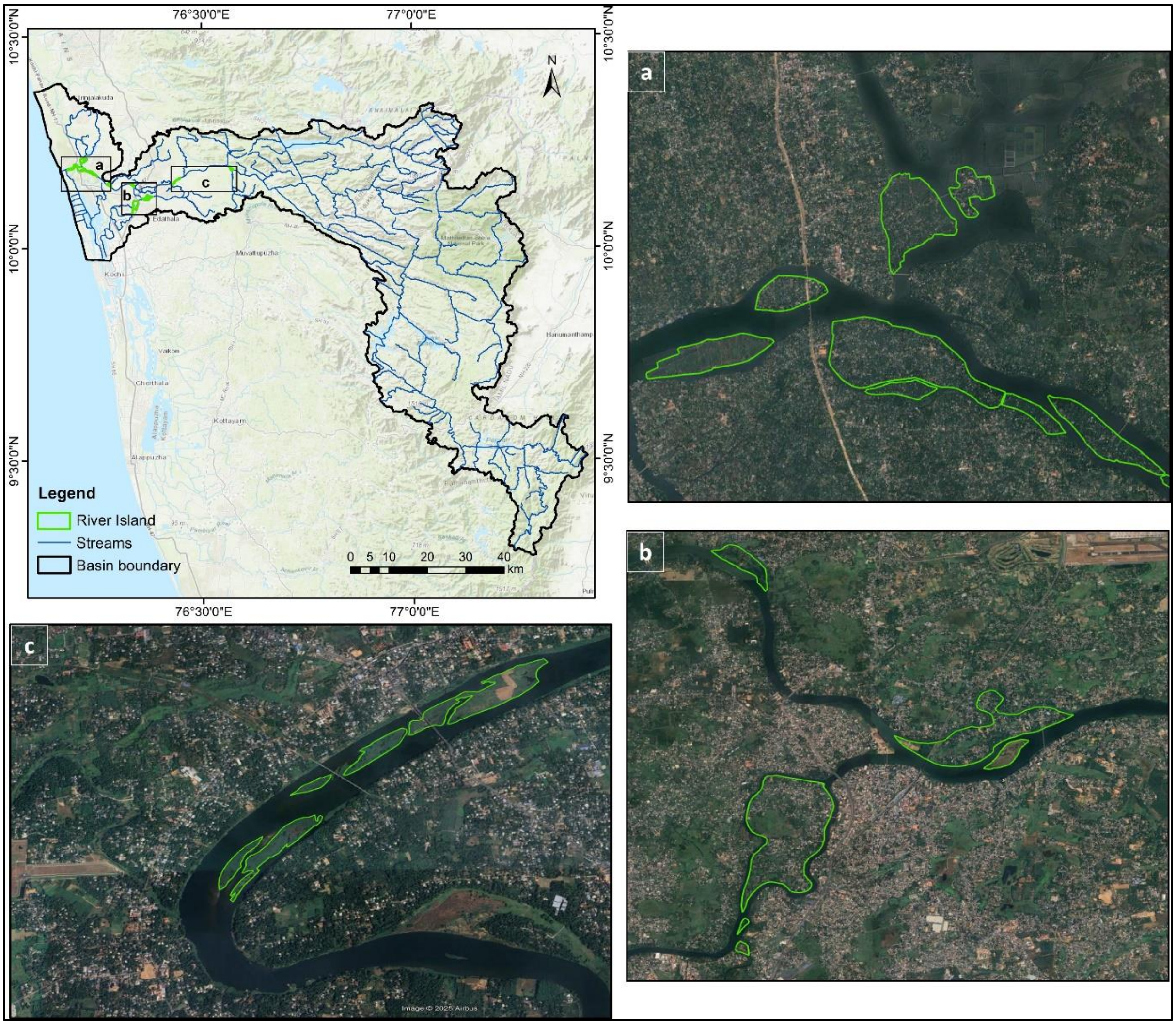

Figure 5: Map showing river islands of Ernakulam district in the PRB, (a) the river islands near Munambam, (b) the river islands near Aluva and (c) the islands in Kalady

3.4 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 changes in the morphology of river islands within the Periyar River. The River Island boundaries, delineated using Sentinel-2 imagery (2024), were overlaid on the Landsat images, confirming the absence of notable morphological changes over time (Figure 6).

However, distinct morphological transformations were noted at the Periyar River mouth and Cochin inlet over the periods (Narayana et al., 2006). The 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.

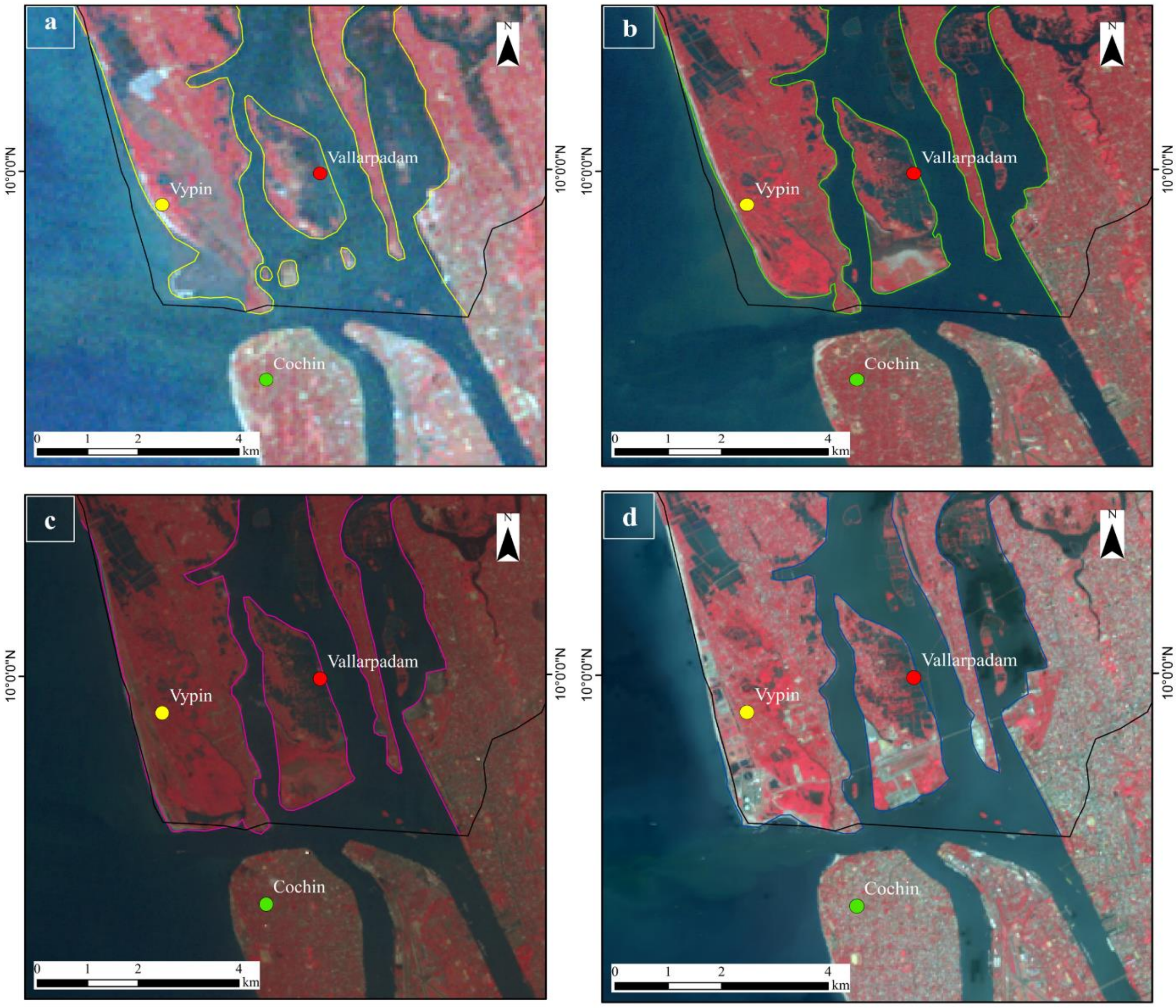

Figure 6: Landsat images of (a) 1973 (b) 1988 (c) 2001 (d)2017 to show the morphological changes in the river islands of PRB in temporal scale

4. Introduction to Floodplain

Floods are one of the most frequent disasters in the world causing significant damage to life and property. 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. Floodplains are land areas adjacent to rivers and streams subject to recurring inundation.

Generally, floodplains are inundated when the river discharge exceeds the capacity of the channel (Eder et al., 2022). Continuous rainfall exceeds the soil's absorption capacity and the flow capacity of rivers, streams, and coastal areas. This causes rivers to overflow and water to spread to nearby lands. The frequency of flood inundation depends on a combination of climatic, hydrological, and geographical factors, as well as human interventions. Based on the frequency, a ‘100-year flood’ describes, a flood expected to occur once every 100 years but there is also a possibility that it could occur more frequently. Active and Passive Floodplains are two distinct types of floodplains that differ in terms of how they interact with rivers and experience flooding. 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 flow due to human activities or natural change.

Floodplain mapping helps to identify the maximum floodplain extent which is important towards understanding the condition of a river basin. The floodplain mapping provides detailed information about the areas at risk of flooding, often categorized by flood risk levels. Along with flood mapping, it is also important to analyze the hydrology of the area, such as stream flow patterns, drainage systems, and potential for flooding. Such information helps in assessing the impacts of flooding on human life, property, and infrastructure and in developing recommendations for emergency response plans, such as identification of evacuation routes, shelters, and communication strategies.

Active radar sensors operating in the microwave region have been of considerable help towards flood mapping, as they function effectively even under cloud cover. Advances in remote sensing, like Synthetic Aperture Radar (SAR) and optical sensors, have transformed flood monitoring and management. SAR with its high penetration capability makes it especially useful for monitoring floods in vegetated or urban areas (Mason et al., 2007).

4.1 Overview of Flooding and its Causes in PRB

Kerala, located in southwestern India with an area of 38,863 km² (Kerala at a Glance, Department of Soil Survey and Soil Conservation), experiences nearly six months of rainfall annually, during the monsoon season, and areas in Western Ghats experience especially heavy rainfall conditions. Recently Kerala experienced a destructive flood during 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.

The PRB is prone to floods due to a combination of its geographical and climatic conditions along with rapid urbanization where the impact of floods is very dangerous. Flooding in the PRB is mainly 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 serious flooding events in the past, including the floods of 1924, 2018, and 2020 (Study Report, Kerala Floods of August 2018). The flood in 2018 caused the opening of the major dams, including Idukki, Mullaperiyar, and Idamalayar. As a result, several low-lying areas were flooded causing 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 Gauge & Discharge site (Periyar sub-basin) records, the maximum discharge passed in Periyar river was 8800 cumec on 16 August 2018. The floods were triggered by high monsoon rainfall, followed by the overflow of dams and rivers. This caused extensive damage to agriculture, homes, and infrastructure. The PRB topography contributed to these events. Human activities, including unplanned urbanization and deforestation, intensified the problem.

Source: Image from CNN World website

Figure7: Image of a temple submerged in Periyar river during flood

Source: Image from Financial express website

Figure 8: Aerial images illustrating the 2018 Kerala flood disaster.

4.2. Data Sources for Floodplain Mapping

Floodplain mapping requires using a wide variety of data sources to assess flood risk. These sources provide important details about the landscape, hydrology aspects and past flood events within a specific area. Combining these different types of data sources with advanced methods enables the creation of accurate floodplain maps, which are important for flood risk management. Table 3 shows the data collected and their respective sources used for floodplain mapping. Figure 9 shows locations of river discharge stations where the data is collected.

Table 3: Data collected and source for floodplain mapping

S. No.	Data type	Source	Last accessed
1	Rainfall	IDRB, Kerala WRIS	22/01/2025
2	Stream Discharge	India WRIS, Kerala WRIS	20/01/2025
3	Sentinel Satellite Images	Copernicus Website (https://browser.dataspace.copernicus.eu)	05/12/2024

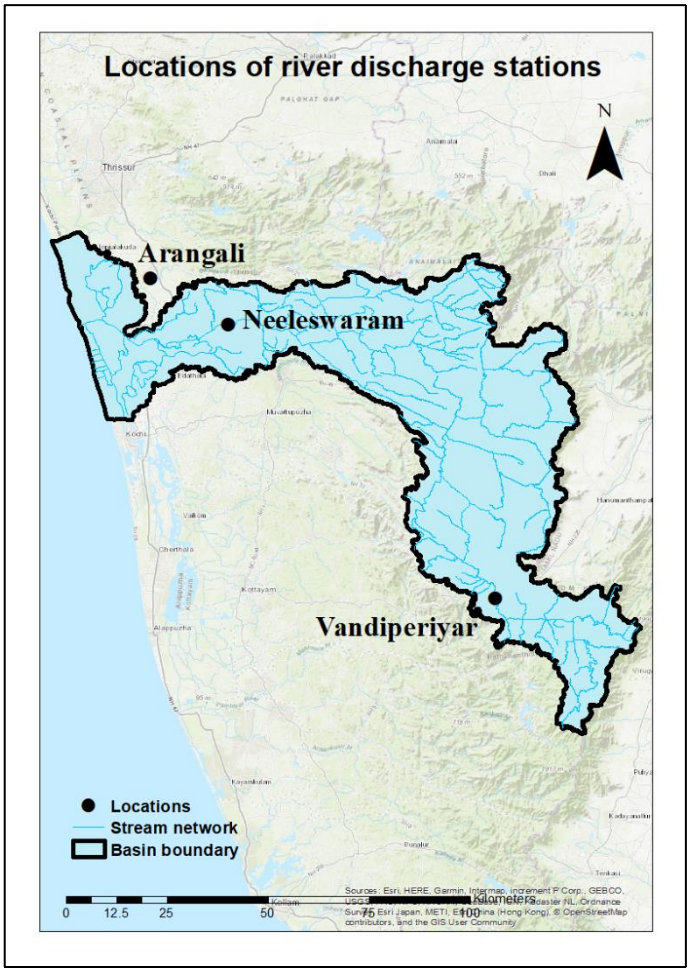

Figure 9: Locations of river discharge stations in the PRB

Remote sensing technologies, mainly SAR and optical sensors, have improved 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 as they actively emit 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 their high penetration capability (Mason, et al., 2012).

The Sentinel-1 satellite system, consisting of Sentinel-1A and Sentinel-1B, provides high-resolution (10 m) SAR datasets for worldwide flood monitoring (Potin et al., 2015; Torres et al., 2012). SAR images have different polarizations like VV, HH, VH, and HV, with VV polarization is especially useful for identifying wetlands and water bodies (Baghdadi et al., 2001; Wang et al., 2011). Thresholding-based methods are used for flood detection, where flood-affected regions are identified by isolating pixels below a specific value (Smith, 1997; Mason et al., 2007). These methods are quick and accurate for real-time flood mapping, helping in disaster risk management and planning (Amitrano et al., 2018).

4.3 Methodology of Flood Plain Mapping for PRB

This study utilized Sentinel-1A radar datasets to map flood-affected areas in the PRB. Images from peak monsoon discharge and maximum rainfall during the 2015–2024 period were analyzed for mapping. The study used Google Earth Engine (GEE), which is a powerful online tool that helps to analyse and process large satellite datasets for free. GEE gives access to a huge collection of remote sensing data, such as Sentinel-1, which is especially useful for flood mapping. Sentinel-1 radar data can capture ground surface changes during all weather conditions. It can detect changes in water levels and soil moisture, making it suitable for monitoring floods. Figure 10 depicts the flow chart of the methodology followed for floodplain mapping.

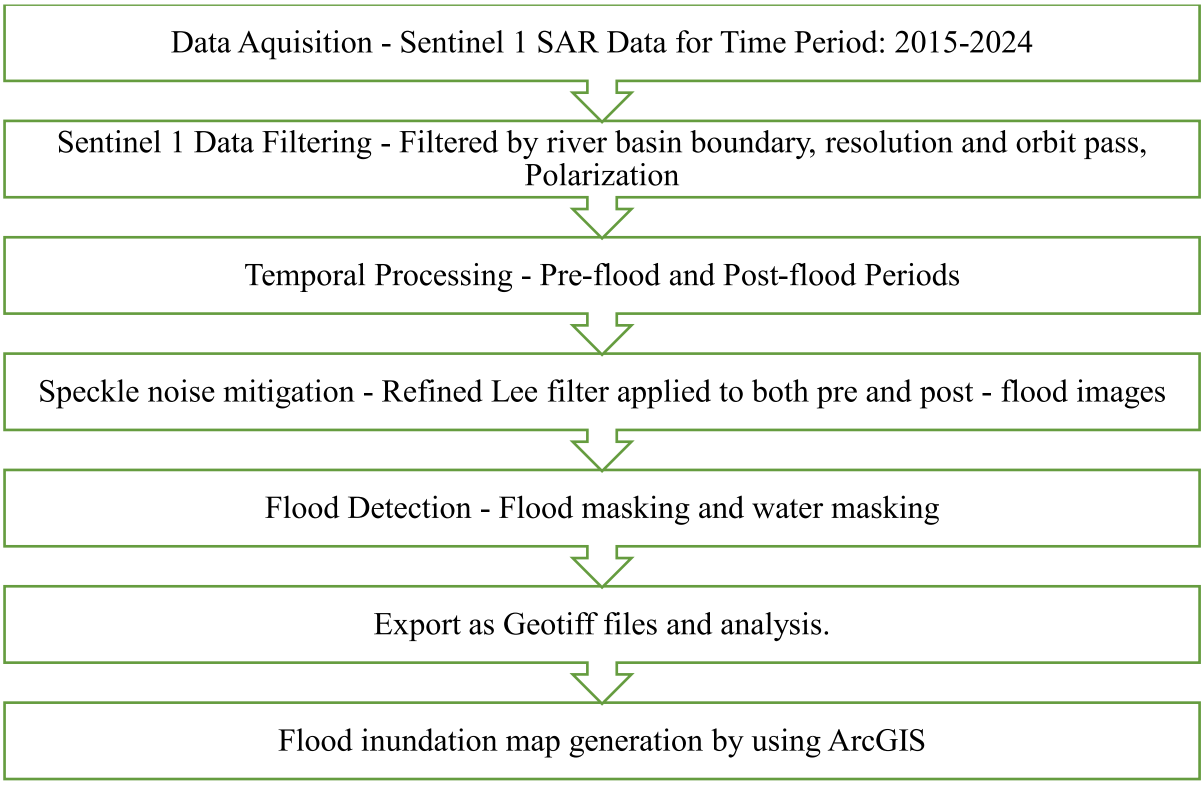

Figure 10: Flowchart of the methodology used for preparing flood inundation map using GEE

Flood mapping using Sentinel-1 data starts by filtering the Sentinel-1 Image Collection based on 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 study flood events, data was divided into periods of before and after floods.. 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 method allowed the creation of detailed flood maps from 2015 to 2024, helping to study how flood changes over time.

To improve data quality, speckle noise was avoided by 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: locations where pre-flood values above -20 dB and post-flood values dropped below -20 dB were marked as flooded. Areas that remain covered with 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 mark the extent of flooding across the AOI. By using Sentinel-1's high resolution, this method successfully generated accurate flood inundation maps for the entire analysis period.

4.4 Criteria for Selection of Periods for Flood Plain Mapping

The mapping of flood inundation areas, studying its impact, and the accuracy of the results depend on the correct selection of the pre- and post-flood images. These periods are important for understanding how floods progress over time. They show how rainfall and river discharge change, which influence when floods start, reach their peak, and eventually decrease. The end of Kerala's summer season from April to May is marked by the lower river flow which is taken as the pre-flood period. The post-flood dates were chosen when the rainfall, as well as discharge, were maximum. The gauge stations considered for the estimation of yearly peak discharge were Arangali, Neeleswaram, and Vandiperiyar for the districts Thrissur, Ernakulam, and Idukki, respectively.

The flood mapping study for the PRB was conducted annually from 2015 to 2024, excluding 2018 due to its classification as an extreme event. 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 4 represents the range of dates in which the sentinel images were used for flood map generation using google earth engine.

Table 4: Date selected for flood mapping

Sl no.	Year	Maximum rainfall	Maximum discharge
1	2015	18/07/2015 - 30/07/2015	22/07/2015 - 28/07/2015
2	2016	05/07/2016 -25/07/2016	12/07/2016 - 25/07/2016
3	2017	18/08/2017 - 30/08/2017	19/08/2017 - 30/08/2017
4	2018	15/08/2018 - 17/08/2018	09/08/2018 - 15/08/2018
5	2019	06/08/2019 - 14/08/2019	08/08/2019 - 14/08/2019
6	2020	22/06/2020 - 30/07/2020	07/08/2020 - 09/08/2020
7	2021	27/08/2021 - 17/10/2021	06/10/2021 - 21/10/2021

8	2022	02/08/2022 - 05/08/2022	02/08/2022 - 11/08/2022
9	2023	06/07/2023 - 25/07/2023	05/07/2023 - 08/07/2023
10	2024	16/07/2024 - 30/07/2024	16/07/2024 - 17/07/2024

4.5 Identification of Floodplain Extent for PRB

The floodplain was successfully mapped in ArcGIS 10.8 using the tiff file exported from Google Earth Engine (GEE) that contained flood inundation data across the PRB. Flood inundation data from the years 2015 to 2024 were consolidated to create a single integrated product, facilitating the extraction of the floodplain extent. By using satellite imagery and accompanying river shapefile, the extent of flood-affected areas was estimated. The delineation of the floodplain was achieved by analysing temporal changes in the flood inundation area, by comparing both pre-flood and post-flood conditions. This approach helps in the identification of flood-prone zones. Figure 13 is the maximum floodplain extent marked adjacent to perennial stream in the region.

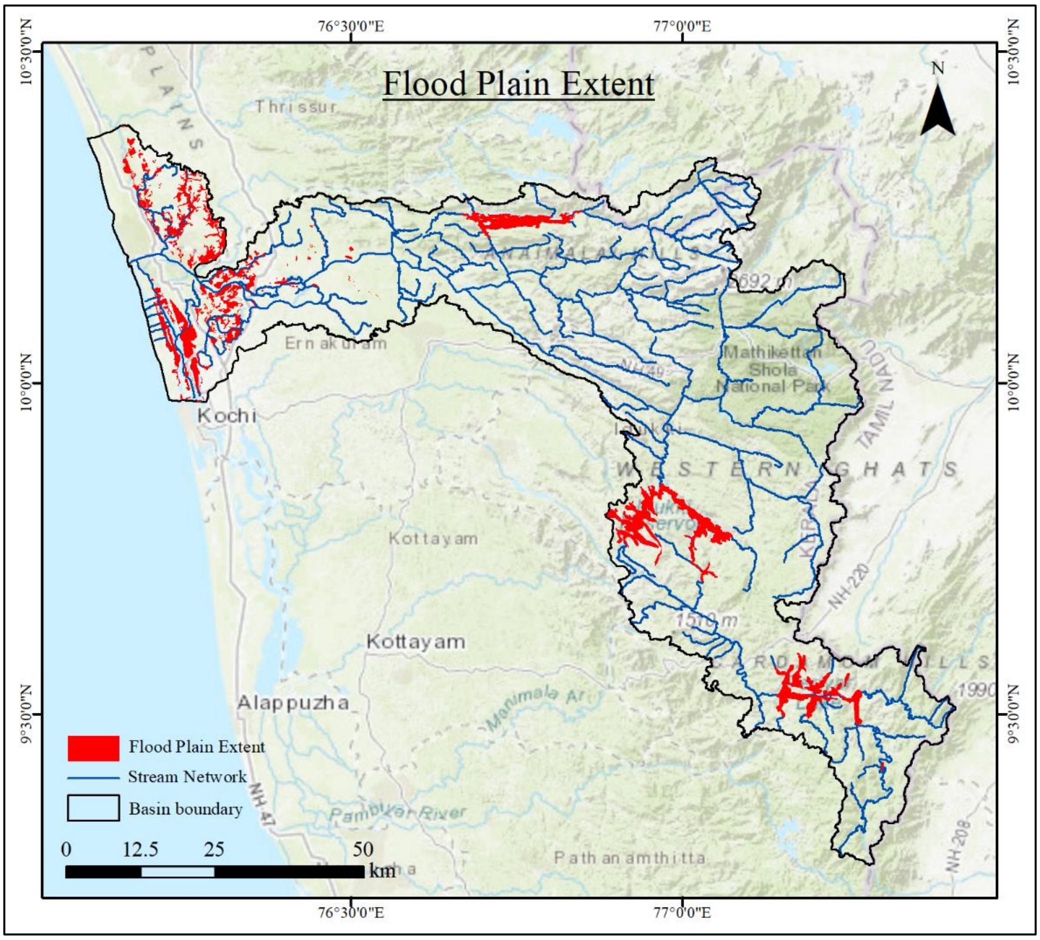

Figure 11: Maximum floodplain extent of PRB

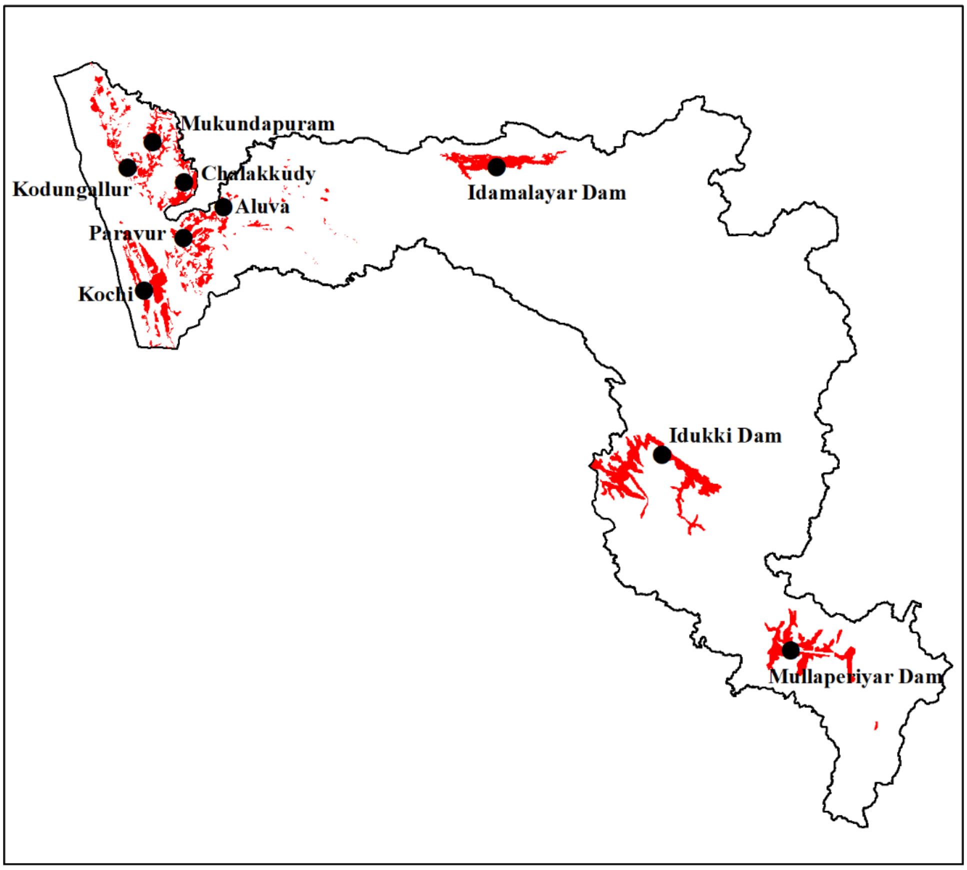

Figure 12: Locations of major flood inundation in the PRB

Figure 12 highlights the major dams in the basin along with areas of maximum flood inundation. It also indicates the names of taluks that are more prone to flooding in the downstream region of the river. The primary regions under built-up facing the flood include the taluks of Aluva, Paravoor, Kodungallur, Kothamangalam and regions of Perumbavoor under Kunnathunadu taluk under Ernakulam district along with the Iringalakkuda region under Mukundapuram taluk of Thrissur district. The total number of floodplain areas identified in the PRB is estimated to be 14 in the mainstream and 6 in the Right bank tributaries (Room for River Report 2022). Out of the 14 identified floodplain areas in PRB, 12 are located between Marthandavarma Bridge and Vaduthala and the remaining 2 of them are in between the origin and the Karimanal Bridge. The topography of this region is characterized by the steep slopes of the Western Ghats and the gently sloping terrain of the central and coastal area. The steep slopes result in high-velocity floodwaters, which significantly impact downstream areas. These regions are severely affected due to the large volume of water flowing from the upstream catchments. This poses a major threat to both human settlements and infrastructure during flood events in the region.

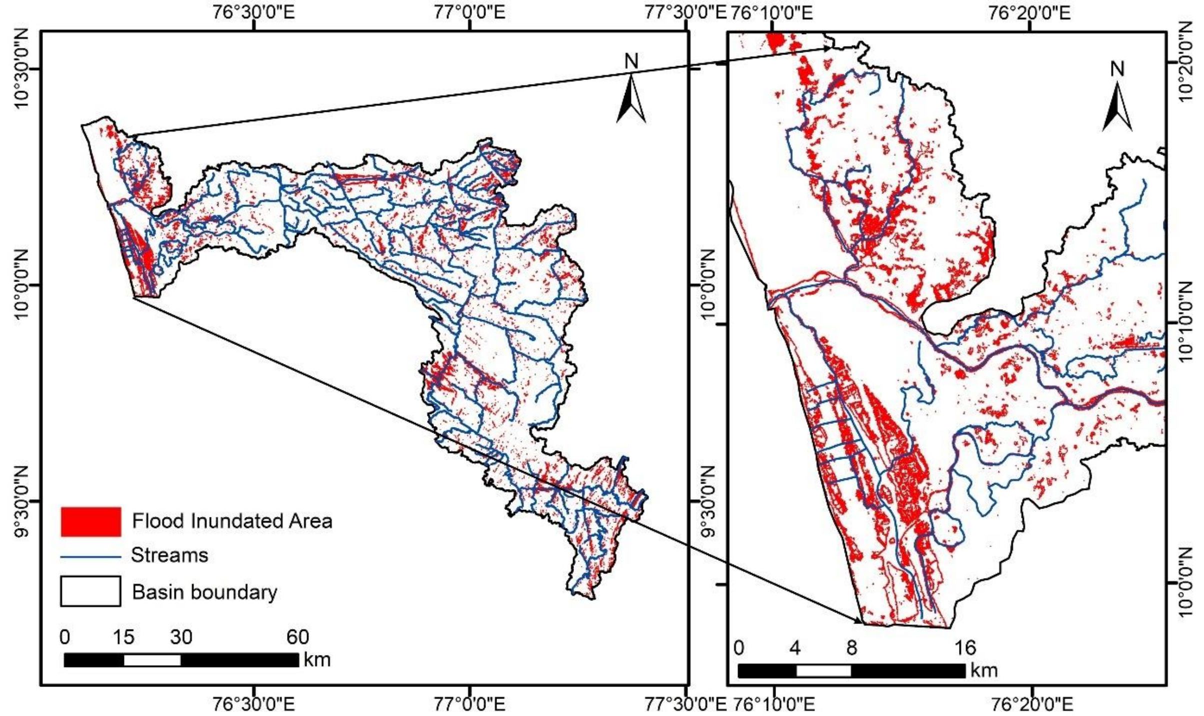

Figure 13: a) Flood inundation map of PRB b) Flood inundated area at downstream

Flood inundations in the region mostly spread westward towards the Arabian Sea. The low-lying areas of Kadamkudi islands (spreaded over Mangalampuzha and Marthandavarma subbasins) are the major portions of flood plain in the downstream region. Also, the low-lying –kole lands in Pullut subbasin are also the main inundation spots. The areas adjacent to Idamalayar Dam have been vastly inundated in this subbasin. Also, there are considerable flood plain regions in upstream regions of the basin (Mullayar subbasin). Though the upstream regions are in hilly regions, the presence of Mullaperiyar and Idukki dams leads to floodplain extent in the Mullayar subbasin. More attention and precautionary measures must be taken against flooding in the subbasins across the taluks of Paravur, Kochi, and parts of Mukundapuram, Kodungallur, Chalakudy, Aluva, Kanayannur, and Idukki. Figure 13 highlights the flood-inundated area at the downstream side.

5. Introduction to river styling

River styling is a scientific method used to study and classify rivers based on their nature, behavior, and ability to recover over time. The River Styles Framework (RSF) includes tools that help us understand a river's physical shape, its current condition, and possible future changes. This framework is based on a geomorphological approach, which means it focuses on understanding the shape and flow patterns of rivers and respecting their natural features. According to the RSF proposed by (Brierley and Fryirs, 2005) and then updated by Macquarie University in 2025, the system helps make informed decisions for protecting and restoring rivers. The framework is based on four main principles: Respecting natural river diversity – It highlights the importance of recognizing and valuing the natural differences in how rivers look and behave across different landscapes:

1. Accepting that rivers change over time – It accepts that rivers are dynamic systems that change over time due to natural processes and human activities. It encourages working with these changes instead of resisting them.

2. Understanding the link between river shape and environmental processes – It stresses the importance of studying how a river's physical form connects with the natural processes around it.

3. Using scientific knowledge to manage and restore rivers – The goal of the framework is to use geomorphological understanding to guide river protection and restoration in a well-informed, scientific way.

5.1. Applications and outcomes of river styling

The RSF has been used to protect rivers in many parts of the world. This has greatly helped improve the health of rivers. In a study of the Tarwal River in Iran, this was used to understand the link between the river's shape and the quality of its water. The study showed that changes in the river's form can affect water quality (Nayyeri et al.,2018). So, this method is very useful for environmental assessments. By including geomorphology, the RSF provides a scientific and comprehensive way to understand the natural variety and changes in rivers, and to manage them accordingly.

5.2. Data used for river styling

1. **Google earth imagery**: The key geomorphic units that have been identified for the river Periyar are valley margin, active floodplain and channel margin each characterized by several geomorphic features. Landsat imagery, SRTM generated DEM along with Google earth images were used to identify the units.

2. **Field verification:** While characterizing a river reach, certain parameters such as bed material characteristics and types of geomorphological features are essential. These were initially identified using Google Earth imagery and subsequently verified through

field visits at key locations along the river. A field trip was conducted in March 2025 to study and confirm these parameters.

3. **DEM:** The SRTM DEM data with a spatial resolution of 30m was utilized to generate the aspect map, curvature map, and hillshade map. Additionally, the DEM was used to compute the slope and elevation across the basin and to classify the landscape into various classes using Google Earth Engine. Conducting a preliminary analysis of these maps was essential to gain an understanding of the valley margin and channel margin. These geomorphic maps, covering the entire stretch of the Periyar River, were used as one of the key inputs in defining the different river styles for the Periyar.

5.3. Methodology for river styling

The RSF follows a nested hierarchical top-down approach and is structured across three key spatial scales (Fluvial Geomorphology Group, Ganga River Basin Environmental Management Plan, 2012).The methodology adopted is the river style approach of the river Ganga. It follows a systematic workflow that begins with identifying the landscape setting, which provides a broad understanding of the regional geomorphic context. This is followed by defining the valley setting, which helps classify the river reach based on valley confinement and shape. The channel setting which describes the relationship between the channel and its adjacent floodplain is then examined. A detailed analysis of geomorphic features is carried out to differentiate islands from other landforms such as bars or mid-channel bars. The planform of the river, which includes the river's shape and pattern (straight, meandering, braided, etc.), is then analyzed to understand how river islands are distributed. Lastly, the bed material is considered to assess the sediment characteristics that influence stability of the river and the transition zones of the riverbed. This structured approach ensures that styling of the river is accurate, consistent, and grounded in geomorphological principles. The representation of workflow is shown in Figure 14.

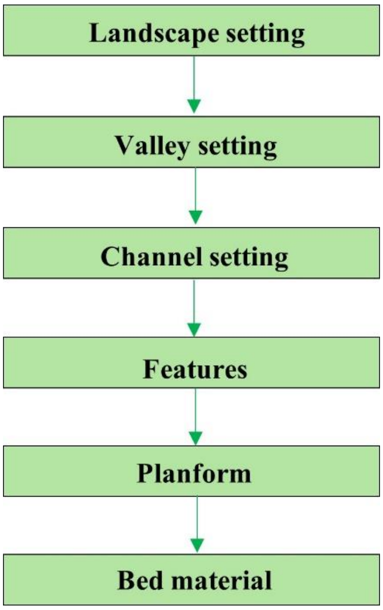

Figure14: Workflow of river styling for the Periyar river

5.3.1. Landscape setting:

The landscape setting forms the foundational layer of river styling, as it determines the geomorphological context in which rivers evolve and interact with their surroundings. In the present study, the landscape of the basin is classified into five major types: Hilly region, Pediment region, Alluvial fan, Alluvial plain, and Coastal plain. For classifying the landscape, two parameters were used; slope and elevation. This approach is outlined by in a work on the Chota Nagpur Plateau, where landforms were systematically categorized based on geomorphological characteristics and terrain analysis (Ghosh et al., 2023). Each landscape type reflects unique fluvial and sedimentary processes, which directly influence the formation, morphology, and dynamics of river islands within the respective regions. In order to classify each landscape, the slope map and elevation map were generated using SRTM DEM 30m resolution, using natural breaks generated in ArcGIS. The slope and elevation data were incorporated in Google earth engine to create a code that classifies the landscape into different classes. The slope map and elevation map are shown in the Figure 15 and Figure 16. Table 5 shows the landscape classification.

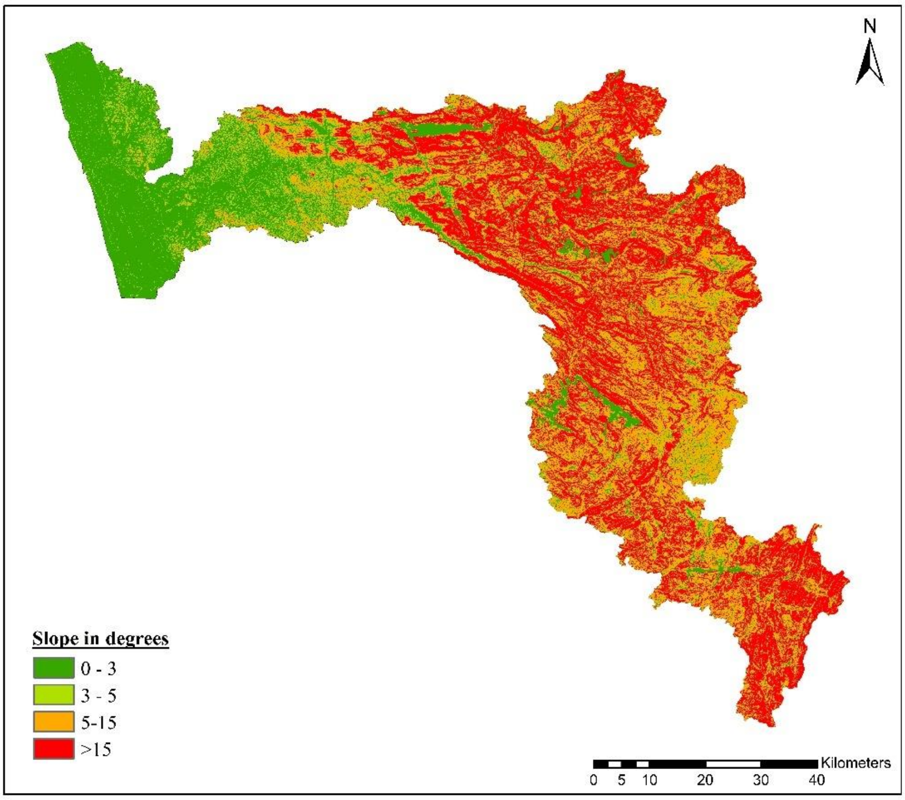

Figure 15: Slope Map of the PRB

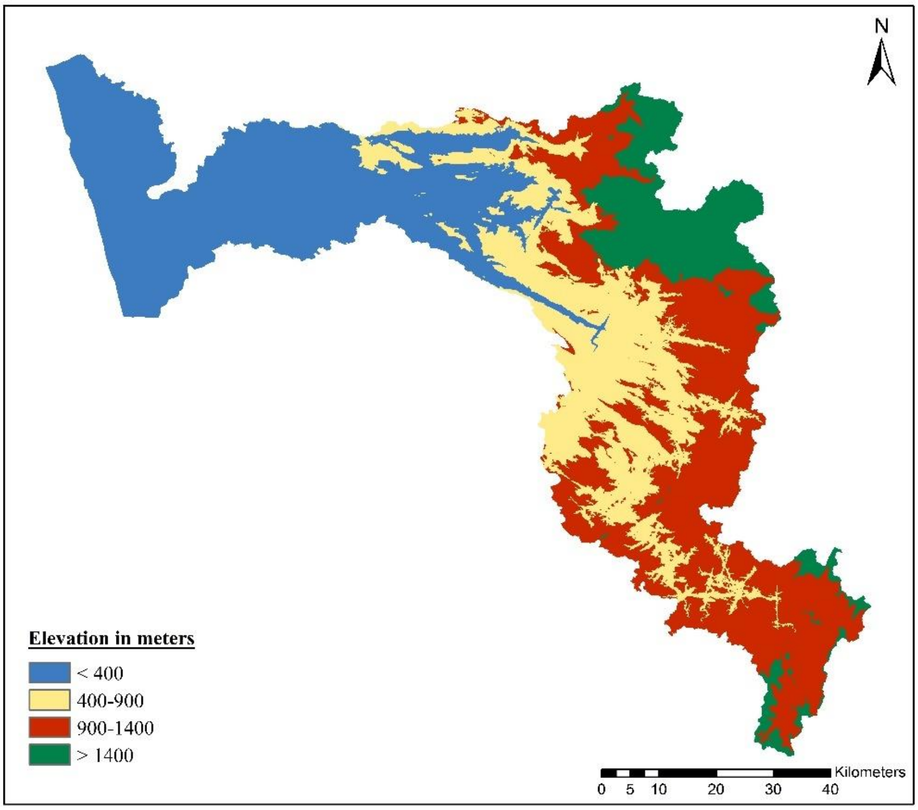

Figure16: Elevation map of the PRB

Table 5: Landscape classification of the PRB

Sl.no	Classification	Definition	Classifying criteria	Geomorphic significance
1	Hilly Terrain	Steep and elevated regions such as escarpments or the upper reaches of the watershed.	slope > 15°	Represents high-relief zones with strong erosional activity.
2	Pediment Zone	Gently sloping land forming a transitional zone between hills and plains.	5° < slope ≤ 15°	Often marks the interface of upland erosion and lowland deposition.
3	Alluvial Fan	Depositional landforms found where a stream exits mountainous terrain and spreads sediments.	slope ≤ 5° and elevation > 360 m	Indicative of sediment spread and reduced channel energy.
4	Alluvial Plain	Flat lowlands generally associated with river valleys and active floodplains.	Slope ≤ 3° and Elevation <360m	High agricultural potential; subject to flooding and sediment deposition.
5	Coastal Plain	Flat or gently sloping terrain influenced by marine or estuarine processes.	Low-lying areas near the coast with slope < 3° and Elevation <360m	Transition zone between terrestrial and marine environments.

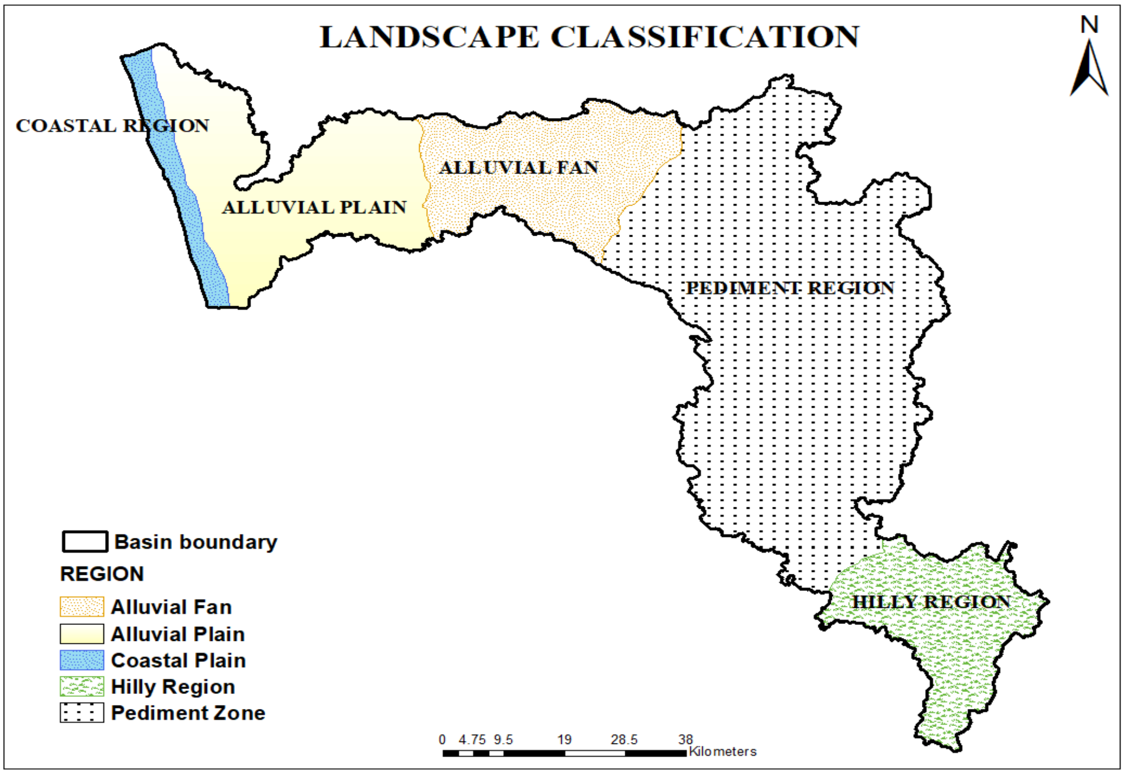

Figure 17: Landscape classification of the PRB

5.3.2. Valley setting and channel setting:

Valley setting is basically the identification of where the valley margins occur. The valley margin is defined as the break in slope between contemporary flood plain and either bedrock hillslopes or other paleo-alluvial landforms in the valley. In the RSF, the valley setting is a crucial determinant in classifying river styles, as it influences the river's capacity for adjustment and the types of geomorphic units present. Rivers are typically categorized based on the degree of confinement within their valleys:

1. Confined Valley Setting: Here, over 90% of the river's channel abuts the valley margin, indicating minimal floodplain development. Such rivers are often constrained by bedrock or terraces, limiting their lateral movement. They are commonly found in mountainous or hilly terrains where valley walls are steep and close to the river channel. (Brierley et al., 2016)
2. Partly Confined Valley Setting: In these settings, between 10% to 90% of the channel is in contact with the valley margin. This allows for some floodplain pockets and limited lateral movement. According to RSF, these rivers exhibit a mix of confined and unconfined characteristics, often occurring in transitional zones between upland and lowland areas.

3. unconfined characteristics, often occurring in transitional zones between upland and Unconfined Valley Setting: Less than 10% of the channel touches the valley margin, permitting significant floodplain development and lateral channel migration. These settings are typical of lowland areas where the valley is broad, and the river can meander freely.

The valley margin and channel margin are preliminarily derived using DEM. The hill shade raster and aspect maps generated in ArcGIS and Google earth satellite imagery were used to identify valley margins and channel margins. These were confirmed by using the cross - sectional checking of the valley margin using the HEC-RAS. Several sections along the river stretch were taken, and the cross- sections of these places were generated with HEC-RAS. The cross-sectional images showed that the entire upstream region of the Idukki dam is confined valley margin. For a better understanding of the valley margins, the hillshade map (Figure 18) and aspect map (Figure 19) has been generated for the PRB. Similarly using DEM, the curvature map (Figure 20) combined with Google earth image also gives a picture about the channel margin. The curvature maps give positive values showing convex curvatures and negatives showing concave curvatures indicating lower areas. This helps to distinguish between the channel and the valley.

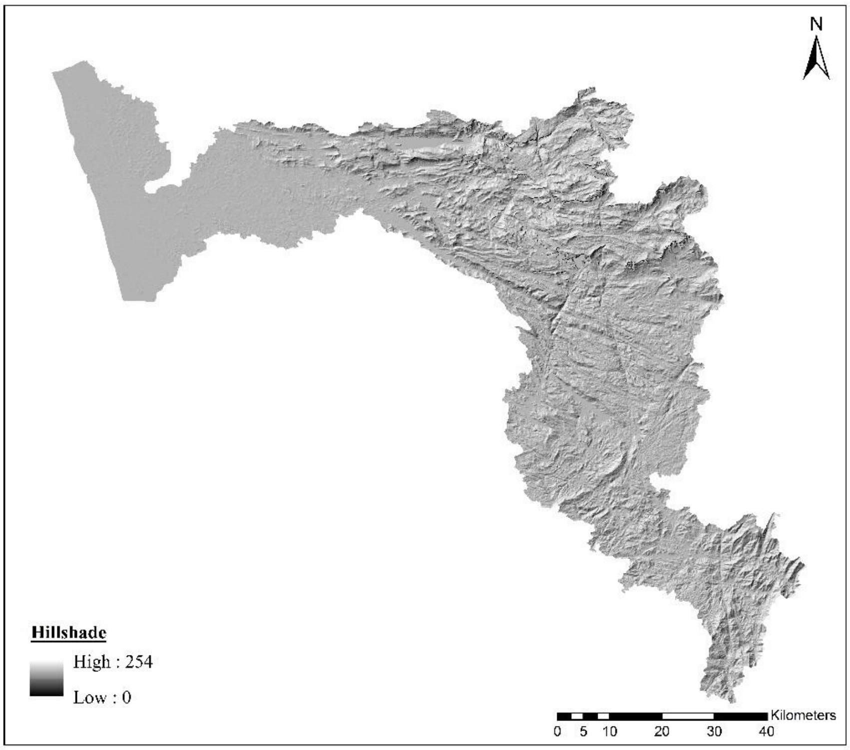

Figure 18: Hillshade map of the PRB

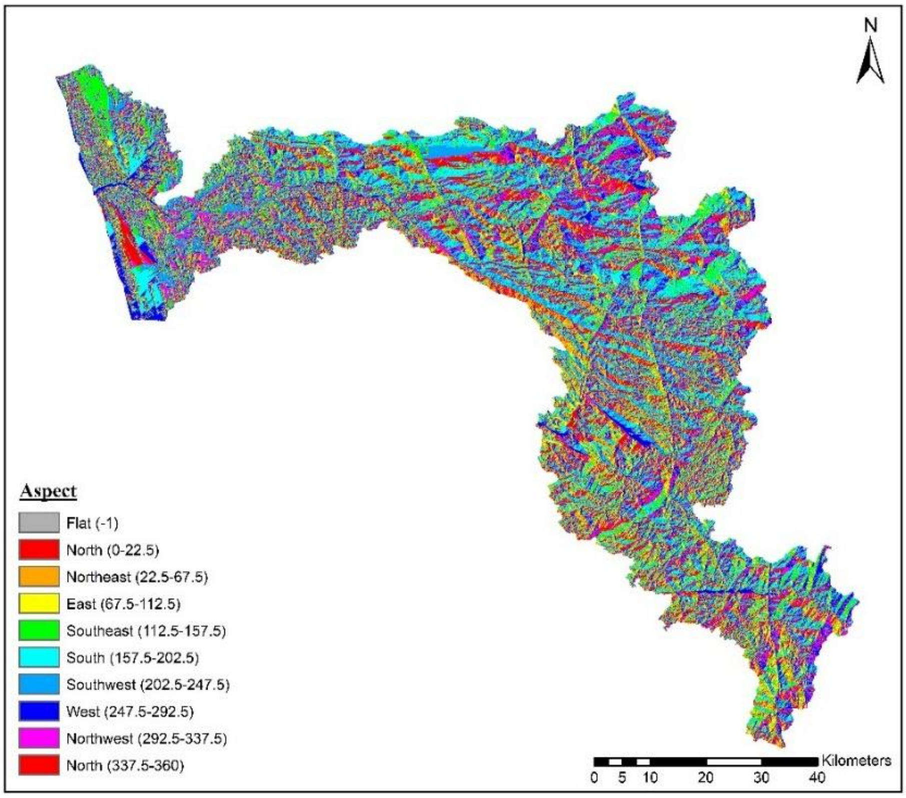

Figure 19: Aspect map of the PRB

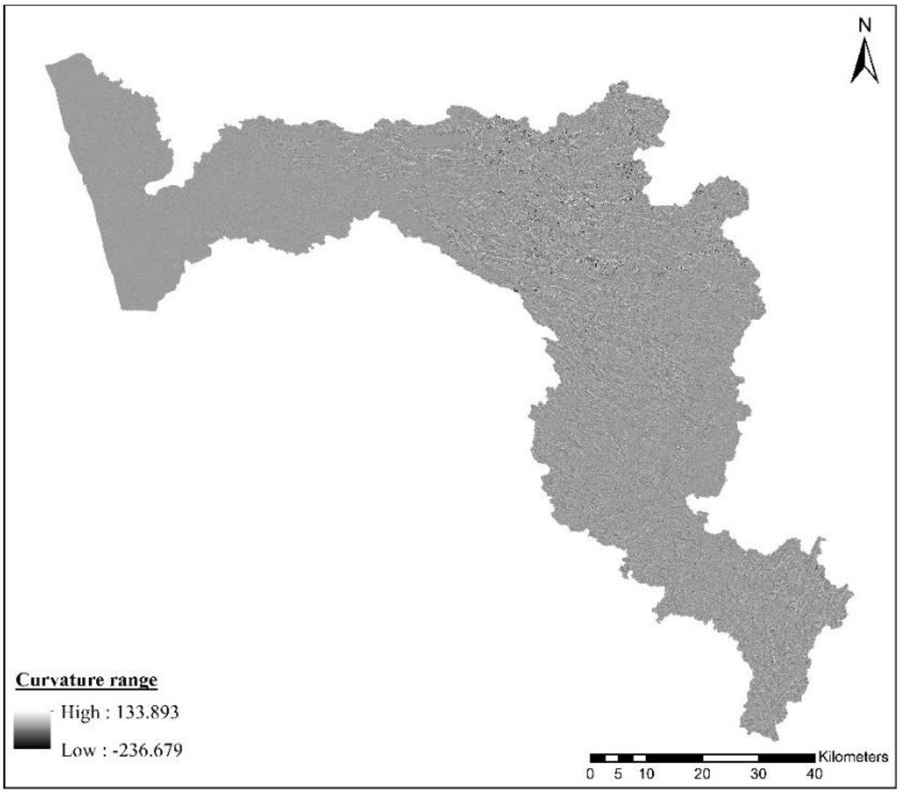

Figure 20: Curvature map of the PRB

In the upstream region of PRB extending to the Neriyamangalam power station (which is a major power station located in the downstream of Idukki dam), observations indicate that the valley margin coincides with the channel margin throughout this stretch. This alignment suggests a confined valley setting, where the river is predominantly constrained by the valley walls, limiting its lateral mobility and floodplain development. Such settings are characteristic of steep, mountainous regions where the river's course is dictated by the surrounding topography. Figure 21 is a sample Google earth image illustrating how the valley setting is classified as confined. It shows the valley margin nearly coinciding with the channel margin. Figure 22 presents sample sections (Sections 1 and 2) along the main course of the Periyar River, which were used to delineate valley margins in HEC-RAS. Enlarged top-view images of each section, along with their corresponding valley margins based on the considered section width, are also provided.

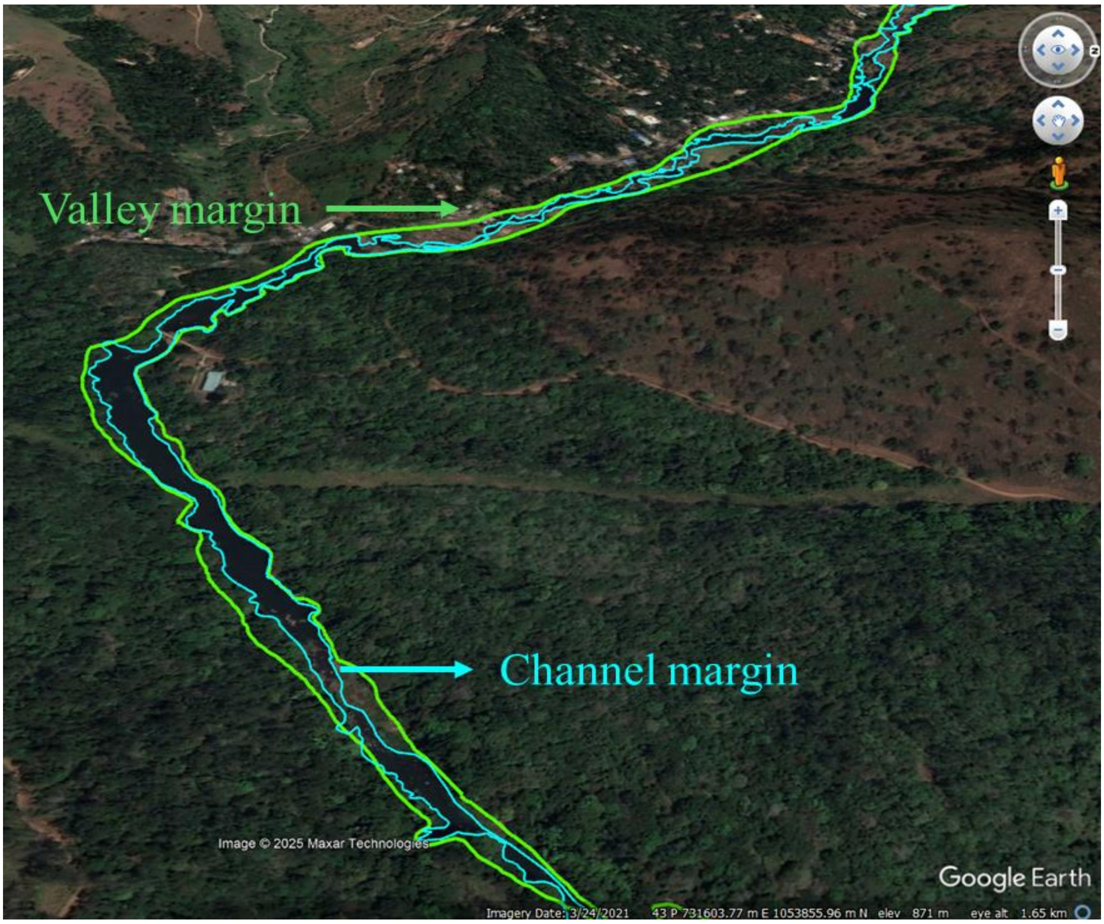

Figure 21: Google earth image of a sample section illustrating the coinciding channel margin and valley margin for a confined -valley-setting in the PRB

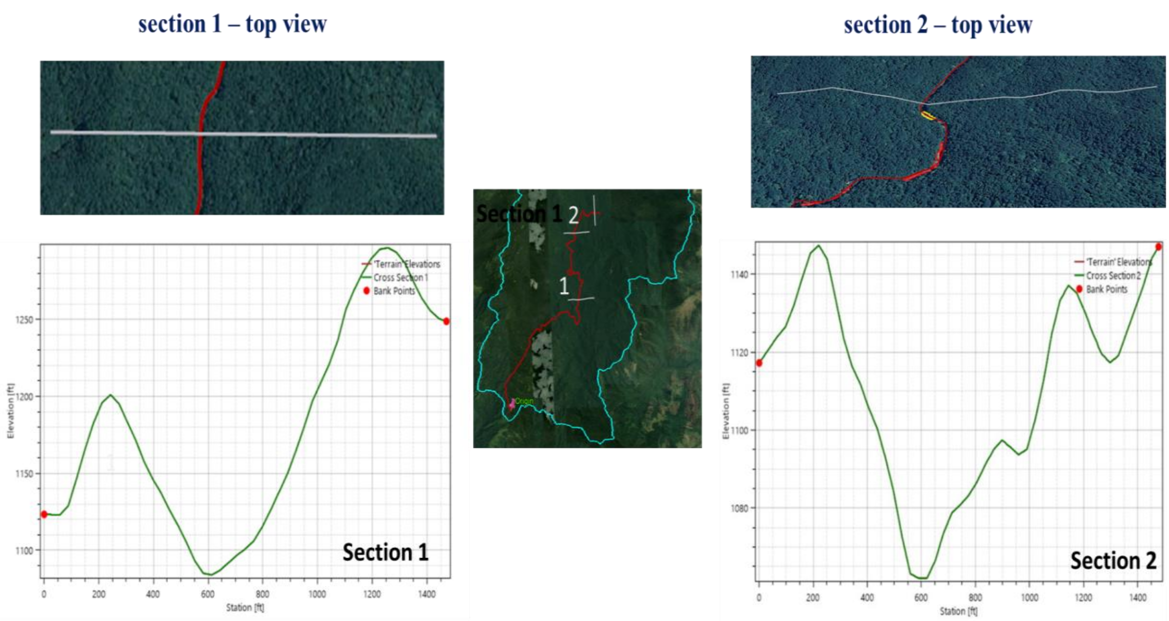

Figure 22: Google earth image of the top-view of sample sections 1 and 2 in a portion of PRB, along with their sectional valley margin generated in HEC-RAS

The Figure 23a displays the locations selected for field verification of valley settings. Figures 23b to 23d include photographs captured during the site visit, which were used to validate the accuracy of the satellite imagery-based analysis in identifying confined valley settings .

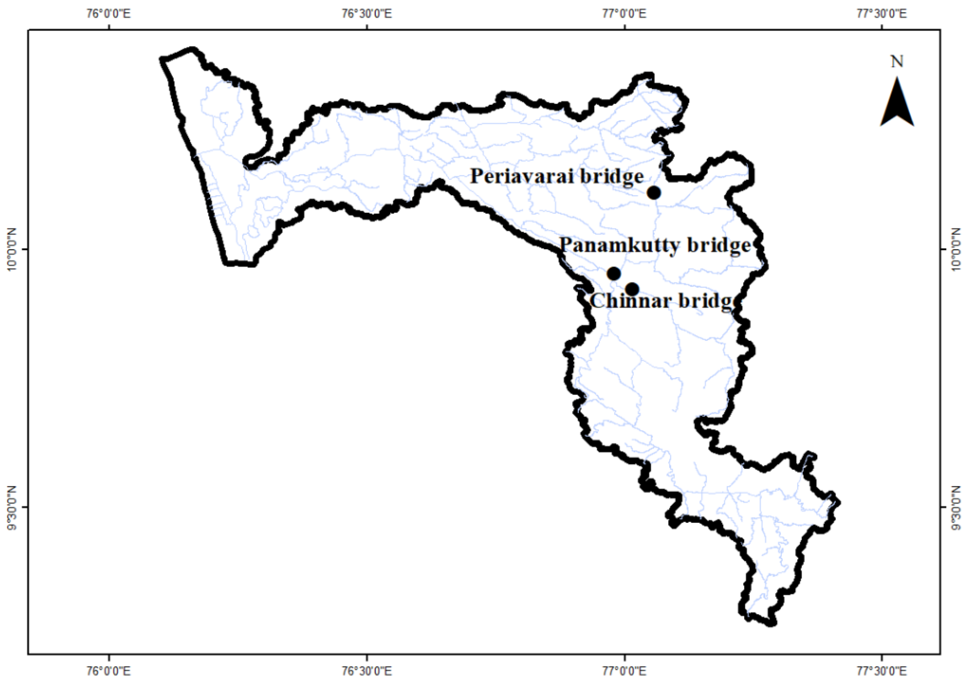

Figure 23(a): The locations in the study area (near Periyavarai Bridge, near Panamkutty bridge, near Chinnar bridge) chosen for site verifications for valley setting identification near the Idukki and Mullaperiyar dams.

Figure 23(b): Photograph showing the confined valley setting near Periyavarai Bridge

Figure 23(c): Photograph showing the confined valley setting near Panamkutty Bridge

Figure 23(d): photograph showing the confined valley setting near Chinnar Bridge

5.3.3. Channel and floodplain geomorphic units:

In the RSF, the channel and floodplain geomorphic units are fundamental building blocks used to understand river behavior and type. The Periyar river shows various channel geomorphic units such as waterfalls, cascades, pools, riffiles, runs, point bars, mid-channel bars, anabranches etc., which together defines the shape and structure of the active channel. The features are mapped using Google Earth satellite imagery and to identify the spatial variability of processes within a river reach.

5.3.4. Identifying geomorphological features:

Identifying geomorphological features within a river channel is a fundamental aspect of fluvial geomorphology, providing insights into the river's current state, evolutionary history, and potential future changes. This process involves a systematic examination of various channel characteristics and landforms, often guided by established methodologies and classification systems. The key geomorphological features to be identified are channel planform and bedforms.

Channel Pattern and Planform:

Understanding the river's planform is fundamental to classifying its behaviour and morphology. The planform refers to the horizontal layout or shape of the river channel, and can typically be categorized as straight, meandering, or braided and also the presence of sinuosity. This classification provides important insights into the river's energy conditions, sediment load, and valley slope. Meandering channels are commonly found in low-gradient terrains with cohesive bank materials, which promote lateral migration and the development of characteristic bends. In contrast, braided channels usually occur in high-energy environments with steeper gradients and abundant, coarse sediment supply. These settings often lack cohesive bank materials, resulting in multiple interweaving channel threads and unstable bars. The upstream regions of PRB are mainly having straight course with presence of sinuosity in some places.

Bedforms and Sediment Characteristics:

Another essential feature to observe is the presence of bedforms such as riffles, pools, dunes, and bars, which are key indicators of flow dynamics and sediment transport processes within the channel. These bedforms reflect the interaction between flow velocity and sediment size and help identify zones of erosion and deposition. The presence of these features is identified within the instream of the channel and floodplain areas. The characteristics of bed material—its size, composition, and degree of sorting—further inform the energy conditions within the river. Coarse, poorly sorted sediments typically indicate high-energy flows, while finer, well-sorted materials suggest lower energy environments. The bed size distribution is done for samples collected from accessible sites in PRB. This information is crucial for understanding sediment supply, channel morphology, and the potential for channel evolution under varying hydrological conditions.

5.4. Nomenclature of styles:

The classification and naming of river styles is undertaken through the integration of multiple geomorphological assessments, providing a comprehensive understanding of the spatial diversity and physical processes governing river systems. Central to this approach is the RSF for the Ganga River, a process-based methodology that emphasizes the significance of evaluating landscape settings, valley confinement, channel morphology, and sediment characteristics to classify and manage river systems effectively. This framework allows for the identification of distinct river styles based on how rivers interact with their broader environmental context and internal geomorphic processes.

The process begins with an assessment of the landscape setting, where the topographical and geological context of the basin is examined (PRB is classified into 5). Following this, valley setting and degree of confinement are assessed to determine the extent to which the river channel interacts with its valley margins. The PRB is categorized as confined, partly confined, or unconfined based on this interaction, with most of the upstream region as confined. Confined rivers are restricted by valley walls, limiting floodplain development and lateral mobility, whereas unconfined rivers are able to migrate across wide floodplains, demonstrating dynamic adjustment and sediment redistribution. Partly confined rivers exhibit transitional behaviour, with intermittent floodplain development depending on local topographic constraints.

A detailed examination of the river's planform and channel morphology further informs the classification. Alongside planform, the identification of geomorphic units such as pools, riffles, bars, runs, cascades and bedforms reveals patterns of erosion and deposition that are crucial for understanding sediment transport and channel evolution. The bed material composition, including grain size, sorting, and stability, also contributes to the identification of river styles by indicating the river's transport capacity and sediment dynamics.

In the present study, ten distinct river styles have been identified across the basin— five of the selected locations are situated upstream of the Neriyamangalam Power Station, while the remaining five are located downstream. This classification incorporates not only the main channel but also all perennial tributaries, thereby accounting for the full geomorphic variability present within the basin. Including tributaries is essential as they contribute significantly to the hydrological and sediment regimes of the main stem, influencing its morphology and behaviour. This holistic classification ensures that the interconnected nature of the river network is adequately represented.

The upstream region of the river system displays a rich diversity of river styles, shaped by varying degrees of confinement, margin control (bedrock or terrace), bed material, and floodplain development. These river styles are essential for understanding the river's geomorphic behavior, sediment transport processes, energy conditions, and its potential for ecological diversity. Table 5 is a classification of ten river styles observed in the upstream stretches, each with unique morphological and sedimentological characteristics. Figure 24 presents the different styles in the PRB, classified as in Table 5.

Table 6: Distinguishing attributes of River Styles in the Periyar River

River style No.	River style	Stretch (Length in km.)	Landscape settings	Channel confinement	Channel type	Average slope	Sinuosity
1	Confined, Bedrock Margin controlled, Sinuosity, Boulder bed **C-BrMc-Sin-Bbed**	•From origin to 16 km along Mainstream • Kizhpattam to Pannimedu kuttu (9.11) • Mankulam to Kandiyam (7.62)	Hilly region/Pediment	Confined	Sinuous	5-15˚	1.4
2	Confined, Bedrock Margin controlled, Exposed Rock, Boulder bed **C-BrMC - ExpRock-Bbed**	•Stretches 5 km after style 1 along Mainstream. •Tributaries(137) •From Mullayar origin 9 km along the river stretch •From Idukki dam 11km along the river Mullayar •Chinnar origin to confluence point with periyar 54km •Muthirapuzha origin to Neriyamangalam Power station - 47km •Karindiri ar origin to Karimkulam 16km	Hilly region/Pediment	Confined	Straight/meandering	5-15˚	nil
3	Confined,Bedrock Margin Controlled,Cascades,Boulder bed **C-BrMC-Cas-Bbed**	•Main sream(23) • From end of style 2 near origin to Idukki reservoir along main stream	Hilly	Confined	Straight/meandering	5-15˚	nil

4	Confined- Bedrock Margin Controlled- Occasional Flood Plain **C-BrMC-OccFP**	•Main sream(67) • Mullaperiyar dam downstream to upstream of Idukki dam.	Pediment	Confined	Straight with meander ing	5-15˚	nil
5	Confined- Bedrock Margin **Controlled-Point Bar** **C-BrMC-Pbar**	•Tributary(8) • Middle stretch of Mullar river (In between style 2)	Hilly	Confined	Straight /meande ring	5-15˚	nil
6	Confined, bedrock margin controlled, gorge, boulder bed **C-BrMc-Gge-Bbed**	• Lower periyar dam to Karimanal (13.49) • Kadan kunnu to Kizhpattam (3.79) • Pannimedu kuttu to Idamalayar reservoir (5.29) • Kankattu mala to Mankulam (6.1) • Valara to Bhoothathankettu reservoir (6.58)	Pediment	Confined	Sinuous	3-5˚	1 – 1.4
7	Confined, terrace margin controlled, occasional floodplain pockets, bedrock bed **C-TrMc-OccFp-Brbed**	• Bhoothathankettu dam to Paniyeli poru (9.37) • Idamalayar dam to Bhoothathankettu reservoir (7.49) • Pooyamkutty to Bhoothathankettu reservoir (7.33)	Alluvial Fan	Confined	Sinuous	<1˚	1 - 1.3
8	Confined, bedrock margin controlled, sinuosity, bedrock bed **C-BrMc-Sin-Brbed**	• Kandiyam to Pooyamkutty (17.08)	Pediment	Confined	Sinuous	<1˚	1.4

9	Partly confined, terrace margin controlled, occasional floodplain, sinuosity, Bedrock bed **PC-TrMc-Sin -OccFp-Brbed**	• Karimanal to Chembankuzhy (6.32) • Adimali to Valara (19.87)	Pediment	Partly-Confined	Sinuous	<1˚	1 – 1.3
10	Laterally Unconfined, Continuous channel, anabranching, fine grained bed **LU-C-An-Fbed**	• Paniyeli poru falls to Vypin (61.57) • Aluva to Munambam (27.49)	Alluvial	Laterally Confined	Anabranching	<1˚	1.2 – 1.48

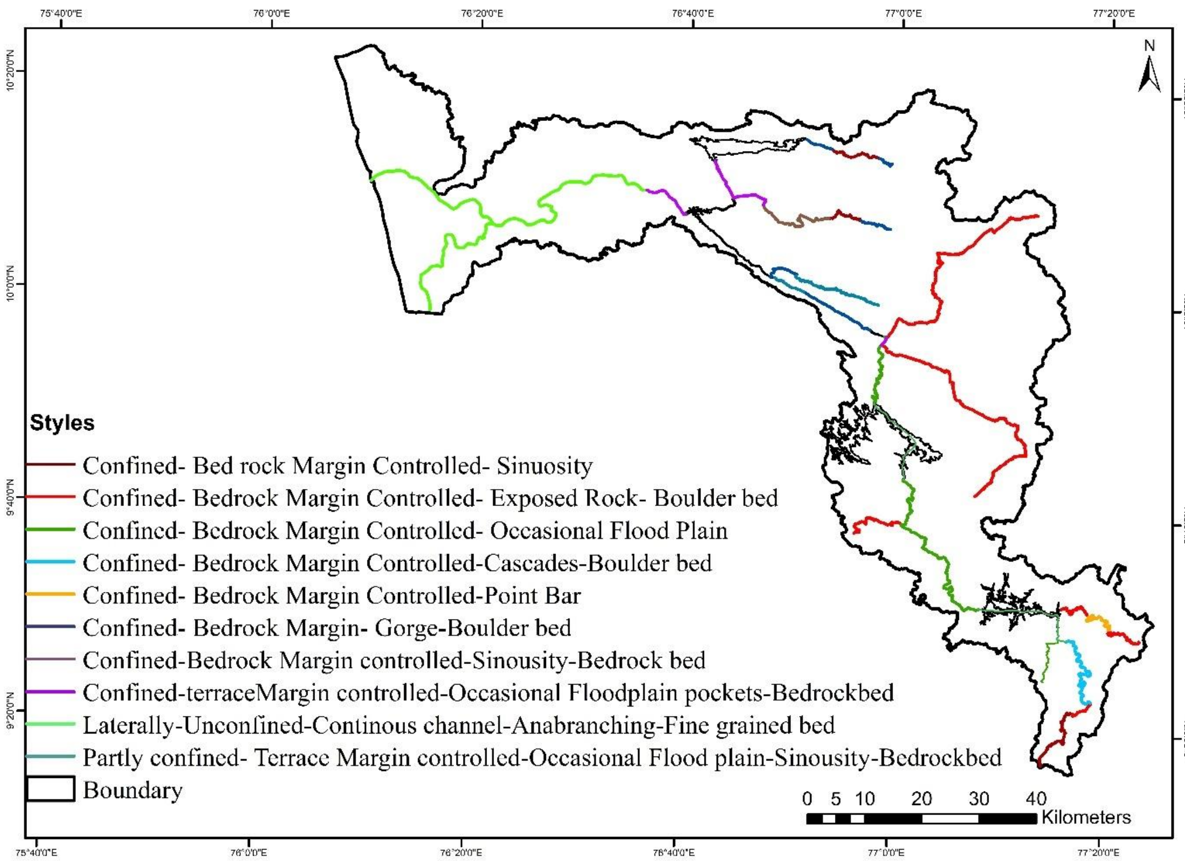

Figure 24 illustrates different river styles in the PRB

5.4.1. River Styles in the confined valley setting

5.4.1.1. Confined, bedrock margin controlled, sinuosity, boulder bed (C-BrMc-Sin-Bbed)

This river style has been defined in a stretch from origin to 16 km along mainstream, in the Idamalayar river from Kizhpattam to Pannimedukuttu (about 9.11 km) and in Pooyamkutty river from Mankulam to Kandiyam (about 7.62 km). In all these stretches, the valley margin coincides with the active channel, as a result, no floodplain has formed. The style is observed in hilly areas. Channel consists of bedrock margin, sinuosity in the channel, presence of instream features like sand bars, boulders mounds, pools and vegetated bed rock exposure (Figure 25 a) and the field images are shown in (Figure 25 b). Coarse-grained sand deposits can be seen as pockets. It is characterized by a gradient of 5 to 15 degrees. The soil type is gravelly sand.

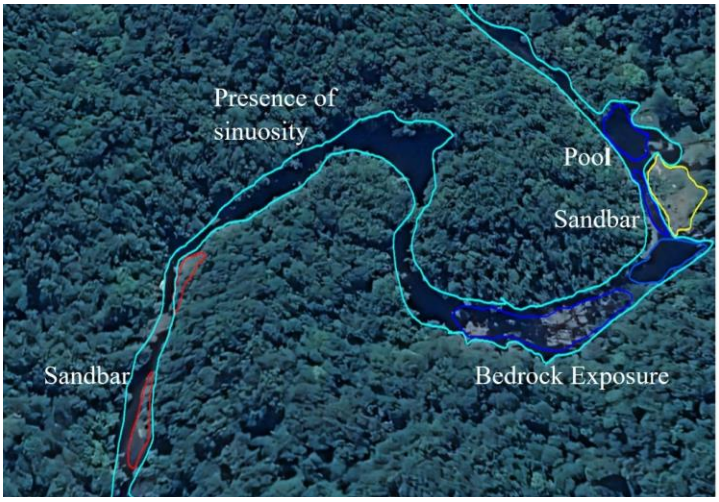

Figure 25 (a): Google earth image of a portion in the PRB exhibiting River Style 1, highlighting key identifying features such as sinuosity, pools, sandbars, and bedrock exposures.

Figure 25 (b): Images taken during field visits verifying the features at River Style 1, showing (a) cobbles and pebbles, and (b) a boulder present in the riverbed

5.4.1.2. Confined, Bedrock Margin controlled, Exposed Rock, Boulder bed (C-BrMC - ExpRock-Bbed)

This river style has been defined mostly in tributaries, stretching from origin to 9 km in Mullayar tributary, about 11 km from Mullayar to Idukki, in Chinnar river from origin till the confluence of mainstream (54 km) and from origin of Muthirapuzha river to Neriyamangalam power station (about 47km). The valley margin coincides with the active channel. The style is observed in hilly areas and in pediment zones at tributaries. Channel consists of bedrock margin, presence of instream features like vegetated sand bars, boulders and bed rock exposures (Figure 26) and the field images are shown in (Figure 27). It is characterized by a gradient of 5 to 15degrees. The soil type is gravelly and sandy in nature.

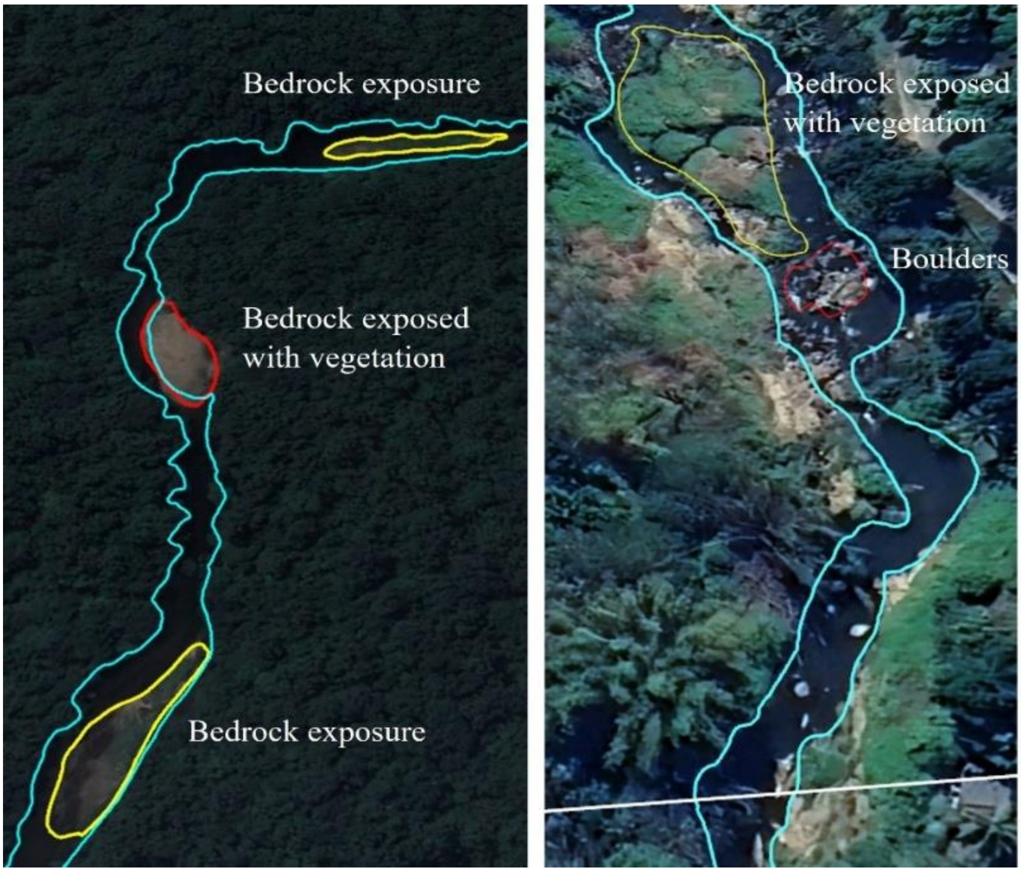

Figure 26: Google earth image of River Style 2, highlighting key identifying features such as boulders, bedrock exposures with vegetation.

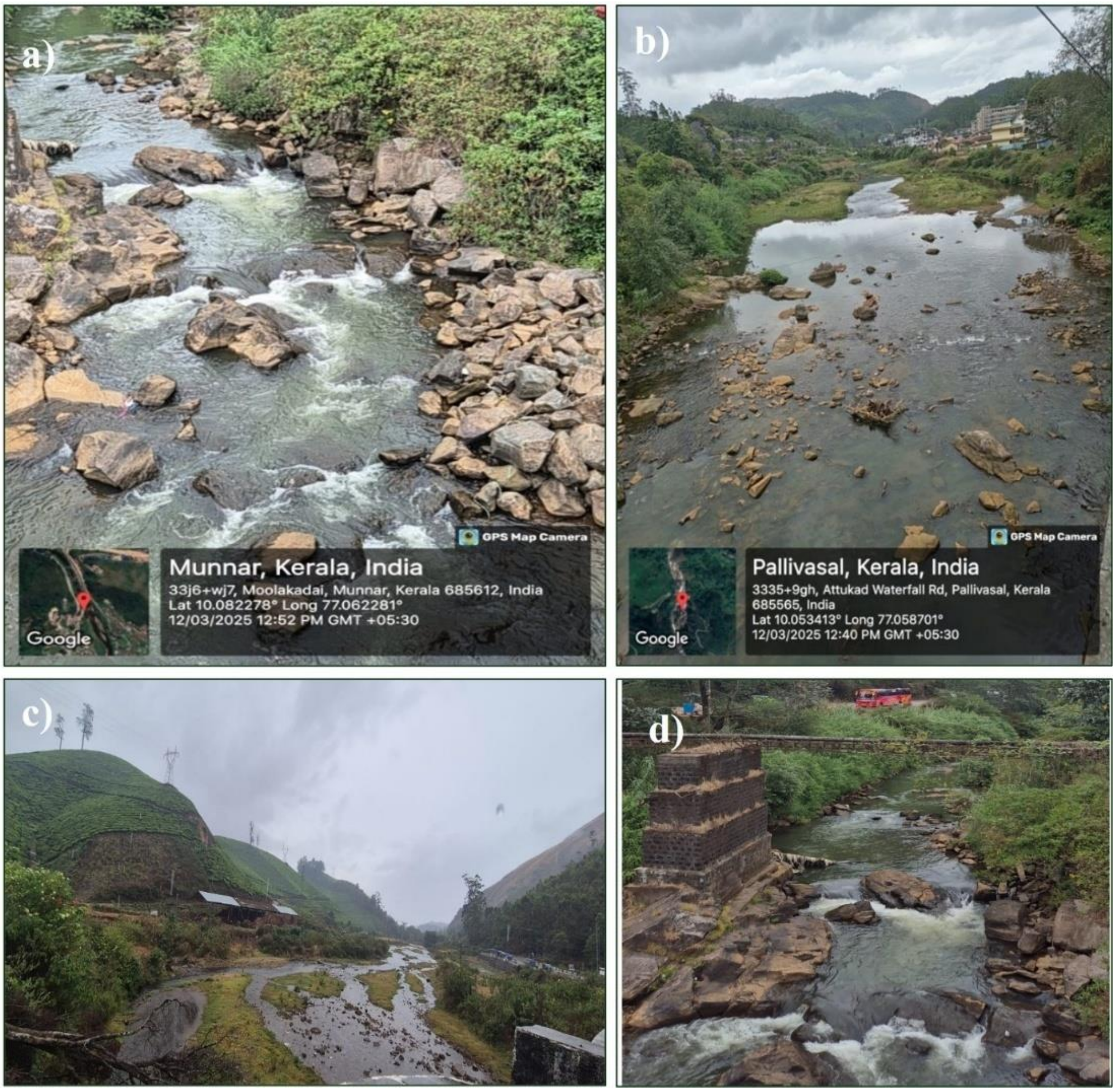

Figure 27: Images taken during field visits verifying the features at River Style 2, including (a) exposed rocks, (b) and (c) vegetated sand bars, and (d) cascades, which help in identifying and characterizing this style.

5.4.1.3. Confined, Bedrock Margin Controlled, Cascades, Boulder bed (C-BrMC-Cas-Bbed)

This river style has been defined only in mainstream extending from upstream region till Idukki reservoir for about 23 km. The valley margin coincides with the channel margin and the style is observed in hilly areas. It is characterized by a gradient of 5 to 15 degrees. Channel consists of bedrock margin, presence of rapids, boulder bed, bedrock exposure, runs, pools, riffles, pebbles, cascades (Figure 28.) The soil type is gravel.

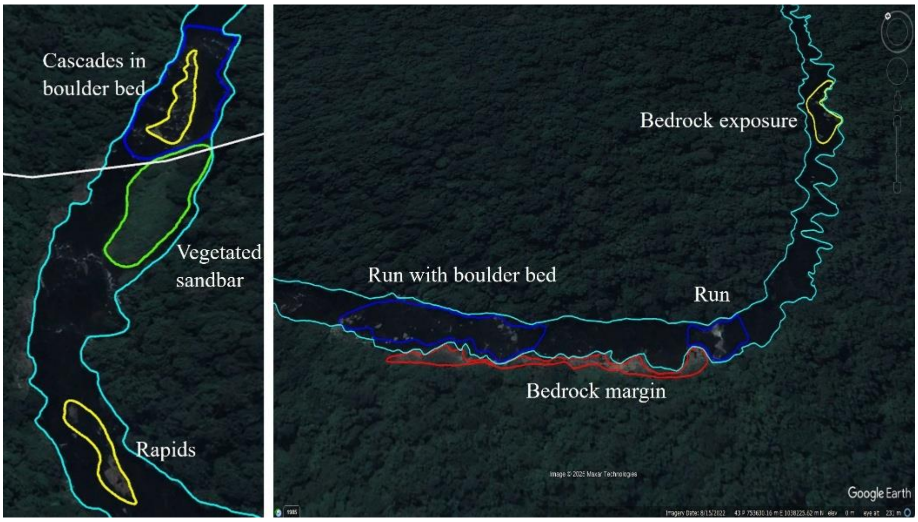

Figure 28: Google earth image of River Style 3, highlighting key identifying features such as cascades in boulder bed, vegetated sandbars, rapids, runs with boulder bed and bedrock exposure.

5.4.1.4. Confined, Bedrock Margin Controlled, Occasional Flood plain (C-BrMC-OccFP)

This river style stretches from stream Idukki reservoir to Mullaperiyar dam for about 64km. The valley margin coincides with the channel margin and the style is observed in pediment zone. It is characterized by a gradient of 5 to 15 degrees. Channel consists of bedrock margin, boulder bed, bedrock exposure, vegetated sandbars, occasional flood plains (Figure 29). The image from site is shown in (Figure 30). The soil type is gravel.

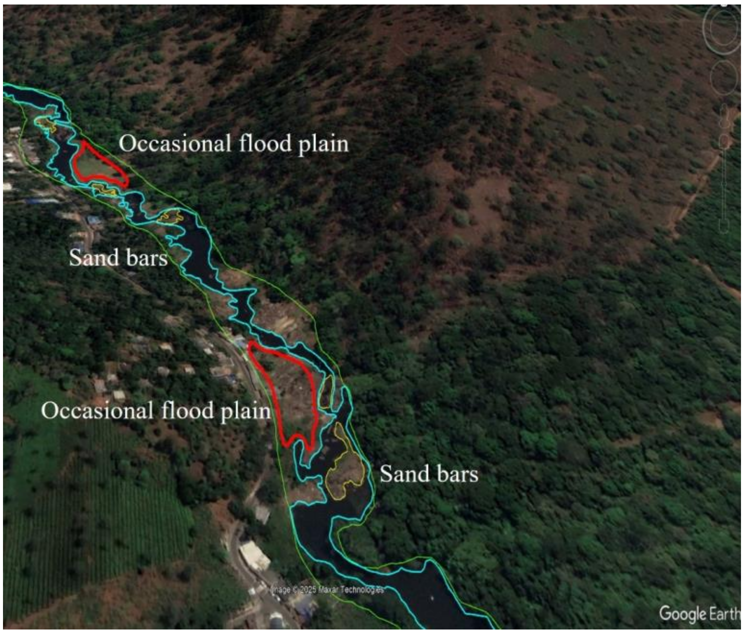

Figure 29: Google earth image of River Style 4, highlighting key identifying features such as occasional flood plains and sand bars.

Figure 30: Images taken during field visits verifying the features at River Style 4, including (a) vegetated sandbars, (b) boulders, and (c) a well-developed floodplain

5.4.1.5. Confined, Bedrock Margin Controlled, Point bar (Controlled-Point Bar C-BrMC-Pbar)

This river style is defined in the middle stretch of Mullayar river for bout 8km. The valley margin coincides with the channel margin and the style is observed in hilly region. Channel consists of bedrock margin, boulder bed, bedrock exposure, vegetated sandbars, point bars (Figure 31). The soil type is sandy in nature.

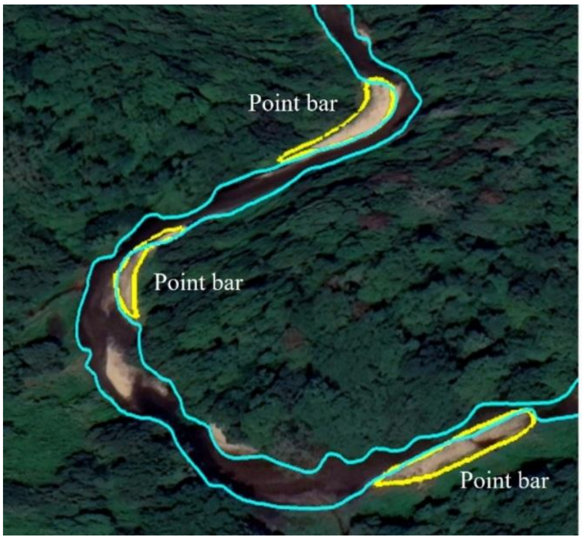

Figure 31: Google earth image of River Style 5, highlighting key identifying feature – point bars

5.4.1.6. Confined, bedrock margin controlled, gorge, boulder bed (C-BrMc-Gge-Bbed)

This style observed in the of Lower Periyar dam to Karimanal, Kadan kunnu to Kizhpattam, Pannimedu kuttu to Idamalayar reservoir, Kankattu mala to Mankulam, Valara to Bhoothathankettu reservoir. The style is seen in the mountainous terrain in which the valley is coinciding with the river channel where valley is deep, narrow and steep.The floodplain is absent because of the confinement. It is characterized by a gradient of less than 5 degrees. Bedrock core, lateral boulders, pools, riffles, waterfall, cascade, compound, mid channel and lateral bars are present (Figure 32). Bed material is dominated by Boulder, cobbles and bedrock.

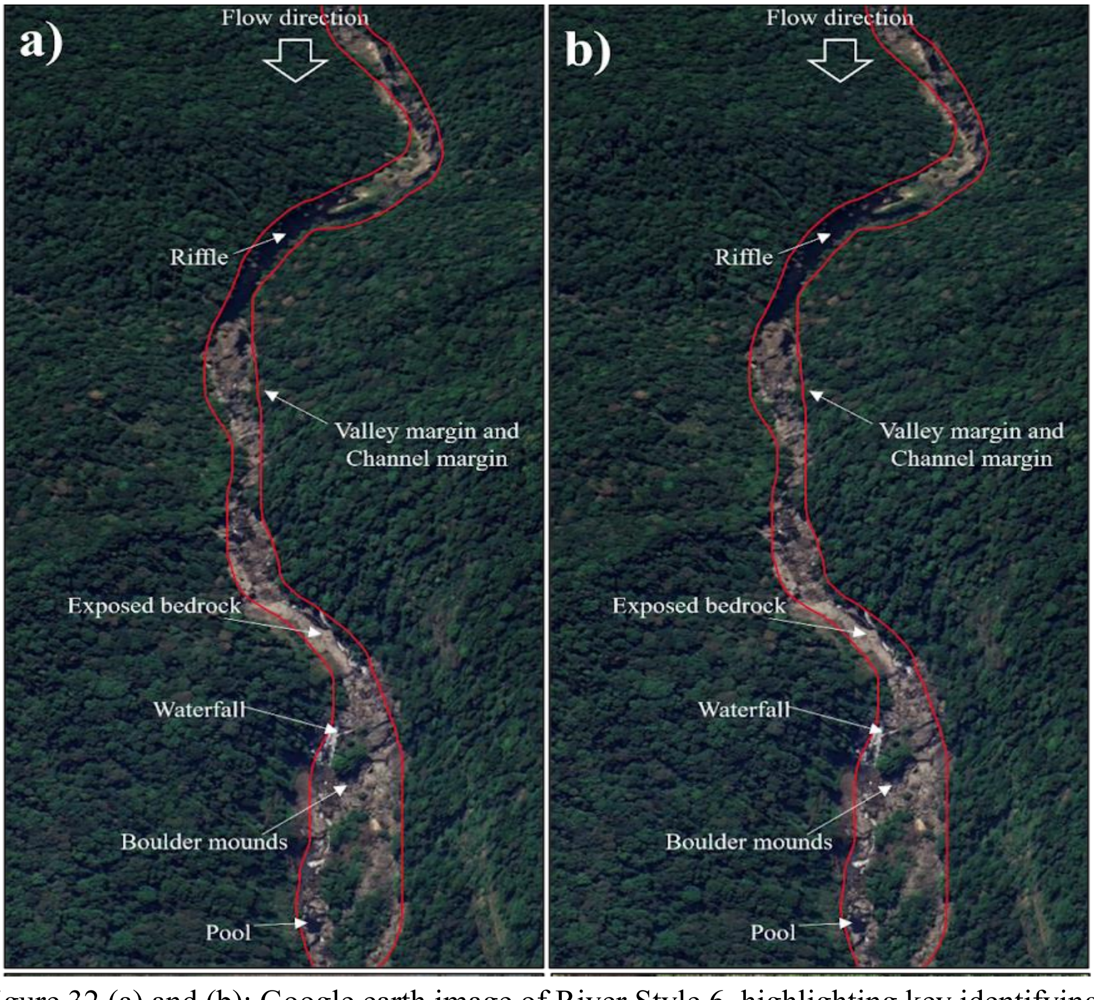

Figure 32 (a) and (b): Google earth image of River Style 6, highlighting key identifying features such as waterfalls, boulder mounds, pools, exposed bedrock.

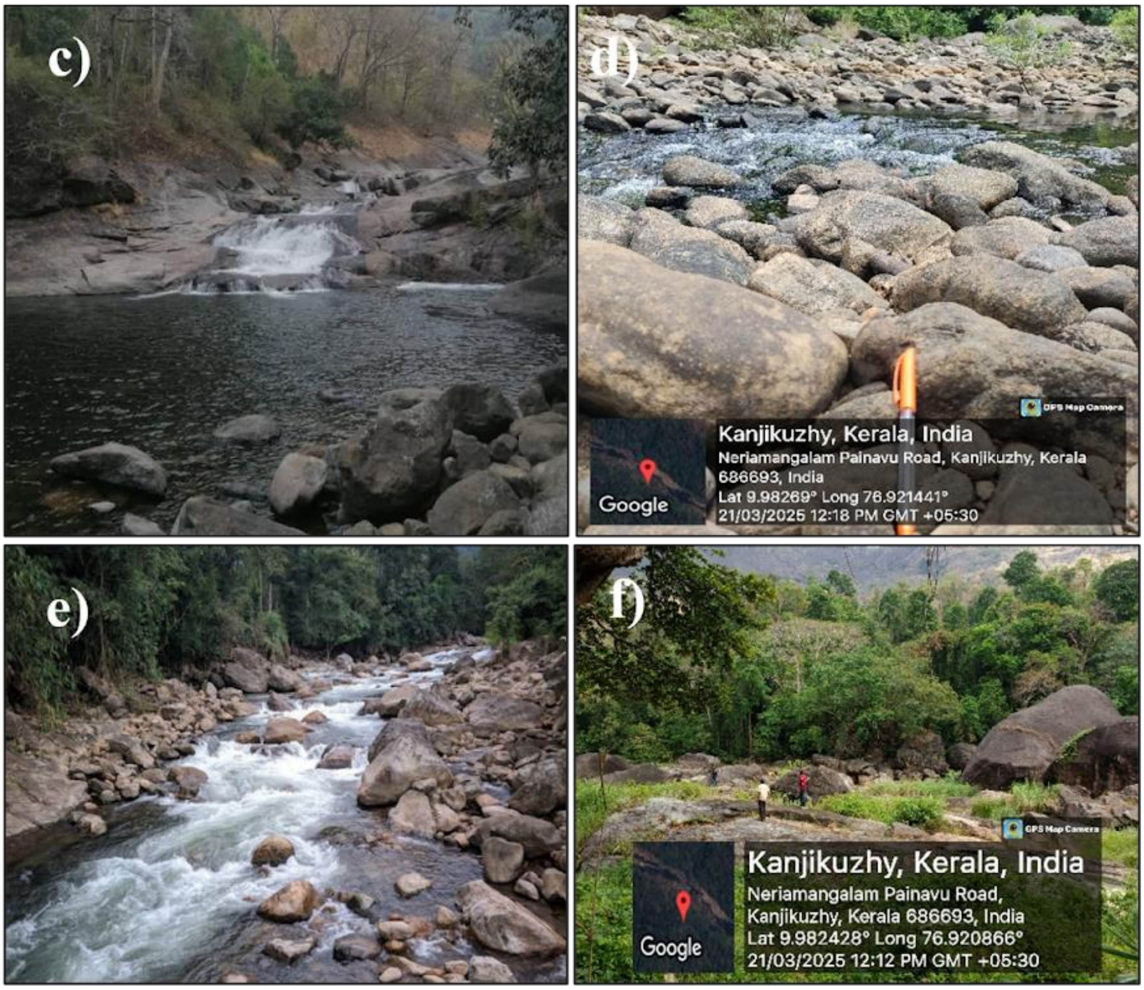

Figure 32 (c) to (f): Field photographs for illustrating key features in River style 6

5.4.1.7. Confined, terrace margin controlled, occasional floodplain pockets, bedrock bed (C-TrMc-OccFp-Brbed)

This river style occurs in the stretch of Bhoothathankettu dam to Paniyeliporu, Idamalayar dam to Bhoothathankettu reservoir and Pooyamkutty to Bhoothathankettu reservoir. It is situated in sinuous valleys with the channel flowing adjacent to the valley where occasional floodplains are observed. Bedrock core, boulders, elongate pool, riffles, run, cascade, chute channel, vegetated compound island and lateral bar are dominant geomorphic features present in the river stretch (Figure 33) and field photographs in (Figure 34). The slope gradient varies from 0.07 to 0.1 degrees. The bed materials are bedrock, cobbles, gravels and fine to coarse sand.

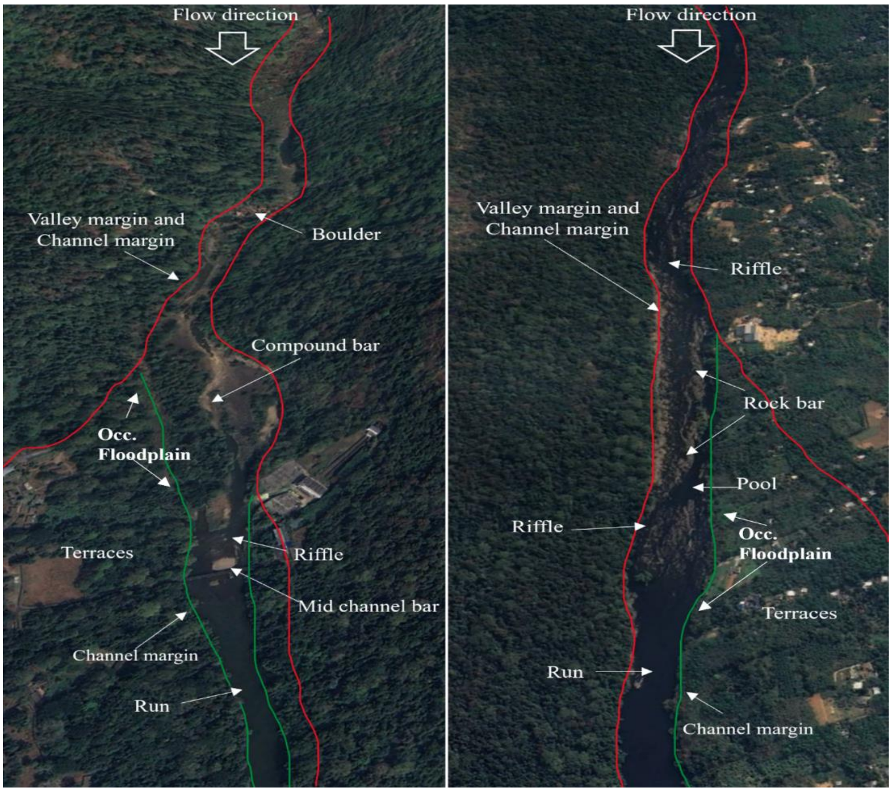

Figure 33: Google earth imageries of River style 7 illustrating key features like boulder, compound bar, terraces, riffles, mid channel bars and rock bars.

Figure 34 (a), (b) and (c): Images taken during field visits verifying the features at River style 7 in the Periyar, Idamalayar and Pooyamkutty river stretches

5.4.1.8. Confined, bedrock margin controlled, sinuosity, bedrock bed (C-BrMc-Sin-Brbed)

The river style defined between Kandiyam to Pooyamkutty is characterized by confined valley in the rugged hills. Floodplains are absent in this stretch where the valley margin and channel margin are completely coinciding in the stretch. The slope gradient is less than 1 degree and most of the stretch are exposed bedrocks. The major instream geomorphic features include bedrock core, pools, riffles, run, cascade, waterfall, compound bar, mid channel and lateral bars (Figure 35). Bedrock, cobbles and gravels are the bed materials.

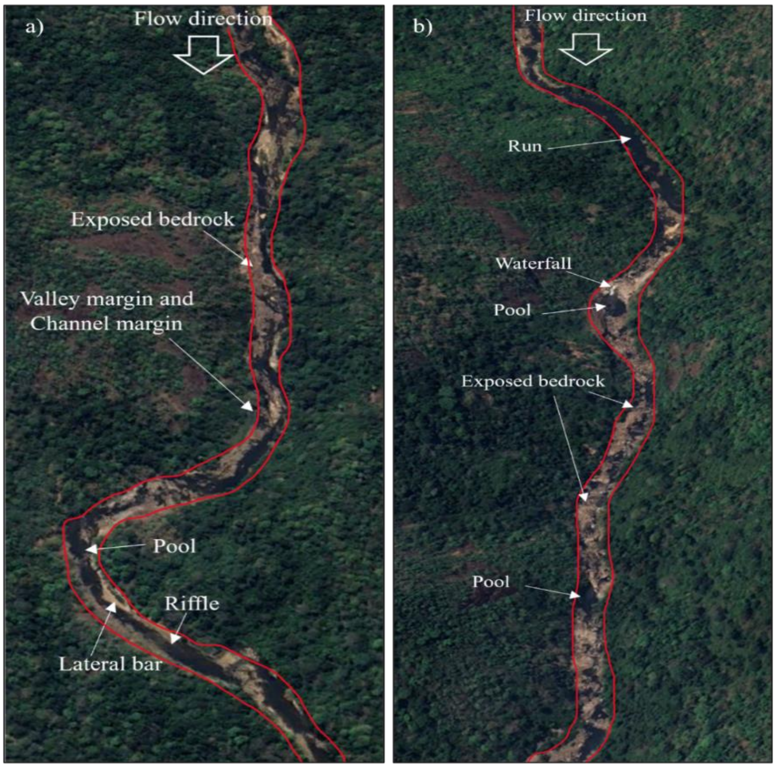

Figure 35 (a) and (b): Google Earth imageries of River style 8 illustrating the key features of the style such as lateral bars, exposed bedrocks, waterfalls, pools and riffles.

5.4.2. River Styles in the Partly-confined Valley Setting

5.4.2.1. Partly confined, terrace margin controlled, occasional floodplain, sinuosity, sand bed (PC-TrMc-Sin -OccFp-Brbed)

This style observed in the stretch from Karimanal to Chembankuzhy and Adimali to Valara where valley is partly-confined, channel flowing adjacent to the valley margin at about 50-90% of its length. It is situated in sinuous valley where occasional floodplains are present. The slope gradient is less than 1 degree. Bedrock core, boulders, pool, riffles, run, compound, point and lateral bars are the dominant geomorphic feature (Figure 36). Bed material in this river course is prominently by coarse sand, where local boulder and gravels are also observed.

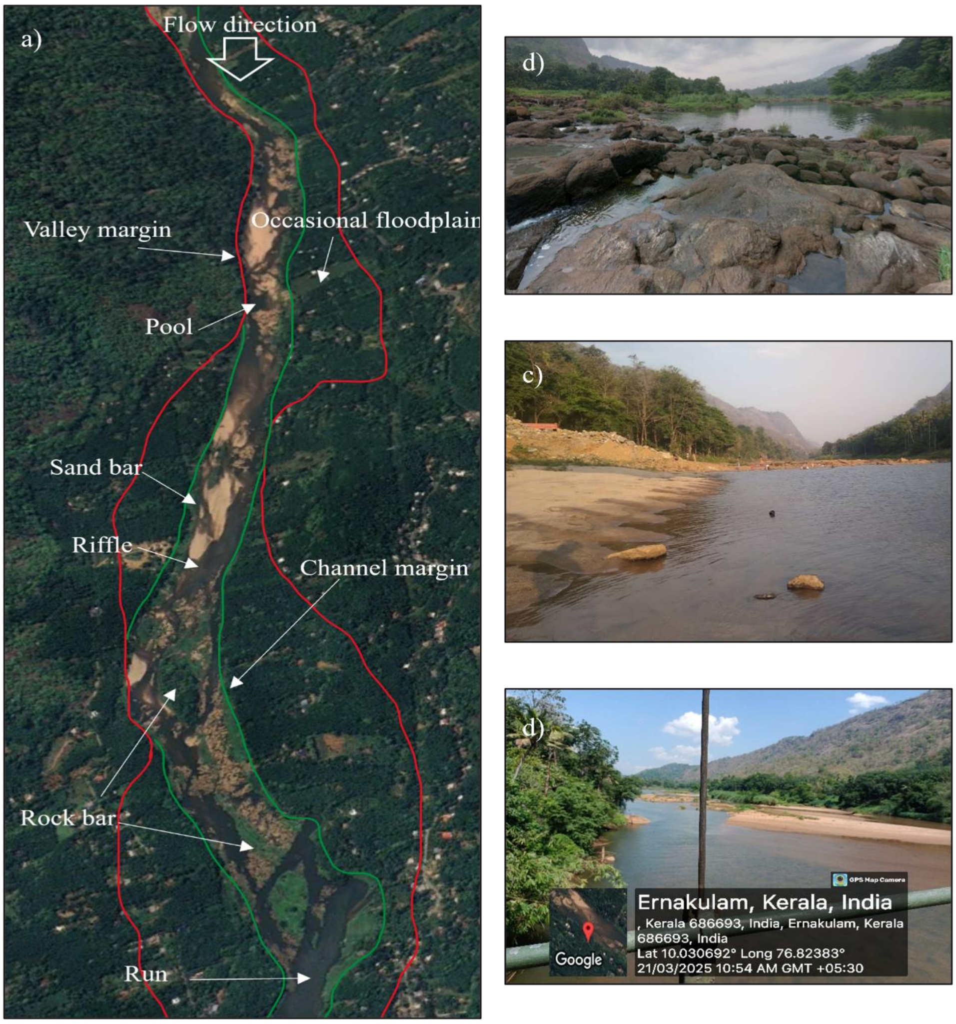

Figure 36 (a): Google earth imageries of River style 9 illustrating the key features like occasional flood plain, pools, sandbars, rock bars and run. Figures (b) to (d) are field photographs for the style.

5.4.3. River Styles in the Laterally Unconfined Valley Setting

5.4.3.1. Laterally Unconfined, Continuous channel, Anabranching, Fine grained bed (LU-C-An-Fbed)

This river style defined in the stretch from Paniyeli poru falls to Vypin and Aluva to Munambam where the valley bottom margin widens and the channel no longer coincides with the valley margin. The channel splits into more than two channels around bars and islands. The river showing braided channels. Continuous floodplains are formed along both banks. The most diagnostic geomorphic features in this river are large, stable alluvial islands dividing the channel into anabranches that rejoin downstream. In some regions exposed bedrock is seen. It is characterized by a slope of 0.01 degree. Most of the islands are vegetated and lateral bar, mid channel bar, pools, riffles, run are also present in this stretch (Figure 37). Bed material is dominated by fine sand to clay.

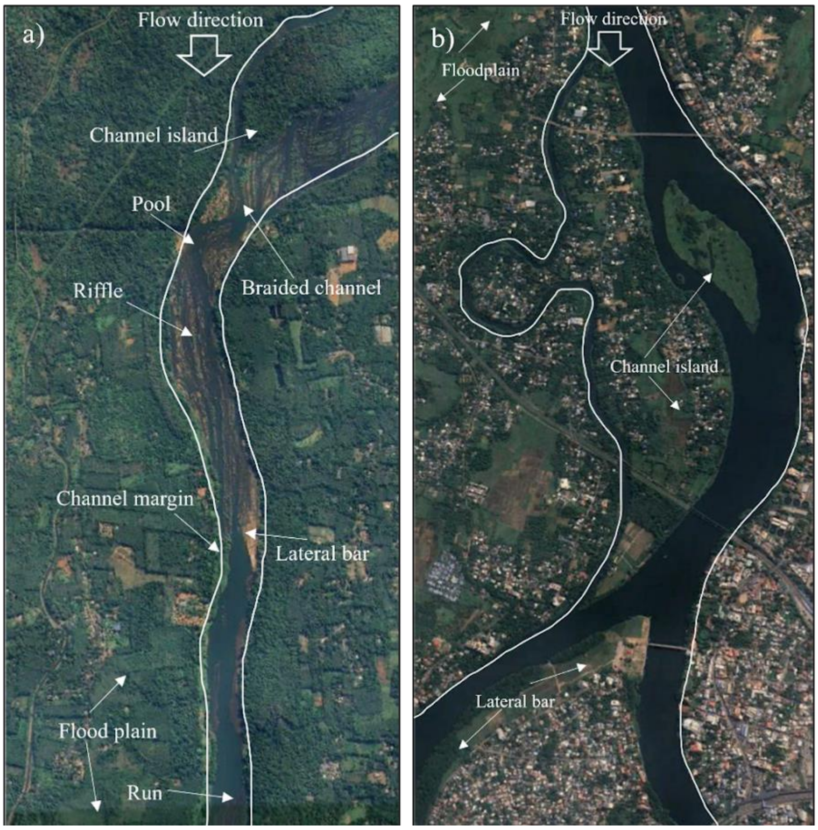

Figure 37 (a) and (b): Google Earth imageries of River style 10 illustrating the key features of the style such as lateral bars, braided channel, channel island and flood plain.

Figure 37 (c) to (f): Field photographs taken for verifying the features in River style 10

5.5. Grainsize distribution

The grain size distribution analysis has been carried out in some selected sites which are accessible. The samples were taken in the upstream region for better accuracy. Figure 38(a) shows the sample locations and Figure 38 (b) illustrates the distribution of soil sample in a sample location 2. The sample locations are sample1(S1)-Karimban bridge, sample2(S2)-Panamkutty bridge, sample3(S3) – Chinnar bridge, sample4 (S4-Moolakadai bridge, sample5(S5)-Periyavarai bridge. The distribution results are, shown Table 6.

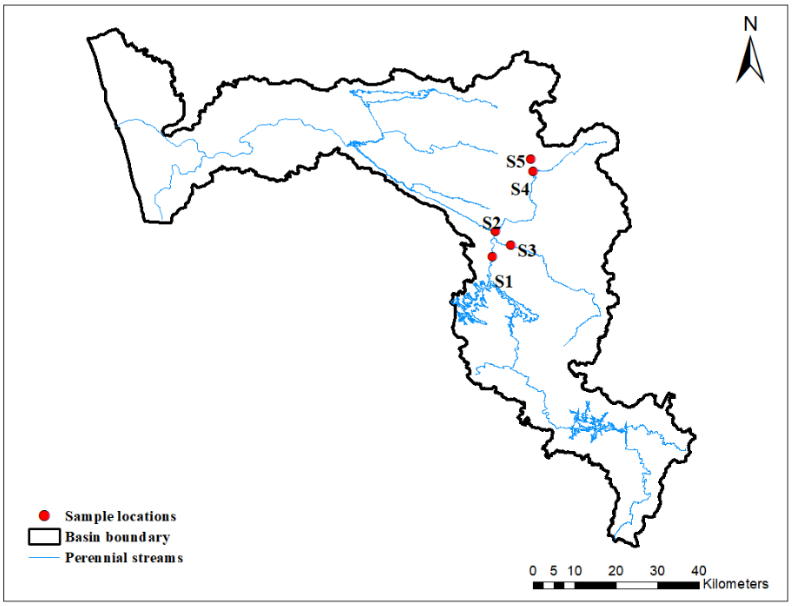

Figure 38 (a): Accessible locations of samples collected for grain size distribution analysis

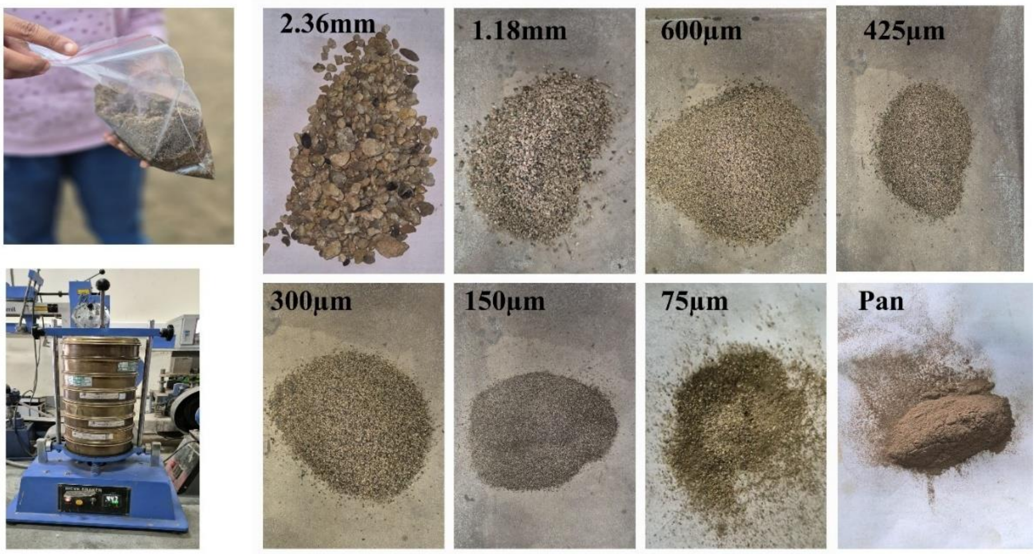

Figure 38 (b): Grain size distribution analysis for Sample 2. This figure presents the results of the laboratory sieve analysis, showing the amount of soil retained on each sieve for Sample 2

The results show,
STYLE 1: Gravelly
STYLE 2: Gravelly and sandy
STYLE 3: Gravelly
STYLE 4: Gravelly
STYLE 5: Sandy

Table 7: Type of soil in each sample location

Sample location	Cc	Cu	Type of soil
Chinnar	1.35	4.48	Poorly graded Gravel
Periavarai Bridge	1.25	3.00	Poorly graded sand
Karimban Bridge	1.20	2.51	Poorly graded sand
Mullakadai	1.23	2.80	Poorly graded sand
Panamkutty	1.23	2.76	Poorly graded sand

The pictorial representation of each of the above discussed styles is shown in Figures 39(a), 39(b), 39(c). The layout follows a hierarchy in which first is the planforms and the confinement of the river, then the geomorphic features, next is the bed form, next the name of the style and finally the style number.

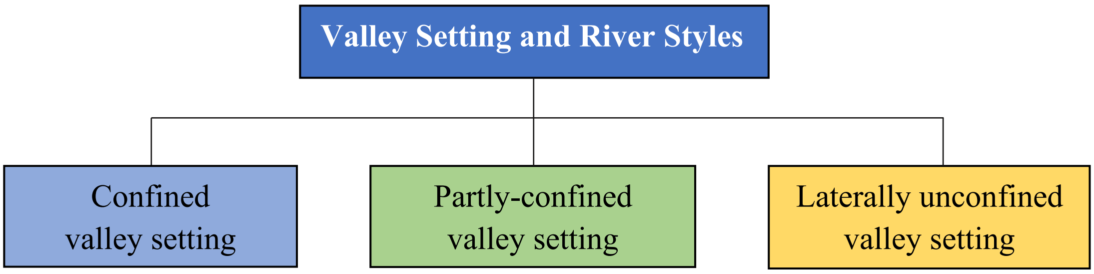

Figure 39(a): The basic classification of styles in the basin

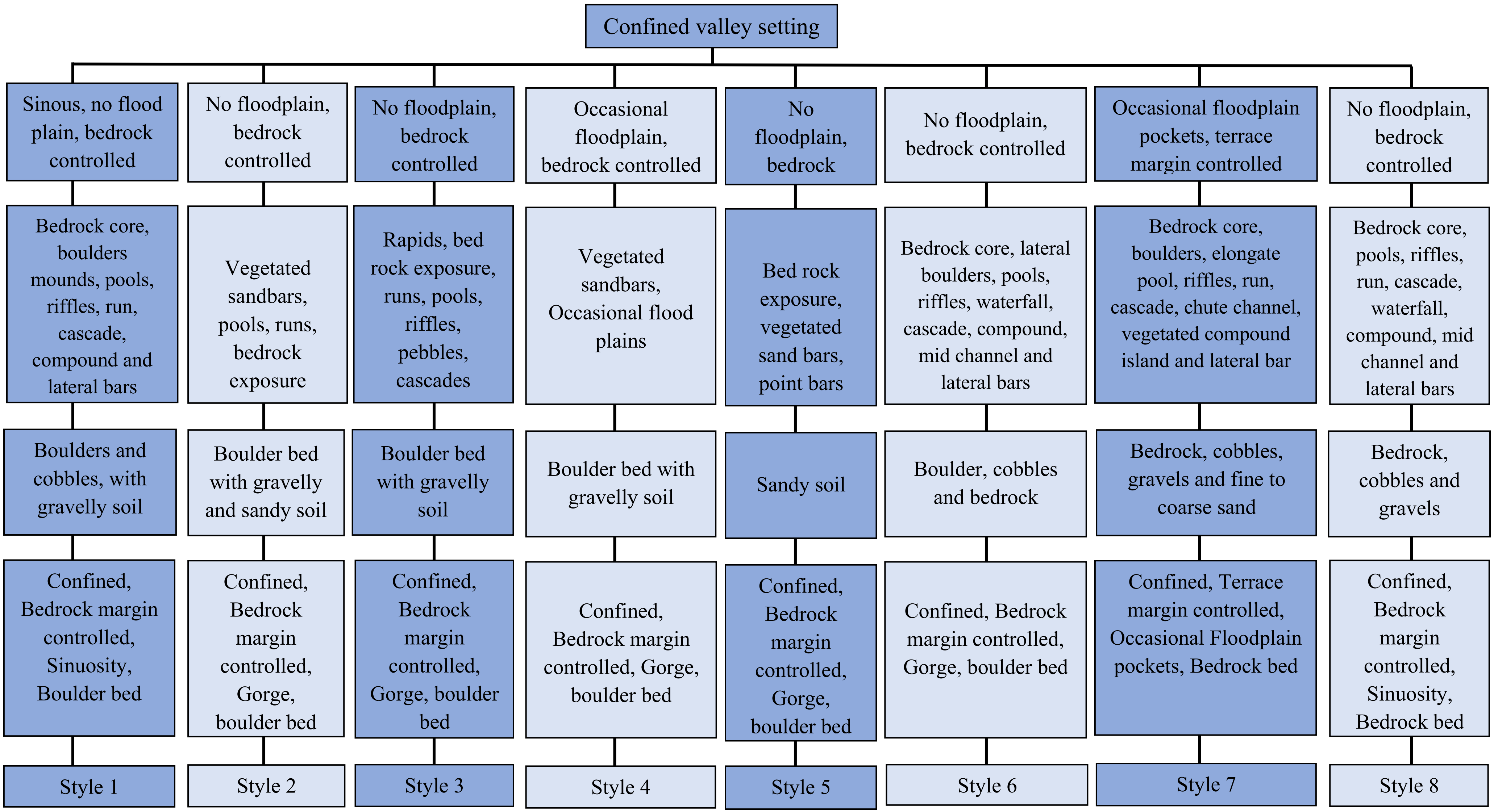

Figure 39(b): Subclassification of confined settings

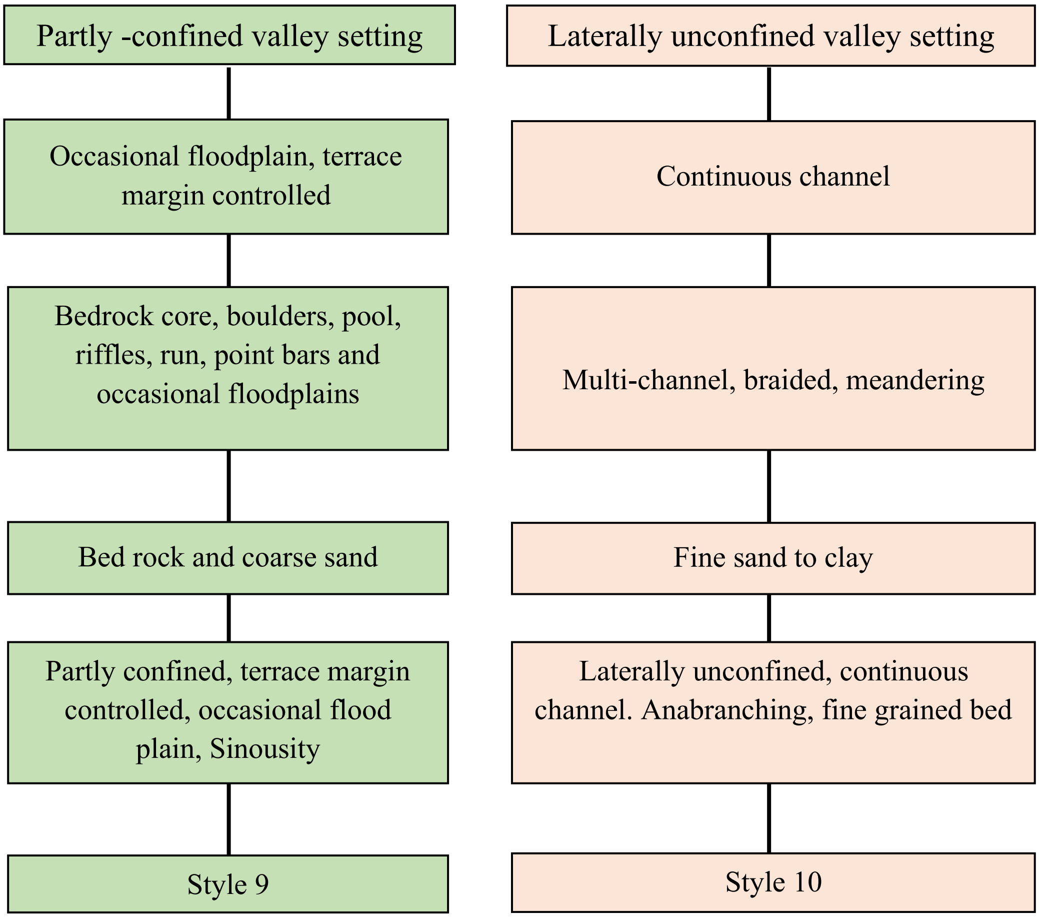

Figure 39(c): Subclassification of Partly confined and laterally confined settings

6. Findings and Summary

6.1 Geomorphology:

The geomorphology of the PRB is shaped by its diverse topography, geological formations, and fluvial processes. The river originates from the western ghats and flows towards the Arabian Sea by creating distinct types of landforms. Based on elevation and terrain PRB is divided into five units. These are lowlands, midlands, foothills, plateaus, and highlands. The lowlands form a thin strip along the shoreline. The midland consists of small hills and valleys along with undulating terrain. The Highlands are part of the Western Ghats, with ridges and high mountain ranges. The major geomorphological units include structural and denudational hills, residual hill, pedi plain, coastal plain, floodplain, marshy area, mudflats, and backwaters.

6.2 River Island Mapping:

River island mapping is very important for understanding how the river shapes the land, sediment movement, river behaviour, and how the ecosystem works. It also supports sustainable river basin management. In this study river islands present in the PRB are mapped by utilizing satellite imageries, such as Sentinel-2 MSI (with a resolution of 10 meters) to accurately map and analyse river islands. The Sentinel-1 SAR, MNDWI, and LULC maps of recent years also aid in supporting the identification of river islands. From the study, it shows that most of the islands are in the downstream portion of the basin. Temporal evaluation of the PRB using Landsat imageries indicates that the morphology of these islands has remained same over time.

6.3 Floodplain Mapping:

Floodplain mapping for the PRB was carried out using Sentinel-1A satellite imagery taken 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. Major floodplains have been observed in regions including taluks of Kodungallur, Mukundapuram, Aluva, Paravur, and Kochi. Areas surrounding the Idamalayar Dam, Idukki Dam, and Mullapperiyar Dam also appear to have experienced flood inundation. Also, 14 floodplains are identified across PRB (Room for River Report 2022).

The drastic change in land use in the PRB during the past three decades (1985-2015), resulted in a notable impact on the floods (Chapter IV- Impact of Change in Land Use and Land Cover Report from the Comptroller and Auditor General of India (CAG) 2021). Mainly urban expansion within flood-prone regions increased the risk of inundation. High intensity rainfall during the monsoon season followed by the release of dams has a major role in flood levels. The provision of an early warning system and community preparedness for the event needs to be strengthened.

6.4 River Styling:

Confined styles (Styles 1–5) dominate the upstream region, largely influenced by resistant bedrock margins and narrow valley walls. These stretches are typically high-energy environments, with features like boulder beds, cascades, and falls. Partly confined and unconfined styles middle lower regions indicate zones of valley widening or softer geological controls, where floodplain development, fine sediments, and anabranching channels begin to appear.Styles with occasional floodplains (Styles 4, 7, 9) suggest transitional zones where the river interacts with adjacent low-lying areas under certain flow conditions. The presence of point bars and anabranching systems reflects zones with relatively lower energy and sediment deposition patterns, essential for ecological diversity and riparian development.

7. Recommendations

The Periyar river, being the longest river in Kerala, is a key state resource that supports agriculture, industry, and domestic needs. This report presents a geomorphological study of the PRB focusing on river landforms, topography, geomorphic units, natural and human-induced processes, river islands, and flood-prone regions. This report integrates data from various sources such as Bhukosh portal, Digital Elevation Models (DEM), satellite data- including the sentinel dataset, rainfall data and discharge data. Also, these data sets are combined using advanced platforms such as GEE and ArcGIS. This report is a valuable tool for assessing the current condition of the PRB and developing effective management plans.

River island data serves multiple purposes, including monitoring and analysing dynamic changes over time, such as variations in size, location, and erosion patterns. This information is essential for flood risk assessment, land use planning, environmental management, and habitat conservation in riverine ecosystems. By identifying erosion-prone areas and potential shifts in river flow, mitigation strategies can be developed to safeguard communities and infrastructure near rivers.

Changes in land use and land cover, such as deforestation, urbanization, and agricultural practices, can significantly impact the hydrological response of a watershed. Providing data on river islands benefits government agencies for land use planning, environmental researchers for studying river dynamics, disaster management authorities for flood mitigation, hydrologists and geologists for understanding sediment transport, urban planners for sustainable development, farmers for agricultural insights, NGOs for ecosystem conservation, and navigation authorities for safer river transport.

Floodplain mapping is important for river conservation as it controls water flow, supports biodiversity, reduces the risk of flooding, and shows how sediment transport and habitat are. This data helps in developing strategies to protect and restore floodplains, which is important for the river system's long-term health and resilience. River styling helps to interpret the river character, behavior, condition and recovery potential. The results from this study can be used for making informed decisions about how to best protect communities and infrastructure from the devastating impacts of floods.

Overall, this report will be helpful to various state and central organizations for developing strategies and plans or disaster risk mitigation and response.

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