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

Protocol For Monitoring & Feedback

In Periyar River Basin

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Protocol For Monitoring & Feedback In Periyar River Basin

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

Centre for Periyar River Basin Management and Studies (cPeriyar)

The Center for Periyar River Basin Management and 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 centre 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

This report is a comprehensive outcome of the project jointly executed by IIT Palakkad (Lead Institute) and NIT Calicut (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It was submitted to the National River Conservation Directorate (NRCD) in 2025. We gratefully acknowledge the individuals who provided information and photographs for this report.

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Preface

The *Periyar River*, Kerala's longest and most economically significant river, sustains millions of people, supports diverse ecosystems, and powers vital industrial and agricultural activities. However, the river basin today faces escalating challenges, including hydrological extremes, pollution, land use change, and competing demands on water. In light of these pressures, a systematic and inclusive approach to river basin management is no longer optional but essential.

This report, *Protocol for Monitoring and Feedback for Periyar River Basin*, provides a comprehensive framework to guide the sustainable management of the basin through continuous monitoring and adaptive feedback. It emphasizes the importance of coordinated involvement across a broad spectrum of stakeholders, central and state government agencies, scientific and research institutions, academic bodies, and regulatory authorities, who play a critical role in data collection, analysis, and policy implementation.

Importantly, the protocol also recognizes the value of local knowledge and the vital contributions of non-governmental organizations (NGOs), civil society, and community groups. Their participation in monitoring efforts and feedback mechanisms ensures greater transparency, accountability, and ownership, while bridging the gap between policy and practice.

The document outlines key parameters to be monitored, ranging from river discharge and groundwater levels to biodiversity and industrial pollution and details required for systematic data collection. By integrating advanced scientific techniques such as GIS and remote sensing with participatory approaches the protocol promotes a balanced model of governance that is both data-driven and people-centered.

We hope this report serves as a practical guide for institutions, researchers, policymakers, and communities alike enabling collective action and long-term resilience in managing the *Periyar River Basin*.

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

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List of Abbreviation

CWC	Central Water Commission
CGWB	Central Ground Water Board
KSPCB	Kerala State Pollution Control Board
KSDMA	Kerala State Disaster Management Authority
IMD	India Meteorological Department
KCZMA	Kerala Coastal Zone Management Authority
KWA	Kerala Water Authority
IDRB	Irrigation Design & Research Board
KSPB	Kerala State Planning Board
KSBB	Kerala State Biodiversity Board
SWAK	State Wetland Authority Kerala
IMD	Indian Meteorological Department
CPCB	Central Pollution Control Board
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
PCB	Pollution Control Board
SW	Surface Water
GW	Ground Water
NMCG	National Mission for Clean Ganga
MoEFCC	Ministry of Environment, Forest and Climate Change
KSLUB	Kerala State Landuse Board
KSDMA	Kerala State Disaster Management Authority
KSPB	Kerala State Planning Board

KFRI	Kerala Forest Research Institute
KSBB	Kerala State Biodiversity Board
CWRDM	Centre for Water Resources Development and Management
IIRS	Indian Institute of Remote Sensing
NCESS	National Centre for Earth Science Studies
KERI	Kerala Engineering Research Institute
NGO	Non-Governmental Organization
LULC	Land Use Land Cover
ET	Evapotranspiration
STP	Sewage Treatment Plant
ETP	Effluent Treatment Plant
GIS	Geographic Information System
HIL	Hindustan Insecticides Limited
FACT	Fertilisers and Chemical Tranvancore
IRE	Indian Rare Earths
DDT	Dichloro-diphenyl-trichloro-ethane
PMVS	Periyar Malineekarana Virudha Samithi
ATREE	Ashoka Trust For Ecology and the Environment
IBP	Indian Biodiversity Portal

1. Introduction

Developing a 'Protocol' for River Basin Management is necessary as it helps to arrive at clear procedures for addressing each issue reported in the river basin. A detailed protocol clarifies the roles and responsibilities of various stakeholders, including government, communities and industries. The development of an institutional framework helps address specific issues within the basin. Therefore, protocol development will help resolve any conflicts arising in the basin.

A monitoring mechanism involves systematically collecting data such as water quality, discharge, biodiversity, water usage statistics, industrial discharges, etc. A continuous monitoring framework helps to identify the change in any of the parameters influencing river health and the location where the changes occur. Such a monitoring mechanism allows the detection of changes, trends and emerging threats in the river basin. The issues in the basin can be identified and sorted out in the early stages. Such continuous monitoring enhances transparency and builds trust among stakeholders.

Feedback mechanisms allow responses, corrections or improvements based on monitoring outcomes. Feedback mechanisms help to identify any flaws in the developed protocols. The protocols can be revised and evaluated based on the feedback. A feedback mechanism ensures community participation. Through feedback the stakeholders inputs are incorporated which enhances the basin management programs. Thus, the combined effect of Protocol, Monitoring, & Feedback is crucial for managing complex dynamics in the River Basin, which often involve multiple stakeholders, competing demands and climate-induced stress.

2. Existing Framework

The existing frameworks within the Periyar Basin for monitoring the river, environment & ecological factors under state and central government agencies are listed below:

2.1 Hydro-meteorological sites by CWC

Hydro-meteorological sites (HMS) of CWC are stations responsible for collecting hydrological, meteorological and water quality parameters.

- Parameters monitored: Hourly Rainfall, Temperature, Humidity and Pressure. Data observed by an autographic rain gauge, thermograph, hygrograph and barograph, respectively
- Hourly Sunshine duration data observed using a sunshine recorder
- Hydrological parameters – Stream gauge, discharge, sediment load
- Water Quality – Chemical & Biological parameters

2.2 Groundwater Monitoring Network by CGWB

Central Ground Water Board (CGWB) monitors groundwater levels on a regional scale four times a year during March/April/May, August, November and January. The network consists of open-dug wells and purpose-built tube wells for water level monitoring. The six-hour water level data were recorded and transferred by the Water Information Management System (WIMS), which was developed and maintained by the National Water Informatics Centre (NWIC) under the Ministry of Jal Shakti.

- Parameters monitored – Groundwater levels
- Groundwater quality – parameters such as pH, Turbidity, CO_3, HCO_3, Cl, SO_4, NO_3, PO_4, TH, Ca, Mg, Na, K, and TDS are monitored

2.3 Water Quality Monitoring by KSPCB

The Kerala State Pollution Control Board (KSPCB) monitors river water quality through the National Water Monitoring Programme (NWMP). Samples are collected every two months (May/June, August, October, December, February, and April) from perennial rivers and 3-4 times from seasonal rivers annually.

- Physical, chemical & biological parameters of the river water are assessed
- The significant parameters monitored include – pH, Alkalinity, Hardness, Ammonia, Chlorine, EC, BO, BOD, TC, FC, FS, Temp, Turbidity, TSS, TDS, TFS, COD, AN, TKN, Nitrate, Fluoride, Boron, K, Ca, Mg, Phosphate, Pesticides
- Sewage treatment plant & solid waste management

Central Pollution Control Board (CPCB), in collaboration with State Pollution Control Boards (SPCBs) in the States, has established a National Water Quality Monitoring Network (NWMP) to assess the status of water quality of water resources and to facilitate the prevention and control of pollution in water bodies.

2.4 Natural Disasters - Early warning of Flood & landslides by KSDMA

The Kerala State Disaster Management Authority (KSDMA) monitors various aspects of disaster risk management, including weather events, sea conditions, and drought conditions, and also prepares disaster management plans and guidelines. The monitoring activities by KSDMA include:

- Extreme weather event alerts - KSDMA utilises alerts from the India Meteorological Department (IMD) regarding rainfall intensity, amount, and expected areas to be affected
- Sea State and Tides - Sea state and tides are monitored by the Indian National Centre for Ocean Information Services (INCOIS)
- Drought Monitoring - KSDMA alerts the government when triggers of drought are identified and requests the convening of the State Executive Committee

- Landslide monitoring - KSDMA monitors parameters like pore water pressure, soil suction, water content, rain intensity, and temperature to assess landslide risk.

2.5 IMD Weather Monitoring Network

- Automatic Weather Stations (AWS) - IMD has established a network of AWS across Kerala, which provide near real-time data in 15-minute intervals
- Automatic Rain Gauges (ARG) & Manual Rain Gauges - IMD has also deployed ARGs to monitor rainfall patterns. In addition to the automatic gauges, IMD maintains a network of manual rain gauges, which are part of the District-wise Rainfall Monitoring Scheme (DRMS)
- Weather Monitoring using Doppler Radars

2.6 **Coastal Zone Management** – Kerala Coastal Zone Management Authority (KCZMA)

Kerala Coastal Zone Management Authority (KCZMA) is functioning under the Department of Environment and Climate Change, Government of Kerala. The activities by KCZMA include:

- Project Review and Recommendation for development projects in Coastal Regulation Zone (CRZ) areas
- Regulates all developmental activities in coastal areas according to CRZ Notification
- Enforcement & Monitoring the provisions of the CRZ Notification - Monitors unauthorized construction, encroachments, wetland reclamation
- Prevention & control of pollution in CRZ areas
- Focuses on conserving sensitive coastal ecosystems (e.g., mangroves, backwaters)

2.7 Water Quality Monitoring by KWA

Kerala Water Authority has a well-established system for monitoring water quality through a network of district laboratories. The main function of Quality Control Wing is surveillance and monitoring the quality of water supplied through various water supply schemes. The quality of water in river sources, wells, private samples etc are also been tested in the labs under the quality control wing.

- Management of drinking water supply from river sources
- Implementation of wastewater treatment projects
- Monitoring water quality in major rivers

2.8 Hydrologic Monitoring Wing - IDRB

The Hydrology Wing of IDRB is responsible for the collection, validation and distribution of all the water-related historical and real-time data on the water resources of the state.

The essential functions of this wing are:

- Collection, tabulation and processing of daily reservoir level and storage volumes from the various completed irrigation projects.
- Flood discharge assessment of Irrigation structures, Peak flood estimation and Water Balance studies of river basins.
- Preparation of State-Specific Action Plan under the National Water Mission
- Implementation of the National Hydrology Project

2.9 Haritha Keralam Mission

Constitutes 3 sub-missions related to water conservation, sanitation and waste management. The primary activities include:

- Revival of ponds, lakes, and wetlands
- Rejuvenation of rivers by preventing encroachments
- Waste management to reduce pollution
- Engages communities in water conservation and pollution control
- Supports ecological restoration of river systems

2.10 Kerala State Planning Board (KSPB)

The major activities carried out by the KSPB are:

- Formulating Five-Year and Annual Plans
- Monitoring Plan implementation through 'Planspace', the Management Information System
- Interdepartmental coordination concerning Plan schemes
- Housing and coordinating the work of the Decentralisation Cell
- Commissioning studies and fulfilling a think-tank function
- Coordinating information and recommendations concerning externally aided programmes, centrally sponsored schemes, NABARD, and CSR funds
- Responding to requests from Departments for instruction and advice

2.11 Kerala State Biodiversity Board (KSBB)

Kerala State Biodiversity Board is an autonomous body of the state government under the Kerala State Environment Department, with its headquarters in Thiruvananthapuram. The KSBB is dedicated to conserving and protecting the state's agro, plant, and fish diversity.

- The primary function of the KSSB is to advise the State Government on any guidelines issued by the Central Government on matters relating to biodiversity conservation.

- KSBB maintains a Biodiversity register at Panchayat, municipalities & corporation levels. The record includes the list of flora & fauna, agricultural biodiversity, natural ecosystems and the list of threatened & endangered species.
- KSBB maintains the health of various ecosystems such as Forest ecosystems, freshwater ecosystems, coastal ecosystems, urban ecosystems & wetlands.
- KSBB promotes community seed banks and supports traditional farming practices that are biodiversity-friendly.
- KSBB identifies & monitors rare, endangered and threatened species under pressure from habitat loss.

2.12 State Wetland Authority Kerala – SWAK

SWAK was established under the Ministry of Environment, Forest & Climate Change (MoEFCC), Government of India, for the integrated management of wetlands. The primary functions of SWAK are:

- Prepare a comprehensive digital inventory of all wetlands within one year and update the inventory every ten years
- Develop a comprehensive list of activities to be regulated and permitted within the notified wetlands and their zone of influence.
- Define strategies for conservation and wise use of wetlands within their jurisdiction.
- Review the integrated management plan for each of the notified wetlands
- Ensure enforcement of these rules and other relevant Acts, rules and regulations on a half-yearly basis
- Coordinate implementation of integrated management plans based on the wise use principle through various line departments and other concerned agencies.
- Function as nodal authority for all wetland-specific authorities within the state.
- Issue necessary directions for conservation and sustainable management of wetlands to the respective implementing agencies.

3. Existing Framework for Continuous Monitoring

Among the various frameworks available for monitoring, some frameworks have continuous monitoring. The continuous monitoring framework includes Groundwater quality monitoring stations by CGWB, Surface water quality monitoring by KSPCB, stream flow measurements by CWC, and weather monitoring locations by IMD and IDRB. The Periyar along with its sub-basins are shown in Fig. 1. Apart from the Periyar main stem, Mullayar, Kattappana, Cheruthoni, Chinnar, Muthirapuzha, Deviar, Idamalayar and Pullut are its sub-basins. The location details of Groundwater quality monitoring locations by CGWB and surface water quality monitoring locations by Kerala State Pollution Control Board are shown in Fig. 2 and 3 respectively.

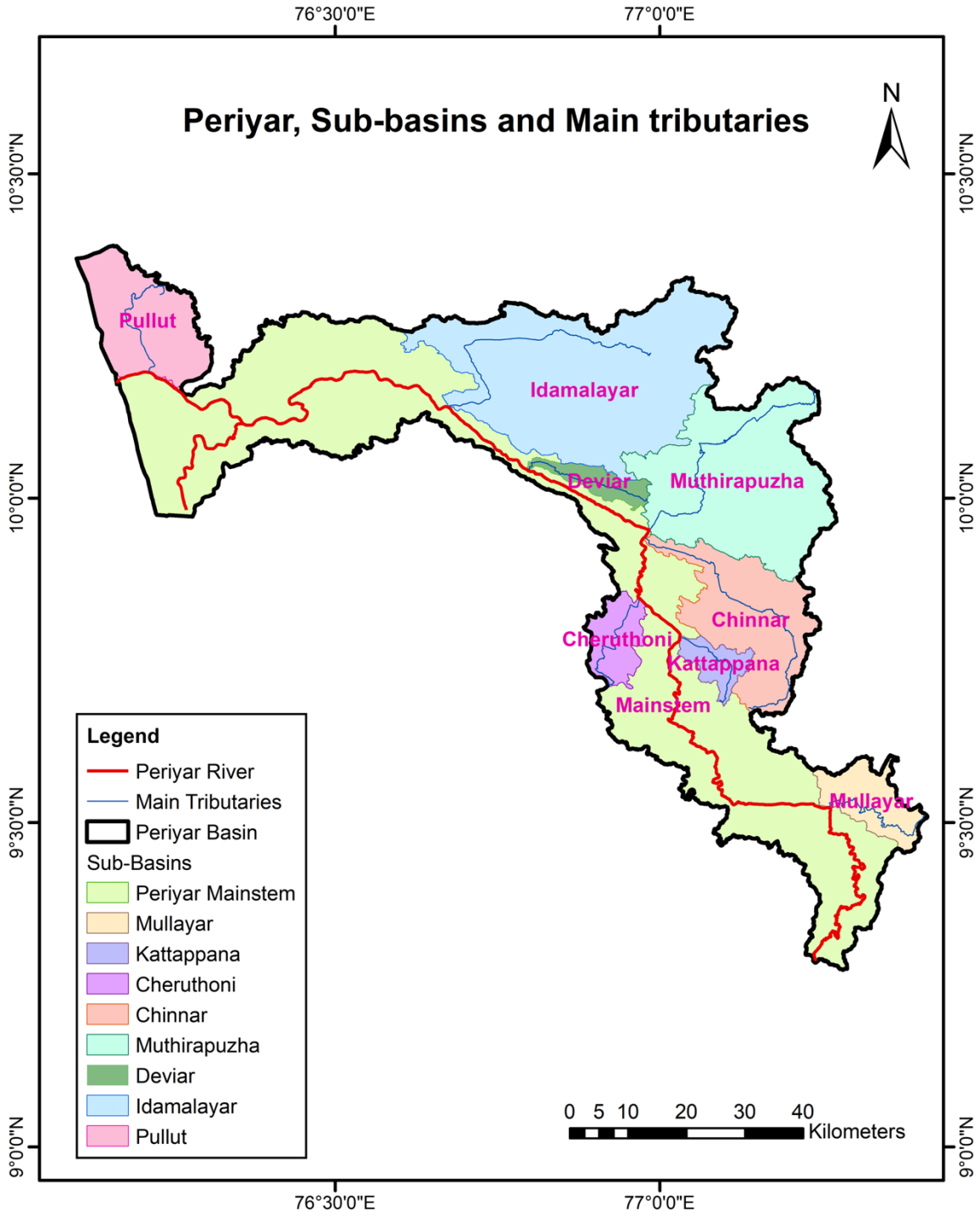


Fig.1 Periyar with its sub-basins & main tributaries

The Periyar River Basin of total area 5216 km^2 extends across two states, covering 5,085 km² in Kerala and 131 km² in Tamil Nadu. The Periyar main stem has a length of 260 km, originating from Chokkampatti Malai of Sivagiri Hills, Western Ghats and drains into the Arabian sea through two outlets, one at Munambam and other through Vembanad lake.

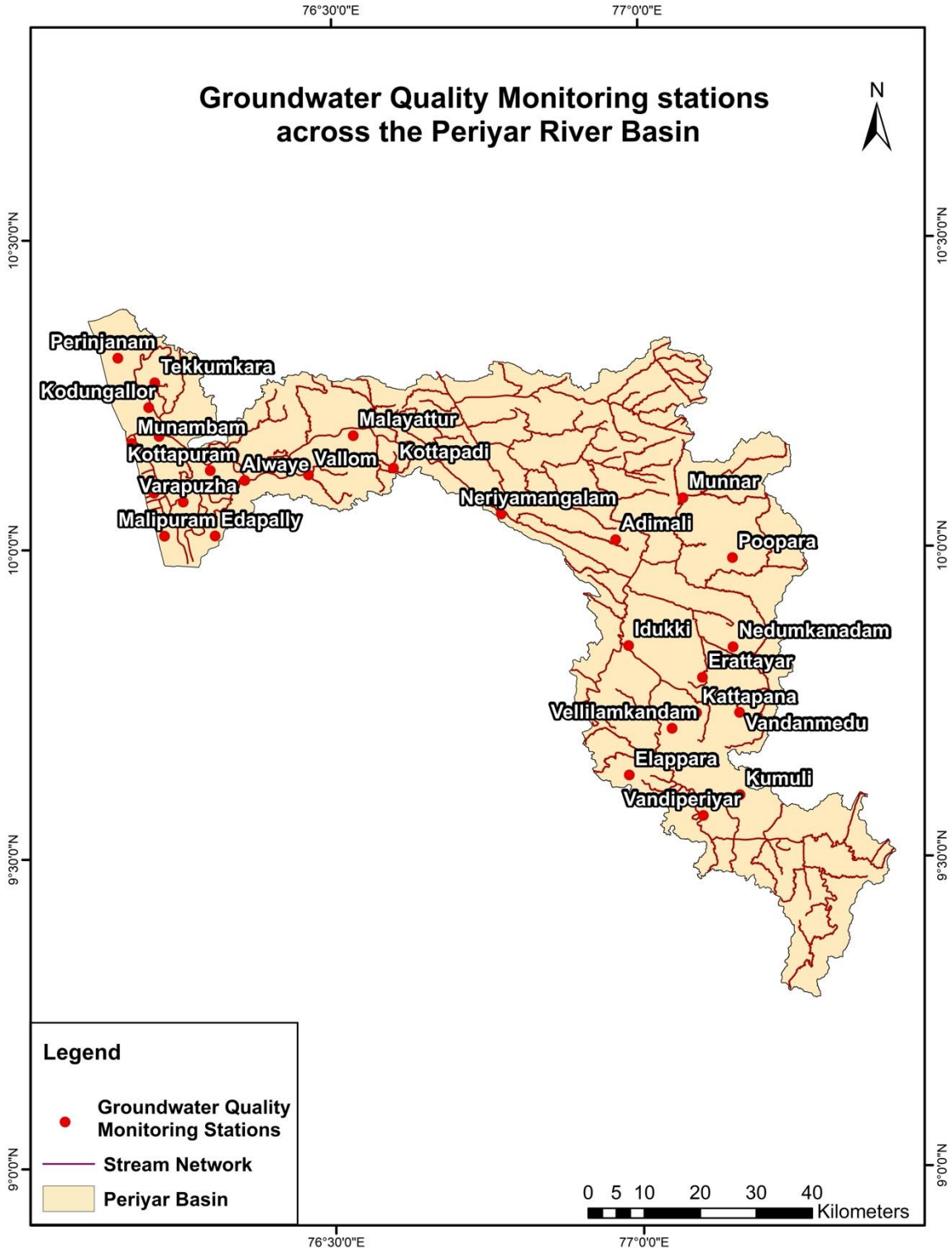


Fig. 2 Groundwater Quality Monitoring location by CGWB in Periyar

Fig.2 shows that more groundwater quality monitoring stations are located on the downstream side of the basin. The number of monitoring stations in the Kothamangalam sub-district has to be increased. The Idamalayar sub-basin need more groundwater quality monitoring locations. Since Munnar is a tourist spot, the chances of pollution are high. The dependency on groundwater has also increased due

to boom in tourism, so having more monitoring networks in the Muthirapuzha sub-basin is recommended. The upstream of Mangalapuzha also lacks monitoring stations. It is recommended that monitoring locations be increased upstream of Mangalapuzha branch.

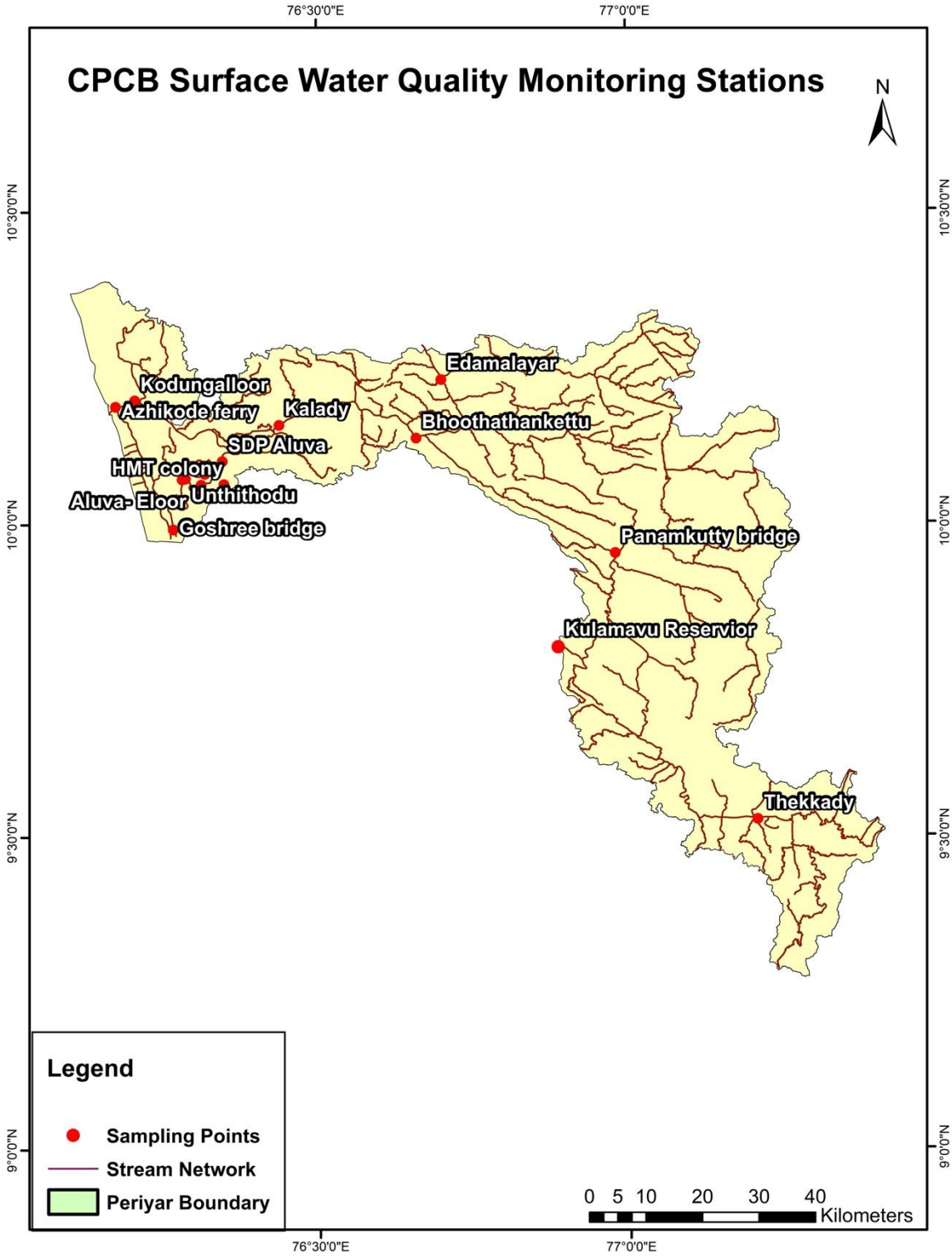


Fig. 3 Surface water Quality Monitoring location by CPCB, Periyar

The surface water quality monitoring locations by the Kerala State Pollution Control Board are shown in Fig.3. There is a lack of water quality monitoring networks in the Kothamangalam & Devikulam sub-districts. It is recommended to have more surface water quality monitoring locations at the Idamalayar sub-basin. Monitoring locations should be increased in the Muthirapuzha and Chinnar sub-basins. Surface water quality should be monitored at Upputhara which has industrial areas along the main stem of Periyar.

Fig. 4 illustrates the stream gauging stations within the Periyar River Basin monitored by the Central Water Commission (CWC). Currently, there are only two such stations in the basin—Vandiperiyar, located in the upstream region, and Neeleswaram, situated in the downstream section. In addition, the Irrigation Department of Kerala (IDRB) operates three monitoring stations downstream at Kalady, Mangalapuzha, and Marthandavarma. However, the limited number of monitoring points along the main stem of the river highlights the need to establish additional flow gauging stations between Vandiperiyar and Neeleswaram. In particular, a new stream gauge is recommended just upstream of the Bhoothathankettu barrage, a key regulatory point in the basin. This location receives substantial inflows from the Chinnar, Pooyamkutty, and Muthirapuzha tributaries, as well as spillover from the Idukki, Lower Periyar, and Idamalayar dams, making it a strategic site for continuous flow monitoring.

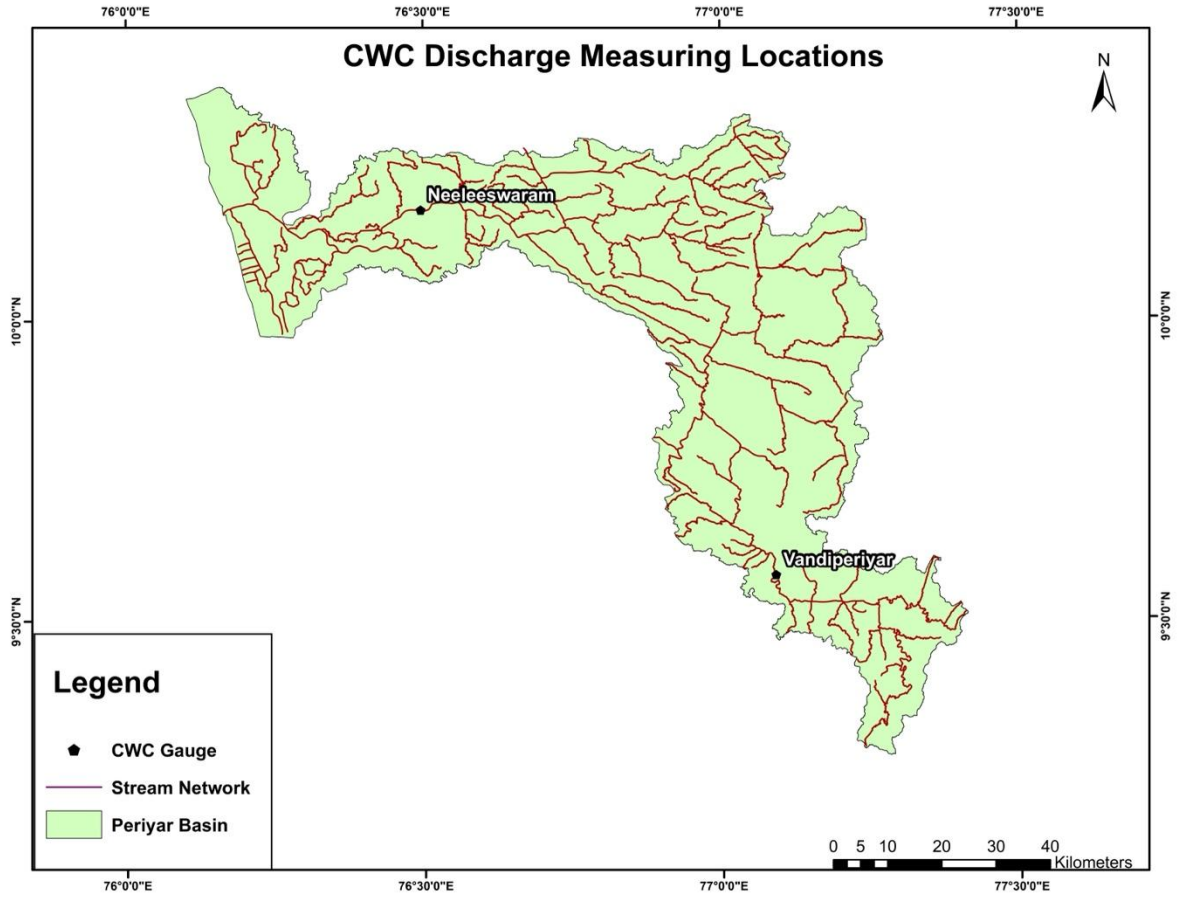


Fig. 4 Discharge Measuring locations in the basin by CWC

The weather monitoring locations within the basin are shown in Fig. 5. The basin has weather monitoring locations by IMD & IDRB.

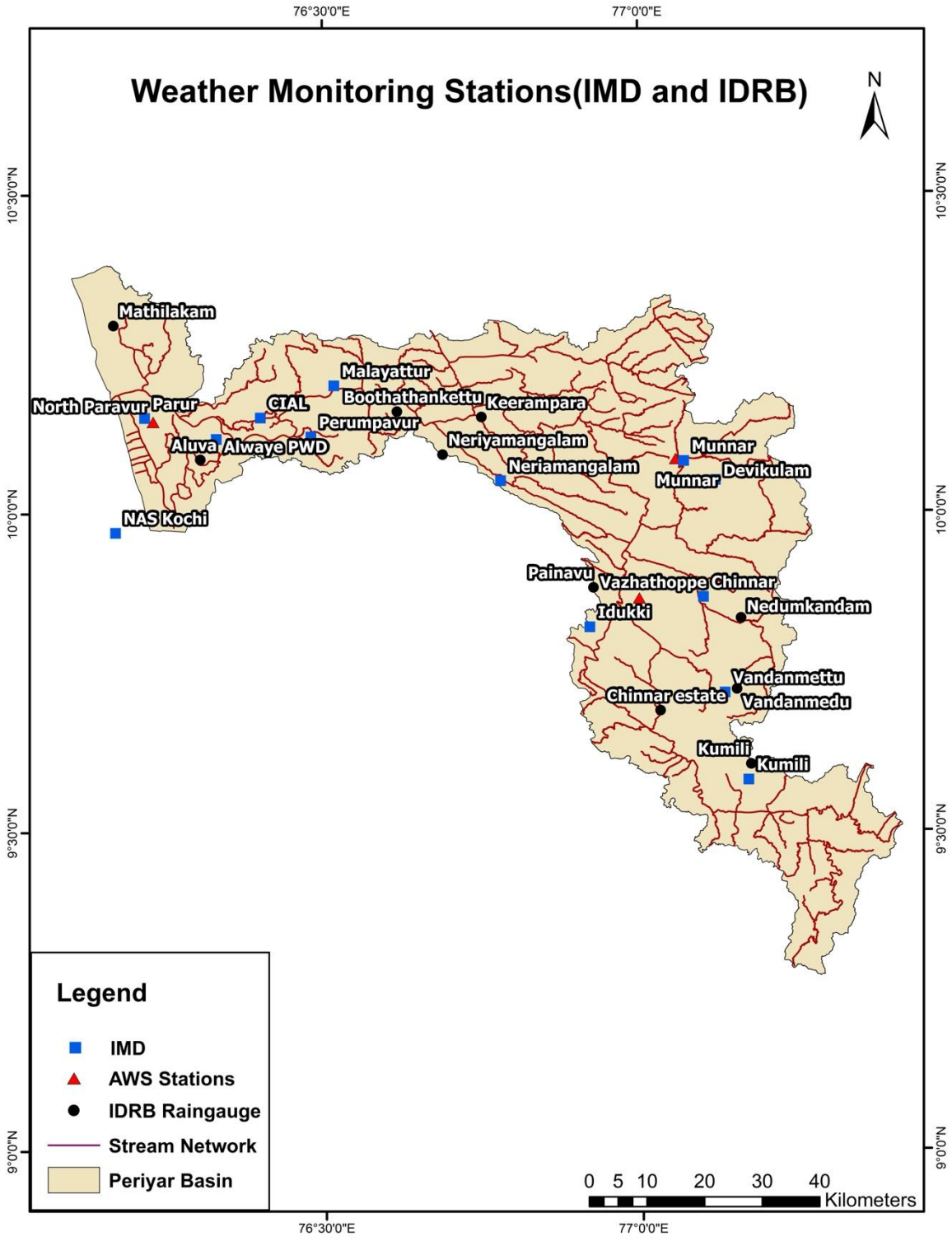


Fig. 5 Weather Monitoring stations by IMD & IDRB

The Periyar River Basin, predominantly hilly up to Neeleswaram, experiences high rainfall intensity with significant spatial variability. Accurate rainfall measurement at critical locations across the basin is essential for reliable hydrological assessments. As per IS 4987:1994, the recommended rain gauge density is one station per 150 sq. km for hilly terrain (Region Type III, up to Neeleswaram) and one station per 500 sq. km for plains (Region Type I, downstream of Neeleswaram). A 2021 report by the Comptroller and Auditor General of India (CAG) highlighted a major shortfall, noting that although 32 rain gauges are required for the Periyar Basin, only 6 were available—resulting in a deficit of 26 rain gauges. This gap severely limits the availability of real-time, spatially distributed rainfall data.

To address this, it is recommended to establish additional monitoring stations in the Idamalayar sub-basin, particularly in its upstream stretches where current coverage is sparse. Similarly, the Muthirapuzha sub-basin requires an increased number of weather monitoring stations to capture basin-wide atmospheric conditions more effectively. Enhancing the spatial resolution of weather monitoring infrastructure will significantly improve basin-scale water resource planning and flood forecasting capabilities.

4. Identification of Issues that policy should monitor & convert to quantifiable measures

The key issues reported in the Periyar Basin are the decline in water quality due to pollution, increased flooding, illegal sand mining and quarrying, loss of biodiversity due to habitat degradation, and waste management crisis due to lack of community participation. The details of each issue are described below:

1. Declining Water Quality – Industrial & Urban Pollution

The key water quality problems faced along the stretches of the Periyar River are:

- Presence of heavy metals like lead, mercury, and cadmium in water and sediments (Nimisha & Sheeba, 2015)
- High biochemical oxygen demand (BOD) and chemical oxygen demand (COD) indicate organic pollution
- Eutrophication in stagnant stretches due to nutrient runoff
- Untreated sewage discharged into the river
- Industrial pollution has resulted in heavy metal contamination, resulting in fish species' death.
- Disappearance of Native Fish Species: Indigenous fish species like the 'Channa marulius' and 'Puntius denisonii' face extinction due to habitat degradation and pollution.

Massive fish death in Periyar (*The Hindu, June 2024*)

Elevated coliform counts were found mainly downstream of Periyar, attributed to faecal contamination from dense urban populations (Jose & Ambili, 2021). High COD levels at Thekkady indicated

anthropogenic pollution. Water quality degradation was reported downstream due to the discharge of untreated or partially treated industrial and sewage waste, especially from Eloor, Kalamassery, and North Paravur (Subin & Husna, 2013). The core cause of pollution is the industrial hub in Ernakulam District, particularly around Eloor, which ranks among the world's most toxic hotspots (Greenpeace, 1999; 2003). Industries in the Eloor–Edayar stretch, including chemical, fertiliser, pesticide, and metal-processing units, extract over 1.8 lakh m^3 of water daily and discharge around 75% back as effluent, laden with pollutants like mercury, copper, zinc, and cadmium. Eutrophication from untreated waste affects aquatic ecosystems on the downstream side of Periyar.

2. Increased flooding

Flooding on the downstream side of the Periyar River is a frequent problem.

- In August 2018, Kerala experienced extreme rainfall, with 42% above-average rainfall (2,346.6 mm), which resulted in significant economic, social, and environmental losses, as well as 331 landslides across 10 districts (Parthasarathy et al., 2021).
- The dams, Idukki and Idamalayar, located within the Periyar Basin, are critical for managing water resources in the region. However, during heavy rainfall, these dams are forced to release excess water, resulting in downstream flooding. The release of water without adequate warning has sometimes contributed to sudden and severe flooding in areas like Aluva and Kottayam.

Flooding in the Aluva region (*The New Indian Express, August 2019*)

- Coastal areas and islands around Kochi continue to suffer from tidal flooding, which makes the situation complex for local residents.
- The operation of dams, particularly during the monsoon season, has contributed to sudden and intense downstream flooding. Poorly coordinated water releases or inadequate communication

of dam operations to local communities increased the flood risk, leaving people unprepared for sudden surges in water levels (Parthasarathy et al., 2021).

3. Illegal Sand Mining & Quarrying

- Sand mining continues to pose a serious threat to Kerala's rivers, including the Periyar, despite regulations introduced in 2016. Excessive dredging in areas like Neeleswaram and Thannipuzha has led to water scarcity and groundwater fluctuations.
- The course of Periyar changed significantly due to bank erosion and sediment shifts between 2008 and 2011 (Lekshmi, 2021), with around 45 mining sites identified in the region.
- Periyar–Chalakudy basin hosts about 525 rock quarries—137 active and 388 abandoned. Mining even occurs in ecologically sensitive zones, contributing to altered drainage patterns and the disappearance of first-order streams (Vandana et al., 2019).

4. Impact of dams in reservoirs on natural flow

The dam construction along the Periyar River has disrupted the river's natural flow. The alteration of natural water flows impacts aquatic species that rely on seasonal flow changes for breeding and migration and also causes reservoir sedimentation.

- The construction of dams causes the fragmentation of ecosystems and reduces the connectivity between different habitats, leading to the decline of many species, especially those that rely on riverine corridors (Ram, 2003).
- The reservoirs created by dams tend to accumulate organic matter and pollutants. In stagnant water bodies, oxygen levels can decrease, and the decomposition of organic matter can lead to eutrophication and the growth of harmful algae.
- Sedimentation in the reservoirs has decreased their storage capacity, reducing the effectiveness of water supply for irrigation and power generation (Sudheer et al., 2019).
- The construction of dams and reservoirs in the Periyar Basin has resulted in the displacement of local communities. Thousands of people have been forced to move due to the submergence of their homes and agricultural lands. This has led to social dislocation, loss of livelihoods, and increased poverty for many of these displaced populations (Sreelakshmi et al., 2021).

5. Habitat degradation and loss of biodiversity

Hydroelectric dams like the Mullaperiyar and the Idukki Arch dams have altered the river's flow, blocking fish migration routes and fragmenting aquatic ecosystems.

- Invasive species, such as water hyacinth (*Eichhornia crassipes*), have further aggravated the situation by reducing dissolved oxygen and blocking sunlight, thus affecting native species.

- The primary causes of habitat loss in the Periyar River Basin are deforestation due to agricultural expansion and urbanisation. Deforestation for plantations, mainly rubber and tea, along with encroachment, has led to the loss of critical habitats for many species.
- Large-scale conversion of forested land into agricultural plantations has fragmented the habitats of several endemic species (Kumar & Prasad, 2019).

6. Lack of awareness and community participation

Human-wildlife conflict has been a significant problem in the Periyar River Basin due to a lack of community participation.

- Local communities living near wildlife habitats often take up activities such as farming and settlement expansion in areas traditionally occupied by wildlife. This leads to frequent encounters between humans and animals, resulting in crop damage, property loss, and sometimes fatalities.
- Without proper community involvement, conservation efforts in the Periyar Wildlife Sanctuary and surrounding areas have been less effective in preventing human-wildlife conflict, especially with species like elephants and tigers (Sreekala et al., 2024).
- The primary cause of environmental degradation in the Periyar Basin is a lack of community awareness and ownership of conservation issues. The unchecked dumping of waste into the river, illegal fishing, and the destruction of riparian habitats are prevalent in certain areas due to a lack of local engagement in conservation efforts.
- The lack of participatory management practices means that people are not adequately educated on the environmental importance of the Periyar River Basin and its surrounding ecosystems.
- The absence of community involvement in designing and implementing these policies has resulted in reduced effectiveness. While government authorities and conservation organisations have taken steps to protect the area, local communities and primary land and water use stakeholders are frequently not consulted.

From the reported problems in the Periyar Basin, the significant policy gaps are as follows:

Fragmented Institutional Framework: Multiple agencies managing different aspects of the river have led to poor coordination and ineffective river basin management. While CWC, the irrigation department, focuses on water quantity and allocation, PCB focuses on water quality. The forest department focuses on biodiversity and riparian vegetation, while urban development authorities focus on infrastructure development. Each agency typically has its mandate, jurisdiction, data systems, and planning processes. The absence of a central coordinating authority or unified river basin body leads to isolated and uncoordinated decision-making by individual agencies. This institutional fragmentation often leads to overlapping mandates, jurisdictional conflicts, and conflicting priorities. It also causes

delays in data sharing, regulations inconsistencies, and difficulty enforcing compliance. To address these challenges, river basin management must be centralised under a single River Basin Authority or multi-stakeholder coordination mechanism with legal backing, clear mandates, data integration protocols, and decision-making power. Strengthening institutional coordination is essential for achieving sustainable and equitable management of river systems.

Absence of Stakeholder Participation: Local communities, fisherfolk, and farmers have limited involvement in decision-making processes. The stakeholders' sense of ownership is important in river conservation efforts. Any problems in the basin indicate the absence of stakeholder participation.

Non-Compliance by Industries: Weak enforcement of pollution control norms by industries has contributed to water quality degradation. Even after regulations on the industries' discharge, the downstream side of Periyar frequently reports pollution and death of fish, which is a severe concern. This indicates that industries are non-compliant, and industrial discharge should be monitored appropriately into the river.

Inadequate Monitoring: Lack of regular water quality monitoring and data transparency. The water quality measurement sites are low on the upstream side of the Periyar Basin. Less monitoring sites are there in and around identified pollution hotspots. All downstream locations of pollution points should have water quality monitoring stations, and the downstream side of all major structures should have a flow measurement system to ensure that the flow is maintained in the river during all periods.

Limited Awareness Programs: Lack of awareness about pollution control, waste management, and sustainable practices among local communities. Illegal dumping has been reported at many locations along the main stem of the Periyar River, especially on the downstream side of the basin. Munnar is a tourist spot in the upstream terrain, and pollution caused by the people visiting the place is also widespread. The lack of awareness among people is one of the main reasons for pollution in eco-sensitive zones where tourism is allowed. Strict rules should be enforced for tourists, especially in the eco-sensitive areas of Munnar.

Inadequate Community Involvement: Insufficient participation of local communities in river conservation initiatives. The activities from the people side are less when it comes to river protection and conservation. Illegal waste dumping can be avoided if the community is active in river protection initiatives. Strong community involvement can save places like Munnar tourist hotspots from getting polluted.

5. Missions under cGanga - how do we know these are achieved?

The three main missions under cGanga include *Aviral Dhara*, *Nirmal Dhara* & *Ecological Restoration.*

a. Aviral Dhara

Aviral Dhara is a mission focused on maintaining the river's natural flow along with the natural constituents across the entire length throughout the year. The missions under Aviral Dhara can be summed up as:

- Ensuring the continuous flow of river, sediments, and natural constituents of the river
- Achieving environmental flow (E-flow) to sustain and support the aquatic life, biodiversity, and natural sediment transport
- Prevention of overutilisation of river water for human and industrial requirements to preserve the natural flow of the river
- Adapting to the climate change, which in turn affects the rainfall pattern and intensity and temperature variations

Quantifiable measures for evaluation

- Continuous measurement of flow along all the major perennial tributaries of Periyar
- Continuous monitoring of all weather parameters at sufficient intervals within the basin
- Measurement of flow at a certain distance from the downstream side of dams
- Regular E-flow assessment to analyse the minimum requirement of water required to sustain a healthy flow of the river
- Major consumers monitor the abstraction of water (SW and GW).

b. Nirmal Dhara

Nirmal Dhara is a mission centralised to achieve clean water in a river free from pollution. The objectives are as follows:

- Elimination of pollution by identifying and mapping the point sources of pollution
- Improvement of water quality and management of wastewater being produced by domestic supplies industries, etc.
- Averting agricultural runoff having high amounts of nutrients being washed off into the Periyar.

Quantifiable Measures for Evaluation

- Water quality monitoring is done at regular intervals along the main stem of the Periyar River and all significant tributaries within the basin (Including all major water quality parameters, heavy metals, and pesticides).
- Mapping the industries along the river stretch and identifying the point sources of pollution
- Identification of pollution hotspots – in case actions are required

- Quantification of waste discharged by industries & household
- Regulation on the waste discharge by the industries
- Identify and map industries and other point sources of pollution and prepare a pollution load map.

c. Ecological Restoration

Ecological restoration involves revitalising and restoring the natural ecological balance by mitigating the influence of anthropogenic factors and enhancing the natural biodiversity of the Periyar River Basin. The primary objectives are as follows:

- Restoration of aquatic and terrestrial biodiversity of the river along its entire stretch
- Enhance the ability of wetlands and natural floodplains for biodiversity support
- Control of alien species invasion and conservation of endemic and endangered species local to the region
- Encouraging local communities, NGOs, and academic institutions to participate in conservation practices and policies actively

Quantifiable measures for evaluation

- Identification of biological hotspots and protection of these zones
- Identification of species that have endangered
- Measures to Recover Threatened Ecosystem
- Periodic monitoring of the health of the ecosystem
- Identification of key triggers in the threatened ecosystem

6. Identification of who can help in commissioning evidence

For continuous monitoring and feedback, different stakeholders must come together and function as a unit. For evidence collection and further studies, it is essential that institutes, agencies, and private players of credibility, capability, and good ground-level understanding of the area are involved. The different agencies that can help in commissioning evidence at central, state and local bodies are given as follows:

Central Agencies

S.No	Agency	How can they help?
1	National Mission for Clean Ganga (NMCG)	• Responsible for implementing the National River Conservation Plan (NRCP) and other river management projects across India, primarily focused on the Ganga • However, it can provide valuable technical guidance and funding models that can be adapted for the Periyar River
2	Central Water Commission (CWC)	• Provides technical and policy advice on issues like flood control, water quality monitoring, and flow measurements • can establish more monitoring networks within the Periyar Basin
3	Ministry of Environment, Forest and Climate Change (MoEFCC)	• MoEFCC is responsible for framing policies and regulations related to environmental protection and conservation • They can provide guidelines for protecting ecosystems, wildlife, and biodiversity within the river basin
4	Central Groundwater Board (CGWB)	• CGWB can increase the frequency of groundwater measurements in the downstream side of the basin where the chances of pollution are more. • Can establish more water quality monitoring stations where data is insufficient.

5	Central Pollution Control Board (CPCB)	• Can provide water quality data along the river stretches • Can establish more monitoring locations where data is missing

State Agencies (Kerala)

S.No	Agency	How can they help?
1	Kerala State Pollution Control Board (KSPCB)	• Data maintained include water quality parameters from regular monitoring of rivers and streams, effluent data from industries, compliance reports from sewage and effluent treatment plants (STPs/ETPs), pollution hotspot identification, and reports from field inspections • can increase the number of continuous monitoring stations in the Periyar Basin
2	Kerala Water Authority (KWA)	• Responsible for managing the water supply and sewerage systems in Kerala. • Can provide technical insights and support related to water distribution, quality monitoring, and water demands within the Periyar River Basin.
3	Irrigation Design & Research Board (IDRB)	• Responsible for designing, planning, and overseeing major irrigation and water resource projects in Kerala • Aims at Water Conservation, Planning and Sustainable Irrigation Management and also to reduce the extent of Climate-Induced Disasters • Can help in providing more hydraulic data, especially related to river cross-sections, at locations not available by CWC
4	Kerala State Landuse Board (KSLUB)	

		• KSLUB collects, organises, and analyses data on existing land use and land resources within the basin area. • Data on geomorphology, statistics of land use changes, and agro-ecological zones can help in condition assessment of the basin • Can help in identifying encroachments along the river ecosystem • Responsible for land use decisions within the basin
5	Kerala State Disaster Management Authority (KSDMA)	• Responsible for coordinating disaster management strategies in the state. • They can provide historical records of natural hazards, helping to understand the regions that need immediate attention. • Any encroachment activities/agriculture in these regions should be restricted. • Can help in disaster preparedness and awareness of the community in case of extreme events.
6	Kerala State Planning Board (KSPB)	• Plays a crucial role in shaping the state's development policy, including water resource management, flood management, and sustainable development. • They coordinate various projects related to river basin management and could assist in policy formulation. • They can address the gap between research and policy implementation
7	Kerala State Biodiversity Board (KSBB)	• Focuses on the conservation and sustainable use of biodiversity • Works with the assistance of various other organisations within the state such as KFRI, Kerala Agricultural University, Zoological Survey of India, Kerala Forest Department

		• Can provide data on the existing biodiversity in the basin and the historical records • Can assist in regenerating degraded ecosystems
8	Kerala Forest and Wildlife Department	• Manages forest resources and wildlife conservation • Can provide historical data on the species in the basin • Can provide the list of endangered/threatened species
9	Kerala State Electricity Board (KSEB)	• Monitors the sediment accumulation in hydropower reservoirs • Can provide information on sediment accumulation in reservoirs

Research and Academic Institutions

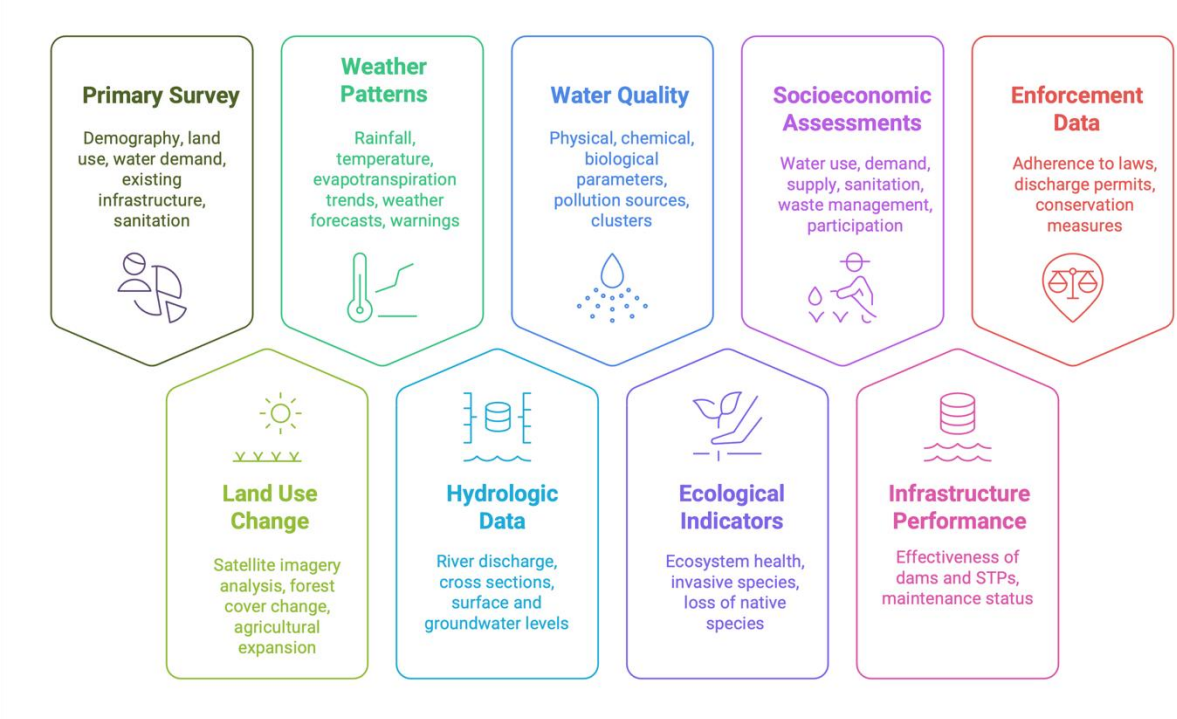
S.No	Agency	How can they help?
1	Centre for Water Resources Development and Management (CWRDM)	• CWRDM offer technical expertise in hydrology, water resource management, flood forecasting, etc • Can assist in providing relevant resources for hydrological modelling
2	Indian Institute of Remote Sensing (IIRS)	• IIRS provides advanced satellite-based remote sensing and geospatial services. • Their services can be valuable for mapping the Periyar Basin, monitoring changes in land use, and tracking water quality.
3	National Centre for Earth Science Studies (NCESS)	• Provides research and advice on various environmental issues, including groundwater management and climate change impacts, which are crucial for designing the protocol for

		designing the River Basin Management Plan for the Periyar River Basin.
4	Kerala Forest Research Institute (KFRI)	• Can help in collecting the database for the species in the Periyar Basin, which will help understand the endangered species and the change in biodiversity over time.
5	Kerala Engineering Research Institute (KERI)	• Provides valuable services by fulfilling needs in Investigation, testing, Hydraulic Model Studies, Consultancy, Training, Quality Control and R&D in Water Resources Engineering. • It serves the needs of the Irrigation Department and related state agencies while also offering testing and consultancy services to both public and private organisations.
6	Local NGOs (e.g., Kerala Sasthra Sahitya Parishad, Janamaithri)	These organisations work closely with local communities and can provide valuable perspectives on community-based river basin management and conservation practices.
7	Periyar River Protection Council	Local committees or councils like the Periyar River Protection Council can help facilitate discussions with local communities, raise awareness about river health, and involve people in conservation and sustainable river management practices.

7. Types of Evidence to Commission

To effectively support river basin management, a wide range of evidence must be commissioned, covering the basin's hydrological, environmental, socioeconomic, and infrastructural aspects. This includes collecting hydrological data such as river discharge, cross sections, surface and groundwater levels, and water quality parameters like BOD, COD, pH, turbidity, and pollution sources. Ecological

indicators, including ecosystem health, invasive species presence, and loss of native biodiversity, are crucial for understanding ecological integrity. Land use and land cover (LULC) changes, identified through satellite imagery, help detect urban expansion, forest loss, agricultural encroachment, and riverbank encroachments. Socioeconomic and institutional assessments are necessary to capture water use behaviour, supply-demand patterns, sanitation infrastructure, waste management, and community participation. Compliance data regarding environmental laws, discharge permits, and conservation measures ensure regulatory enforcement. Climate-related evidence such as rainfall, temperature, evapotranspiration, and extreme weather trends help in risk mitigation and disaster preparedness. Infrastructure performance must be assessed for effectiveness and maintenance, especially of dams and sewage treatment plants. Additionally, primary surveys provide critical demographic, land use, and infrastructure data. This evidence can be commissioned through remote sensing, GIS tools, field monitoring, stakeholder consultations, review of official records, and collaborations with academic and technical institutions.



Types of Evidence to Commission

The different types of evidence required to commission involve water quality, quantity, ecosystem health, changes in land use over time, climatic parameters, performance of existing infrastructure, etc., which denote the present condition of the basin.

S.No	Type of evidence	Details of evidence
1	Primary Surveys	• Demography of the basin • Land use practices • Water demand and supply • Existing water infrastructure • Sanitation facilities
2	Climate and Weather Patterns	• Rainfall, temperature, ET, humidity, wind speed • Extreme weather event forecasts • Disaster warnings
3	Hydrologic data	• River discharge • River cross-sections and longitudinal profile • Surface water levels • Groundwater levels
4	Water Quality Data	• Physical, chemical & Biological Parameters • Point and non-point pollution sources • Pollution clusters
5	Ecological Indicators	• Ecosystem Health • Invasive species • Record on the loss of native species
6	Land Use and Land Cover Change	• Satellite imagery analysis to detect urbanisation • Change in forest cover • Agricultural expansion • Encroachments on riverbanks
7	Infrastructure Performance	• Effectiveness of dams • Effectiveness of STP's • Maintenance status of infrastructure
8	Socioeconomic and Institutional Assessments	• Water use behavior • Water demand patterns and supply • Sanitation facilities • Waste collection & management facilities • Community participation
9	Compliance and Enforcement Data	• Adherence to environmental laws and discharge permits • Implementation of conservation measures

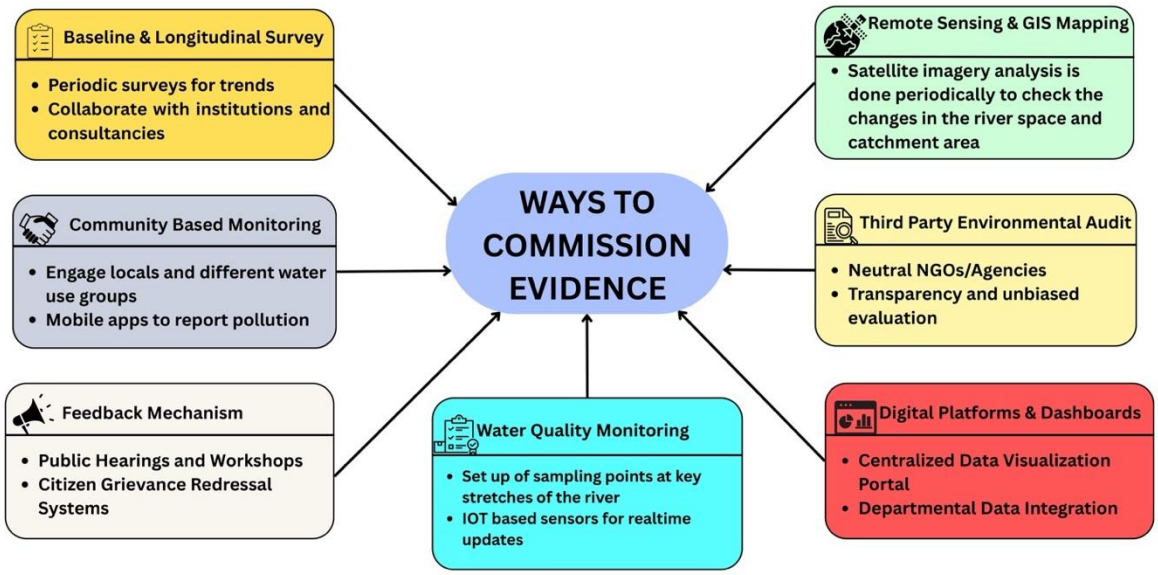
8. Ways to Commission Evidence

Commissioning evidence for river basin assessment involves multiple approaches to ensure comprehensive and reliable data collection. Baseline and longitudinal surveys conducted periodically help monitor environmental trends and can involve academic institutions and consultancies for detailed fieldwork. Remote sensing and GIS mapping play a critical role by providing spatial and temporal data on land use changes, river morphology, catchment degradation, and encroachments. Regular analysis

of satellite imagery enables the detection of patterns such as urban expansion, deforestation, or agricultural shifts that influence river health.

Community-based monitoring is another vital method wherein local communities, water user associations, and citizen volunteers are engaged to collect real-time, ground-level data. These efforts can be strengthened through mobile applications and participatory tools that allow reporting of water pollution incidents, illegal dumping, or changes in water levels. This bottom-up approach enhances data collection and promotes community ownership and awareness.

Water quality monitoring stations should be strategically established across river points to assess physical, chemical, and biological parameters. These stations can be manual or automated and should ideally be equipped with IoT-based sensors to provide real-time updates on parameters such as BOD, COD, pH, turbidity, and the presence of heavy metals. This helps in the early detection of pollution events and informs regulatory action.



Ways to commission evidence

Independent third-party environmental audits by neutral agencies or NGOs offer unbiased evaluations and promote transparency. Digital platforms and centralised dashboards facilitate data collection, visualisation, and integration from various departments, supporting informed and coordinated decision-making. Additionally, incorporating feedback mechanisms such as stakeholder consultations, public

hearings, and citizen grievance platforms ensures that local perspectives are considered in the planning and implementation processes.

The details to be carried out in each piece of evidence are given below:

1. **Baseline and Longitudinal Surveys**

    - Periodic surveys ensure continuous monitoring and trend analysis
    - Include educational institutions and consultancies for field survey

2. **Remote Sensing & GIS Mapping**

    - Satellite imagery analysis is done periodically to check the changes in the River space and catchment area.

3. **Community-Based Monitoring**

    - Engage local communities and water user associations to collect citizen science data.
    - Use mobile apps or participatory tools to report pollution and illegal dumping.

4. **Water Quality Monitoring Stations**

    - Set up automated or manual sampling points at key stretches of the river
    - Integrate IoT-based sensors for real-time updates

5. **Third-Party Environmental Audits**

    - Appoint neutral agencies or NGOs for independent evaluations
    - Ensure transparency and unbiased feedback

6. **Digital Platforms and Dashboards**

    - Develop centralised portals to collect, visualise, and analyse basin-wide data.
    - Link databases from multiple departments for integrated decision-making

7. **Feedback Mechanisms**

    - Conduct stakeholder consultations, workshops, and public hearings
    - Incorporate citizen feedback via grievance redressal platforms

9. Role of Independent audits or third-party monitoring

Independent audits play a vital role in ensuring transparency, accountability, and effectiveness of environmental policies and programs. Different NGOs and citizen action groups have worked closely with agencies and are involved in auditing, monitoring, and implementing policies, practices, and management. Some of the NGOs that have worked in the basin are:

1.Greenpeace International

Based in Canada, Greenpeace International identified the Eloor Industrial Belt in the Periyar Basin as India's third most toxic hotspot and 35th in the world. Greenpeace International conducted a case study of industrial effluents being dumped, majorly organochloride, by HIL (Hindustan Insecticides Limited) in the Udyogmandal Industrial Estate located to the north of the Eloor Islands along the banks of the Periyar River. Along with HIL, other major industries along the belt contributing to pollution were FACT (Fertilisers and Chemicals Travancore), IRE (India Rare Earths), and Merchem (Stringer et al., 2003). The study found that the complex mixture of chemicals in the water and sediment of Kuzhikandam Thodu constitutes a long-term threat to aquatic life, fish, birds, and humans, as many of these compounds are toxic, persistent, and bioaccumulative. A measure study suggested the Indian government should move to phase out DDT production and implement measures to eliminate the sources of the other pollutants. Greenpeace International appointed Mr. V. J. Jose as Periyar River Keeper to regularly monitor the quality of the Periyar River (*Earth5R*).

2.Periyar Malineekarana Virudha Samithi (PMVS)

Periyar Malineekarana Virudha Samithi is a public forum constituted by working-class members, including fish workers, farmworkers, and daily wage labourers, that acts to protect the Periyar River from pollution. Established over 25 years against the pollution caused in the Eloor Industrial Belt, PMVS advocates for environmental protection through legal actions, public engagement, and research studies. Water and sediment samples were collected by the PMVS following the recent incident of massive fish kills in the Periyar River in May 2024. Their analysis found the presence of hazardous substances such as mercury, arsenic, cadmium, and hexavalent chromium, findings that contradicted the Pollution Control Board's (PCB) report, which claimed the absence of these toxins. PMVS alleged that the PCB's report diluted the severity of pollution, thereby misleading the Kerala High Court. PMVS filed a series of petitions in the high court, in response to which the panel made the recommendation of the formation of a dedicated authority, akin to the National Ganga River Basin Authority, to oversee the conservation of the Periyar River (*The New Indian Express, 2025*).

3.Aluva Environmental Protection Forum

Prof. S. Sitaraman established the Aluva Environmental Protection forum. It has been an active voice in raising the issue of pollution and illegal sand mining. In 2022, the Aluva Environmental Protection

Forum protested the proposal to establish an uptake pump. The Aluva Environmental Protection Forum had planned to prepare a report and submit it to the industries minister (*The Times of India, 2022*).

4. Ashoka Trust For Ecology and the Environment (ATREE)

The Ashoka Trust for Ecology and the Environment, headquartered in Bangalore has contributed to conservation science and sustainable resource management in Periyar. ATREE has launched a program called ‘Jalapaadom', which is focused on connecting students with nature. This involves the training of students and teachers about water and nature. 'Bioblitz' a citizen science program initiated by ATREE-CERC, in association with India Biodiversity Portal (IBP), to document the biodiversity with the participation of school and college students, teachers and the enthusiastic general public. This program is expected to promote interest, awareness, and participation in conservation activities as well as the sustained monitoring of the region's biodiversity.

10. Analysing data and evidence

The descriptive analysis entails the systematic characterization and quantification of hydrological, ecological, and land-use data to explain temporal and spatial patterns within the basin. This includes statistical evaluation of river discharge records, precipitation data, water quality indices, and watershed land cover dynamics to identify trends such as alterations in flow regimes, frequency of hydrological extremes, or shifts in nutrient concentrations. The causal analysis focuses on identifying and quantifying the underlying drivers and mechanisms influencing these observed patterns. These analysis enable understanding of the behaviour, facilitating evidence-based decision-making for sustainable river basin management.

Analysing hydrologic parameters provides critical insights into the availability, and variability of water within a river basin. The variation in annual rainfall over a 30-year period obtained from IMD is depicted in Fig. 6, revealing significant fluctuations across the upstream and downstream of the basin. Notably, 2012 experienced a marked decline in annual rainfall, with the upstream station at Idukki recording 1823 mm and the downstream station at Aluva receiving 1436.8 mm. This indicates that, even during low-rainfall years, the upstream region received greater precipitation than the downstream area. Conversely, 2018 exhibited a substantial increase in rainfall, with Idukki registering a peak of 5115.9 mm, which contributed to the catastrophic Kerala floods of that year. Post-2019, rainfall at Idukki consistently exceeded that at Aluva by 450–1000 mm annually. The long-term annual average rainfall for Idukki stands at 3578 mm, approximately 682 mm higher than Aluva’s average of 2896 mm, underscoring a persistent gradient in precipitation from upstream to downstream. An exception to this pattern was observed in 2006, when the downstream station Aluva recorded 349 mm more rainfall than Idukki, illustrating variability in spatial rainfall distribution within the basin.

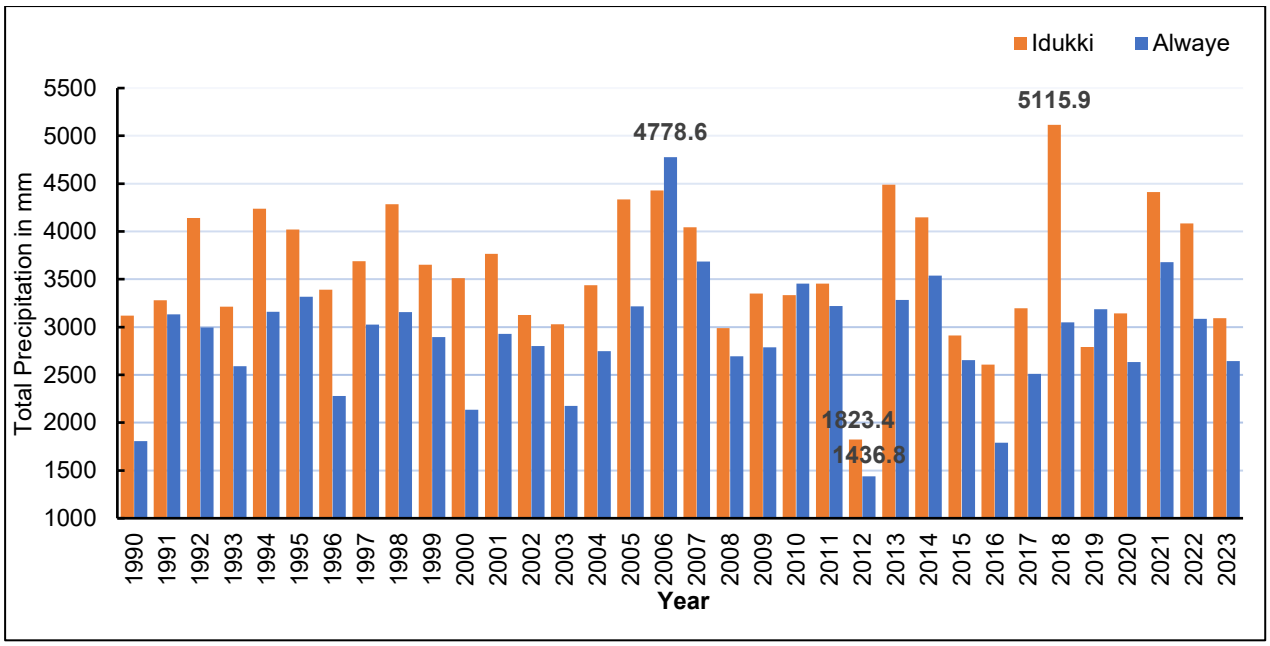


Fig. 6 Variation of Annual Precipitation for Idukki and Aluva

Discharge variations at two Central Water Commission (CWC) monitoring stations within the Periyar River Basin—Vandiperiyar (upstream) and Neeleshwaram (downstream)—exhibit distinct spatial and temporal patterns. At the upstream station, Vandiperiyar, streamflow during the dry months (March and April) is typically negligible, with recorded discharge approaching zero in most years, except for a few s years including 2006, 2007, 2008, 2011, 2012, 2015, 2016, and 2022. In 2022, the dry-season discharge reached 0.134 m^3/s. The station recorded its highest discharge during the monsoon of 2018, peaking at 1023 m^3/s, corresponding with extreme rainfall events. In contrast, the downstream station Neeleshwaram historically recorded maximum monsoonal discharges below 3000 m^3/s until 2012. A significant increase was observed in 2013, with discharge reaching 6323 m^3/s, after the dry year in 2012. The highest recorded flow occurred in August 2018, at 9218 m^3/s, contributing directly to the catastrophic Kerala Floods of 2018. In the post-flood period, discharge values remained elevated, with maxima exceeding 4000 m^3/s in 2019, and around 2000 m^3/s in both 2020 and 2022.

The data suggest that post-2018 flood conditions have resulted in a sustained increase in peak discharge, with peak flows rising by approximately 1.5 times compared to pre-2018 levels. This trend indicates intensifying hydrological responses in the basin and underscores the urgency of implementing robust flood risk mitigation and watershed management strategies to address the escalating streamflow extremes observed in recent years.

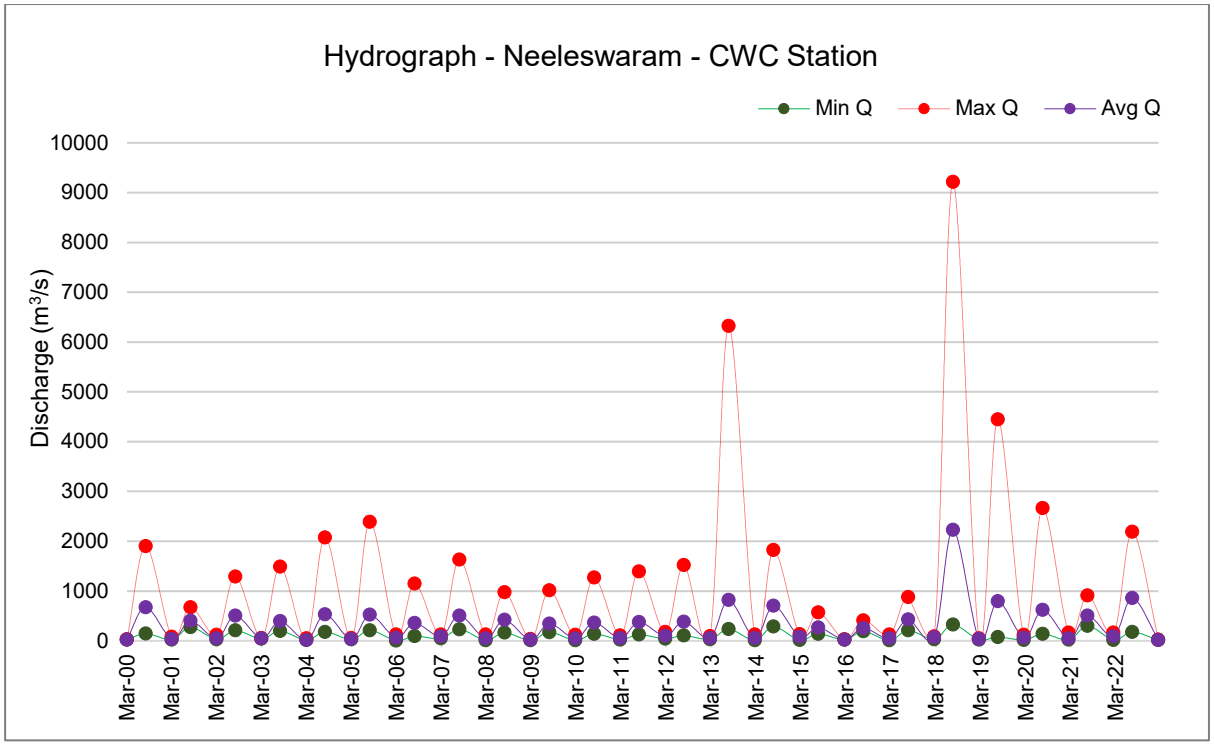


Fig. 7 a Hydrograph for Neeleshwaram (downstream)

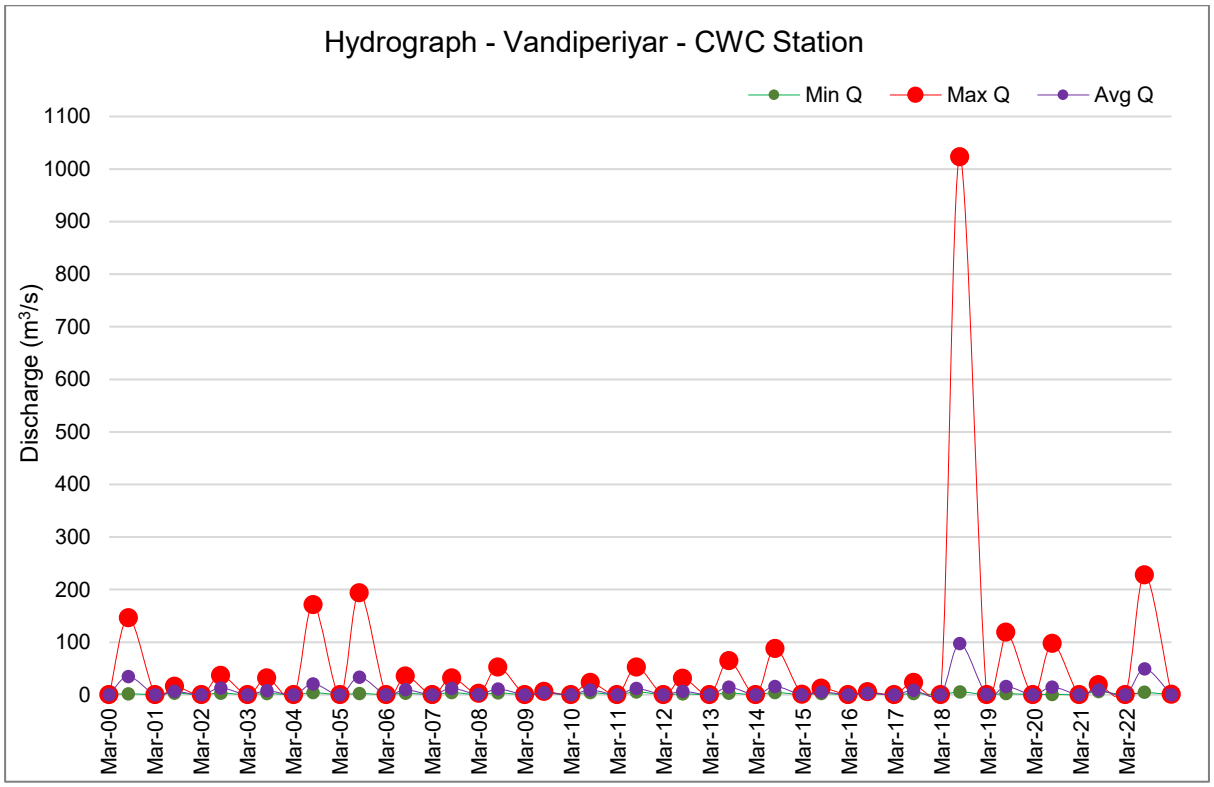


Fig. 7 b Hydrograph for Vandiperiyar (Upstream)

Water quality data obtained from the Central Pollution Control Board (CPCB) indicate a significant increase in Total Hardness levels in river water at downstream monitoring stations during the pre-monsoon season of 2023. The variation of Hardness at monitoring location at Aluva is given in Fig. 8. This spike in hardness is particularly pronounced at locations situated near the Eloor industrial belt, suggesting potential anthropogenic influences from industrial effluent discharges or altered hydrological conditions due to reduced baseflow during the dry season. The observed trend aligns with similar patterns recorded at adjacent monitoring stations within the lower reaches of the basin, reinforcing concerns regarding the cumulative impact of industrial activity on downstream water quality. These findings highlight the need for targeted source tracking, effluent regulation enforcement, and seasonal water quality monitoring, particularly during low-flow periods when pollutant concentrations tend to rise due to limited dilution capacity in the river system.

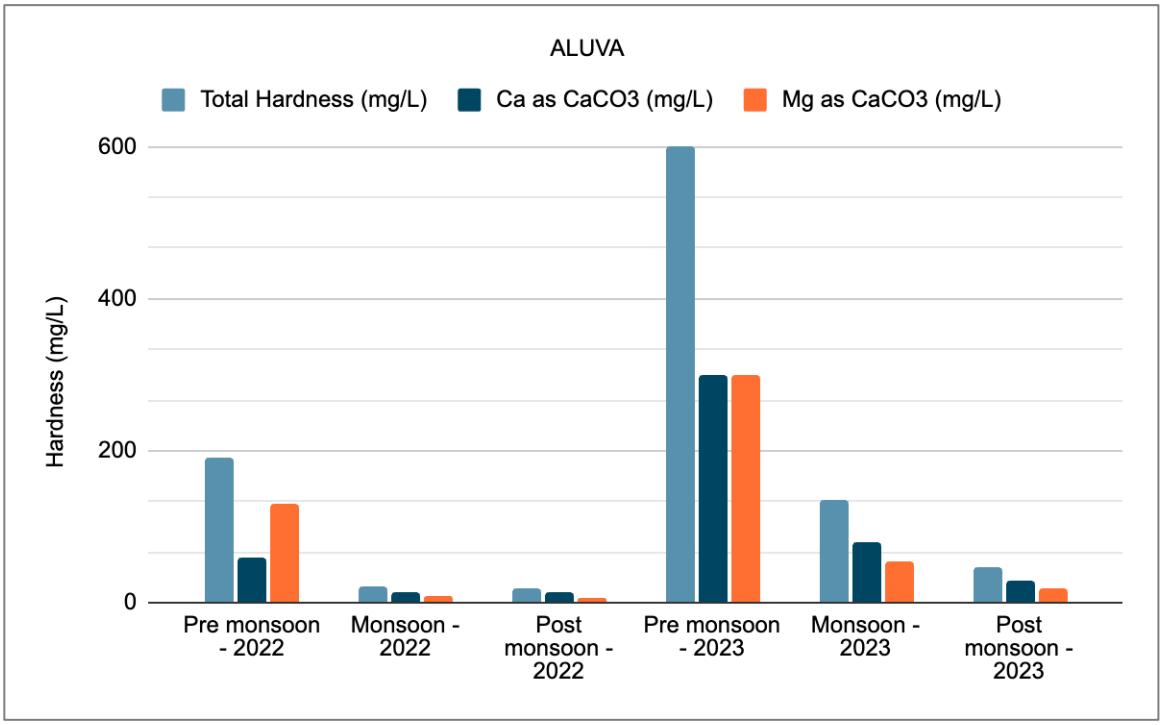


Fig. 8 Hardness of surface water at Aluva

Summary

Developing a detailed protocol for river basin management is fundamental to establishing defined roles and responsibilities among stakeholders—government agencies, communities, and industries, resolving conflicts within the Periyar River Basin. A 30-year analysis of hydrologic data reveals significant temporal and spatial variability in rainfall and river discharge, with upstream areas consistently receiving higher precipitation than downstream. Extreme events such as the 2012 drought and the catastrophic 2018 floods driven by unprecedented rainfall and peak discharges have resulted in

sustained elevated flow levels, highlighting intensifying hydrological responses and increased flood risk. Water quality monitoring data by CPCB, indicates troubling increases in total hardness downstream, especially near industrial zones like the Eloor belt, pointing to anthropogenic pollution exacerbated by low-flow conditions during pre-monsoons. These findings emphasize the need for stringent regulatory enforcement, ongoing seasonal water quality assessments, and targeted pollution mitigation to safeguard aquatic ecosystems.

A robust and continuous monitoring mechanism is essential, involving systematic collection of hydrological, ecological, water quality, socioeconomic, and infrastructural data. Key parameters include river discharge, groundwater levels, water quality indicators (BOD, COD, pH, turbidity, hardness), biodiversity status, land use and land cover changes, and industrial discharge levels. Monitoring enables early identification of changes and emerging threats, promoting transparency and building stakeholder trust. Data collection employs diverse methods, including periodic baseline surveys in collaboration with academic and consultancy bodies, remote sensing and GIS mapping to track land use and river morphology changes, and community-based participatory monitoring supported by mobile applications. Such integration of top-down scientific methods with bottom-up community engagement enriches data reliability and ownership.

Complementing monitoring, an adaptive feedback mechanism incorporates stakeholder inputs, enabling iterative refinement of protocols and enhancing community participation. This ensures that management strategies remain responsive to evolving conditions, promoting sustainable and equitable basin governance. A continuous monitoring mechanism systematically tracks critical parameters to detect early changes, trends, and emerging threats, promoting transparency and building trust among stakeholders. Complementary feedback mechanisms enable iterative refinement of protocols, incorporating community inputs and adaptive management practices. Central to these efforts is the development of a detailed Protocol for River Basin Management that clearly defines stakeholder roles and responsibilities across government, communities, and industries, facilitating conflict resolution and coordinated action.

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