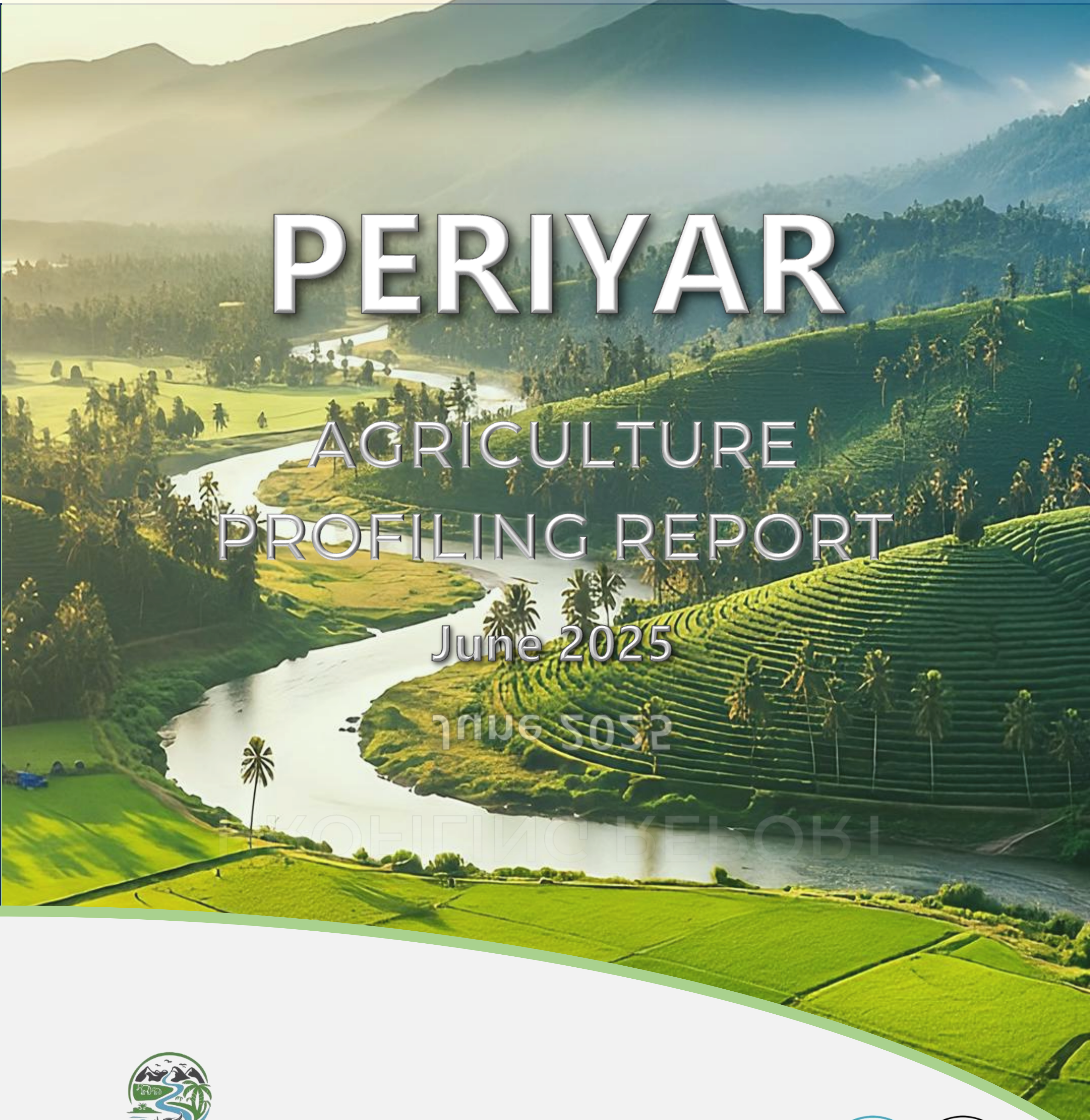
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India



PERIYAR

AGRICULTURE PROFILING REPORT

June 2025

Centres for Periyar River Basin Management Studies
IIT Palakkad & NIT Calicut

Centre for Ganga River Basin Management and Studies

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Centre for Ganga River Basin Management and Studies

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 Centre 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 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

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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 for this report.

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Preface

This report presents a comprehensive agricultural profiling of the Periyar River Basin, a region of paramount ecological and economic significance in Kerala, India. As the longest river and the second-largest river basin in the state, the Periyar plays a vital role in supporting Kerala's diverse farming systems by supplying essential water for irrigation and contributing substantially to the regional economy.

In this study, we identified and mapped the key geographical areas where major agricultural activities occur across the basin. We assessed the total agricultural land under various farming practices and conducted an in-depth analysis of crop patterns, crop intensity, and land-use dynamics. The study also evaluated the extent of irrigated land, primary irrigation sources, and critical groundwater parameters. Irrigation practices, crop production trends, and average yields were thoroughly examined, along with the quantified use of chemical fertilizers and plant-protection inputs.

Socio-economic aspects, including agricultural labour patterns and livestock holdings, were documented, and relevant government programs supporting sustainable agriculture in the basin were compiled and analysed. The study also addressed major agro-ecosystem concerns, such as nutrient and sediment loads entering the river system, and assessed the effectiveness of existing flow- and nutrient-trapping structures.

A detailed review of agricultural practices, including tillage systems, deep placement of urea, the System of Rice Intensification (SRI), crop rotations, intercropping, and diverse irrigation and pest-management techniques, was completed. Furthermore, the assessment identified agricultural factors exerting significant impacts on the river and proposed measures to mitigate these effects. Potential sites suitable for forestation, orchard development, and organic farming were also identified, alongside an evaluation of the economic viability of current and prospective sustainable agricultural practices.

Through this extensive analysis, the report offers valuable insights to support informed decision-making and promote resilient, environmentally responsible agriculture within this ecologically important river basin.

Centres for Periyar River Basin Management and Studies (cPeriyar)

IIT Palakkad & NIT Calicut

Table of Contents

List of Tables

List of Figures

Abbreviations

AEU : Agro Ecological Units

ha : Hectares

CD Blocks: Community Development Blocks

CESS : Centre for Earth Science Studies

CGWB : Central Ground Water Board

CI : Cropping Intensity

CRB : Chalakudy River Basin

CWRDM: Centre for Water Resources Development and Management

DFe : Dissolved Iron

DIN : Dissolved Inorganic Nitrogen

DIP : Dissolved Inorganic Phosphorus

DON : Dissolved Organic Nitrogen

DOP : Dissolved Organic Phosphorus

DSi : Dissolved Silicon

EC : Electrical Conductivity

E. coli : Escherichia coli

FACT : Fertilizers and Chemicals Travancore Limited

FPD : Farm Plan Based Development

GCA : Gross Cropped Area

GP : Grama Panchayat

GSVA : Gross State Value Added

KSPCB : Kerala State Pollution Control Board

IFS : Integrated Farming System

IREL : Indian Rare Earths Limited

LSGI : Local Self Government Institution

MBGL : Meters Below Ground Level

NCESS : National Centre for Earth Science Studies

NEERI : National Environmental Engineering Research Institute

NSA : Net Sown Area

PLI : Pollution Load Index

PLS : Periyar Lake Sampling Station

PMKSY: Pradhan Mantri Krishi Sinchayee Yojana

PPC : Plant Protection Chemical

PRB : Periyar River Basin

ppm : Parts Per Million

PTEs : Potentially Toxic Elements

SPCB : State Pollution Control Board

t/ha : Ton/hectare

TCCL : Travancore Cochin Chemicals Limited

TDS : Total Dissolved Solids

THg : Total Mercury

TIP : Total Inorganic Phosphorus

TKN : Total Kjeldahl Nitrogen

TSS : Total Suspended Solids

WGs : Western Ghats

VCB : Vented Cross Bar

1. Introduction

Agriculture is the lifeblood of any river basin. It anchors food security, fuels economic growth, and sustains the communities that have long depended on river systems for their wellbeing. For thousands of years, fertile riverine landscapes, rich in alluvial soils and supported by steady water flows, have nurtured agriculture and, in turn, shaped human civilization. This timeless partnership between water and farming continues to drive regional development today.

At its core, agriculture is a powerful biological engine: it converts solar energy into biomass, providing the food, fuel, and feed that support both people and livestock. By strengthening local food self-sufficiency, it also creates pathways for surplus production and export potential. Economically, agriculture contributes substantially to the Gross Regional Product (GRP), not only through primary crop production but also through allied sectors, processing, storage, transport, and marketing, generating livelihoods across the entire value chain.

Rivers themselves remain central to this system. Their waters irrigate fields, especially in monsoon-dependent and semi-arid regions, ensuring crop stability even in variable climates. Infrastructure such as dams, barrages, and canal networks helps regulate and deliver water efficiently, enhancing productivity and resilience.

Beyond economics and productivity, agriculture in river basins safeguards cultural continuity. It preserves traditional knowledge, sustains age-old practices, and reinforces the identities of communities whose heritage is deeply intertwined with the rhythms and ecology of the river.

Periyar (‘Peri’ – Big, ‘Aar’ – River), is the longest river in Kerala, extending 260.7 km. It is also the state’s second-largest river basin, covering an area of 5,216 km². Most of the river’s catchment area, about 5,097 km², lies within Kerala, with the remaining 119 km² located in the Anamalai Hills of Tamil Nadu. The Periyar River Basin, often called the "Lifeline of Kerala," illustrates the complex relationship between agricultural significance and environmental sustainability within this river. The Periyar River Basin encompasses significant areas of three Kerala districts – Idukki (3025.6 km²), Ernakulam (1735.3 km²), and Thrissur (329.1 km²), – and a small area of Coimbatore (114 km²) district in Tamil Nadu. The basin features distinct agricultural zones. In the highland areas, particularly in Idukki district, commercial plantations like Elettaria cardamomum (cardamom), Camellia sinensis (tea), and Piper nigrum (pepper) are prominent. These crops are vital to the state's agricultural exports (Joseph, 2009). In contrast, the midland region mainly grows annual and perennial food crops such as Oryza sativa (paddy) and Cocos nucifera (coconut), which are essential for local food security. The Periyar's water network, including dams and extensive canals, is crucial for supporting these various agricultural practices through managed irrigation (Irrigation-kerala, 2022).

Despite its economic and social importance, intensive farming in the Periyar basin causes significant environmental problems. Research and news reports consistently point out the issue of agricultural non-point source pollution. Runoff from fertilized and pesticide-treated farms carries high levels of chemicals, particularly nitrates and phosphates, into the river (The New Indian Express, 2023). This results in eutrophication, leading to algal blooms and low oxygen conditions, which can cause fish deaths (Rajmohan et al., 2000). Media coverage of these ecological crises raises public and governmental awareness (Mone, 2022). Additionally, changes in land use, especially deforestation for farming in the upper catchments, have worsened soil erosion. This increases sediment and reduces soil water storage capacity, leading to a higher risk of floods, an issue often discussed in environmental policies (Joseph, 2009; The Hindu, 2024).

To address these challenges, adopting sustainable farming and integrated river basin management (IRBM) is vital. Best management practices, such as precision farming, organic methods, and riparian buffer restoration, can curb pollution. NABARD's "green agriculture" initiatives further promote ecological balance, ensuring the Periyar River Basin's environmental and economic sustainability.

2. Geographical delineation of significant agricultural area in the Periyar River Basin

Geographical delineation of key agricultural areas within a river basin is crucial for effective resource management and allocation. It allows for accurate water distribution for irrigation, balancing farming needs with other demands. This mapping helps find specific areas that contribute to agricultural runoff pollution. It supports targeted strategies like encouraging sustainable practices or creating buffer zones (Rajmohan et al., 2000). This spatial knowledge also helps evaluate soil erosion risks and their effects on reservoir sedimentation and flood risk (Joseph, 2009). For the Periyar River Basin, identifying intensive plantation areas informs effective land-use planning and conservation, which is key for integrated basin management.

2.1. Idukki District

Table 1 Land utilization in Idukki district (*Source: Principal Agricultural Office, Idukki*)

Sl. No	Land utilization in Idukki district	
	Land Use Category	**Area (ha)**
1	Total Geographical Area	436,328
2	Forest	198,413
3	Land put to Non-Agricultural Use	14,493.41
4	Barren & Uncultivable Land	1,338.16
5	Permanent Pastures & Grazing Land	0
6	Land under Miscellaneous Tree Crops	102.1

7	Cultivable Waste	15,460.89
8	Fallow Other Than Current Fallow	1,049.45
9	Current Fallow	1,326.35
10	Still Water	10,560
11	Social Forestry	1,251
12	Net Area Sown	206,196.32
13	Area Sown More Than Once	56,401.8
14	Gross Cropped Area	265,981.2

The total geographical area of Idukki district is 436,328 hectares, of which 302,500 hectares falls within the Periyar River Basin. The largest portion of this area is covered by forests, which occupy 198,413 hectares, or about 45.5% of the total. The net sown area is 206,196.32 hectares, making up roughly 47.26% of the geographical area. This shows significant agricultural land use. Additionally, 56,401.8 hectares is reported as land sown more than once, resulting in a gross cropped area of 262,598 hectares. This highlights the use of multi-cropping practices in the district. Land used for non-agricultural purposes amounts to 14,493.41 hectares, which is 3.32% of the total area. Barren and uncultivable lands cover 1,338.16 hectares, or about 0.31%. Cultivable waste lands extend over 15,460.89 hectares, representing 3.54%. This suggests that there are marginal lands that could be reclaimed for agriculture. Fallow lands include 1,049.45 hectares classified as other than current fallow and 1,326.35 hectares classified as current fallow, totaling 2,375.8 hectares or approximately 0.54% of the district. The district reports no area designated for permanent pastures and grazing. Land used for miscellaneous tree crops is only 102.1 hectares, or 0.02%. Social forestry activities cover 1,251 hectares, equaling 0.29%. Water bodies, classified as still water, cover 10,560 hectares, representing 2.42% of the total area.

2.2. Thrissur District

In Thrissur District, Mala Block has the highest aerial extent of barren and uncultivable land (205 ha) and still water coverage (1225 ha), along with substantial fallow lands. Chalakudy Block also shows a considerable presence of fallow lands and moderate coverage under other land types. Vellangallur Block stands out for its high area under current fallows, while Mathilakam has a balanced distribution across all categories. In contrast, Irinjalakuda Block and the Municipalities of Kodungallur and Irinjalakuda have very limited agricultural land, particularly in cultivable and water-covered areas. This pattern reflects a diverse agricultural land use across the region, ranging from actively cultivated zones to areas with limited agricultural potential. The classification of agricultural land in various Blocks and Municipalities in Thrissur District is presented in Table 2.

Table 2: Land utilization in Thrissur district (*Source: Principal Agricultural Office, Thrissur*)

Sl. No	Land utilization in Thrissur district							
	Land Use Category	Chalakudy	Mala	Mathilakam	Irinjalakuda	Vellangallur	Kodungallur Municipality	Irinjalakuda Municipality
1	Area of current fallows (ha)	30	111	51	5	128	15	10
2	Area of fallows other than current fallows (ha)	601.83	696	79	15	122	15	0
3	Barren and uncultivable land area (ha)	147.8	205	58	10	61	1	0
4	Area covered by still water (ha)	248.53	1225	510.5	5	48	15	0

2.3. Ernakulam District

Ernakulam District spans a total geographical area of 308,526 hectares, of which approximately 70,617 ha (22.9%) is covered by forest. A further 47,785 ha falls under the category of land not available for cultivation, reflecting the district's urban infrastructure and non-agricultural uses. Notably, no area is officially classified as permanent pasture or grazing land, and only a negligible 105 ha is recorded under miscellaneous tree crops.

The district has a net sown area of 144,223 ha, representing about 46.7% of the total geographical area. Gross cropped area stands at 164,464 ha, indicating that nearly 20,241 ha is cultivated more than once annually, pointing to moderate levels of cropping intensity.

Significant attention is warranted for the cultivable wasteland (15,956 ha), current fallow lands (7,624 ha), and other fallows (6,753 ha). Together, these account for over 30,000 hectares of potentially reclaimable land for agricultural purposes. (NABARD, (2023), (Potential Linked Credit Plan (PLP) 2023–24 – Ernakulam District.) The classification of agricultural land in Ernakulam District is presented in Table 3.

Table 3: Classification of Land in Ernakulam District

(Source: NABARD (2023) Potential Linked Credit Plan (PLP) 2023–24 – Ernakulam District.)

Classification of Land	Area (ha)
Total geographical Area	308526
Forest Land	70617
Area not available for cultivation	47785
Permanent Pasture and Grazing land	0
Land under miscellaneous Tree crops	105
Cultivable wasteland	15956
Current Fallow	7624
Other Fallow	6753
Net sown Area	144223
Total or Gross cropped Area	164464
Area cultivated more than once	20241

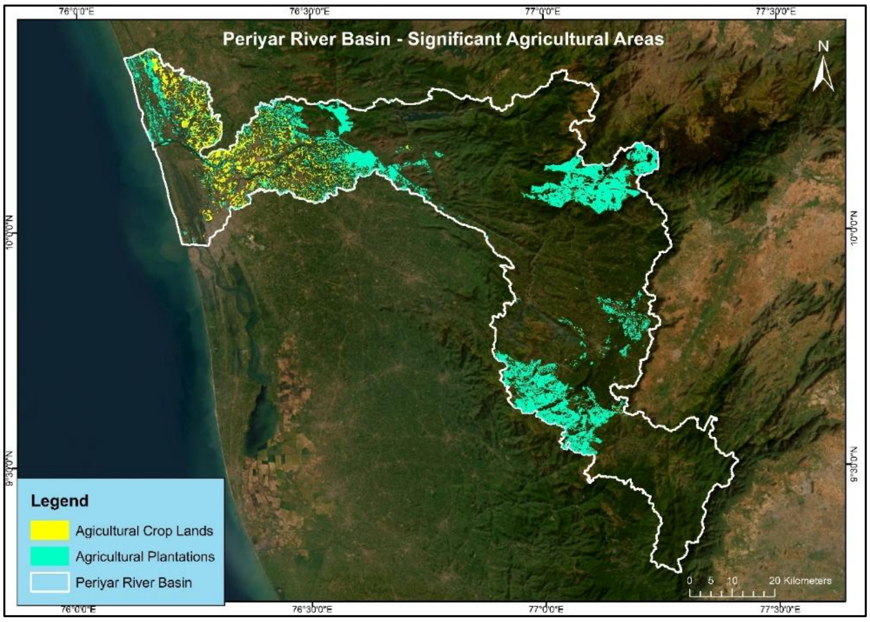

Fig 1 Geographical extend of significant agricultural areas in Periyar River Basin (PRB)

3. Total agricultural lands under different types of farming practices

3.1. Idukki District

Agricultural lands in Idukki district are mainly divided into four major Agro Ecological Units (AEU's). Agro-ecological units (AEUs) are land mapping units defined by consistent combinations of climate, landform, and soil, sometimes including land cover. They are important for sustainable land use planning. This allows for optimal crop selection, which maximizes yields and reduces resource waste. Identifying AEUs, like in the Periyar Basin, helps locate areas that are sensitive to certain environmental issues, such as pollution or erosion. Whereas, an Agro-Ecological Zone (AEZ) is a land resource mapping unit defined by the combination of climate, soil, and terrain characteristics that collectively determine the length of the growing period and the land's potential for agricultural production. It represents areas of relative homogeneity in ecological conditions relevant to crop suitability and land-use planning (FAO, 1996; Fischer et al., 2002). This information guides targeted actions to reduce harm and encourages sustainable farming practices (Joseph, 2009). The four Agro Ecological Units (AEU's) in the Idukki district are:

1. AEU 12 – Southern and Central Foot Hills (AEZ-3)
2. AEU 14 – Southern Hill Ranges (AEZ-4)
3. AEU 16 – Kumily Hill Ranges (AEZ-4)
4. AEU 17 – Marayoor Hill Ranges (AEZ-4)

Southern and Central Foot Hills (AEU 12) belongs to AEZ-3 and includes the Elamdesam block in the PRB. It shows a variety of agricultural practices due to its midland-highland terrain. Panchayats like Alakode, Karimannoor, Kodikulam, Kudayathoor, and Vannappuram grow many crops. These include paddy, coconut, banana, arecanut, and various vegetables. High-value crops such as pepper, nutmeg, clove, cinnamon, ginger, turmeric, coffee, rubber, and medicinal plants also flourish here. This diversity in crops demonstrates mixed and integrated farming systems that fit the region's agro-climatic conditions. It plays an important role in ensuring food security, generating income, and supporting ecological sustainability in the upland areas of Idukki district.

Southern Hill Ranges (AEU 14) includes areas like Adimali, Devikulam, Peermade, Kattappana, Elamdesham, Idukki, and Nedumkandam. It features a diverse agricultural landscape. This AEU supports many crops, including staple foods like paddy and coconut, various fruits and vegetables, and a wide range of high-value plantation crops. Common high-value crops are banana, pepper, nutmeg, clove, cinnamon, ginger, turmeric, vanilla, tamarind, and coffee. The presence of oilseeds and fodder grass suggests a mixed farming system that likely includes both subsistence and commercial agriculture.

Kumily Hill Ranges (AEU 16) covers parts of Peermade, Chinnakanal, Kattappana, and Nedumkandam. It shares many features with AEU 14 but also has its own unique traits. While staples like paddy and coconut are grown, this AEU emphasizes traditional plantation crops such as pepper, nutmeg, clove, cinnamon, ginger, turmeric, tea, and cardamom. The addition of medicinal plants, garcinia, cocoa, and millets further enhances the agricultural profile, indicating a robust focus on commercial farming along with local food production.

Finally, Marayoor Hill Ranges (AEU 17), located in the Devikulam block, has a more specialized agricultural focus. This unit is known for growing sugarcane and potatoes, along with cold-season vegetables and various fruits. While it shares some crops like banana, tea, coffee, and cardamom with other AEUs, the prominence of sugarcane and potatoes highlights specific micro-climatic or soil conditions that favor these crops. This suggests a specialized agricultural economy within this particular hill range unit.

Table 4 Area under different crops – Idukki district *(Source: Principal Agriculture Office, Idukki)*

Sl.No	Crop	Area (ha)	Sl.No	Crop	Area (ha)
1	Paddy	488	13	Rubber	40570
2	Coconut	15305	14	Tapioca	5553
3	Arecanut	1748	14	Banana	3534
4	Pepper	40780	16	Plantain	3200
5	Cardamom	50348	17	Pineapple	1225
6	Tea	25508	18	Papaya	748
7	Coffee	13240	19	Jack	16652
8	Cashew	867	20	Sugarcane	838
9	Ginger	470	21	Vegetables	4748
10	Turmeric	192	22	Tuber crops	1212
11	Nutmeg	3846	23	Pulses	85.3
12	Cocoa	9617			

3.2. Thrissur District

The total agricultural land under different farming practices varies considerably across the Blocks and Municipalities of Thrissur District. Mala Block (8981ha) stands out as the largest agricultural area, followed by Mathilakam (5776 ha) and Vellangallur (4620 ha). Chalakudy also contributes significantly with 2861.8 ha, while Irinjalakuda Block reported a smaller area of 1200 ha under cultivation. Among the Municipalities, Irinjalakuda Municipality has a modest area under agriculture (500 ha) Blocks in rural areas such as Mala and Mathilakam are major areas of agricultural activity, whereas those in urban areas have limited farming land (*Source: Principal Agricultural Office, Thrissur*).

3.3. Ernakulam District

According to the Agricultural Department of Ernakulam, the extent of agricultural land differs across the various blocks of the district. Kothamangalam Block accounts for the largest share (16,221 ha) followed by Angamaly (9,934 ha) and Aluva (4,809 ha). Perumbavoor and North Paravur also hold substantial agricultural areas with 4,269 and 3,710 hectares respectively. Moderate extents of land are observed in Nedumbasserry (3,360 ha), Keezhmadu (2,696.1 ha), and Narakkal (2,232 ha), while Kalamasserry (1,548.75 ha) and Vyttila (200 ha) represent smaller farming areas. Poothrikka (25 ha) records the least agricultural use. Overall, agricultural land is more concentrated in the rural blocks, particularly Kothamangalam and Angamaly, while urban and semi-urban blocks have relatively limited cultivable areas (*Source: Principal Agricultural Office, Ernakulam*).

4. Cropping Pattern and Cropping Intensity of the Periyar River Basin

The percentage of area that is under different crops at a given time and place is known as the cropping pattern (Bharathkumar & Mohammed-Aslam, 2015). Whereas Cropping intensity is a crucial input variable for many global climates, land surface, and crop models. It also plays a significant role in crop yield and food security at the local, regional, and national levels (Liu et al., 2020). Cropping intensity is the number of crop planting cycles per year which is crucial for enhancing food production and safety at local, regional, and national levels (Pan et al., 2021). It is computed using the formula

$$Cropping\ Intensity = \frac{Gross\ Cropped\ Area}{Net\ Sown\ Area} \times 100$$

It is useful for determining the intensity of land use for agricultural production, providing information on land utilization and farming efficiency.

4.1. Cropping Pattern and Intensity in the Idukki district

Idukki district, among the 8 block panchayats in total, the areas of 7 block panchayats are included in the Periyar river basin. They are Adimali, Azhutha, Devikulam, Elamdesom, Idukki, Kattappana and Nedumkandam. All these block panchayats are diverse in terms of geography and hence different types of crops are grown in these areas. These areas also show different cropping patterns.

Table 5 Cropping intensity (%) of the Periyar River Basin - Idukki District

(Source: Department of Agriculture Development and Farmers' Welfare, 2018)

Block	Total Geographical Area (km²)	Gross Cropped Area (km²)	Net Sown Area (km²)	Area Sown more than once (km²)	Cropping Intensity (%)
Adimali	411.76	290.59	209.06	81.53	1.39
Azhutha	1133.18	339.49	244.24	95.25	1.39
Devikulam	891.64	628.72	452.32	176.40	1.39
Elamdesom	352.79	266.03	191.39	74.64	1.39
Idukki	413.96	172.18	123.87	48.31	1.39
Kattappana	343.23	173.39	124.74	48.65	1.39
Nedumkandam	349.93	329.18	236.82	92.36	1.39

Adimali block panchayat of the basin has a total area of 411.76 km²s. The area has a gross cropped area of 290.59 km²s and net sown area of 209.06 km²s. In the area, 81.53 km²s of agricultural land are sown more than once in a year. The area, renowned for its rich agricultural heritage, especially in pepper, cocoa and coffee cultivation has a cropping intensity of 139%. Adimali block panchayat also oversees several initiatives to improve the area's agricultural development including agricultural support, livelihood programs and wildlife protection measures for an area like Adimali, which is very prone to wildlife attacks. Mixed cropping pattern is seen in the Adimali block panchayat dominated by perennial and cash crops like pepper, cardamom and coffee.

Azhutha block panchayat of the basin has a total area of 1133.18 km²s.The area has a gross cropped area of 339.49 km²s and net sown area of 244.24 km²s. In the area, 95.25 km²s of agricultural land are sown more than once in a year. The block's agro-climatic conditions favours it to be a famous location for the cultivation of various plantation crops, including tea, coffee, rubber, coconut, pepper and cardamom, and also has a cropping intensity of 139%. The area is also famous for the tribal agricultural practices of the Paliyan community, who are primarily engaged in agriculture, cattle breeding and gathering of forest products. More than 80% of the agricultural area in the Azhutha block panchayat is perennial plantation crops and spices.

Devikulam block panchayat of the basin has a total area of 891.64 km²s. The area has a gross cropped area of 628.72 km²s and net sown area of 452.32 km²s. In the area, 176.40 km²s of agricultural land are sown more than once in a year. The block encompasses several grama panchayats, including Devikulam, Edamalakudy, Marayoor, Kanthalloor, Vattavada, Munnar, Chinnakkanal, Santhanpara and Mankulam. Area which is famous for the cultivation of Kanthalloor-Vattavada Garlic and Onattukara Ellu (Sesame) shows a cropping intensity of 139%. This area has a cropping pattern dominated by plantation crops, spices, and cool-season vegetables and fruits.

Elamdesom block panchayat of the basin has a total area of 352.79 km^2s. The area has a gross cropped area of 266.03 km^2s and net sown area of 191.39 km^2s. In the area, 74.64 km^2s of agricultural land are sown more than once in a year. The area is famous for the cultivation of spices and plantation crops. The region's favourable agro-climatic conditions favours the cultivation of pepper, cardamom, tea, coffee, rubber, coconut and paddy. This area has a cropping pattern dominated by plantation and spice crops. The area shows a cropping intensity of 139%.

Idukki block panchayat of the basin has a total area of 413.96 km^2s. The area has a gross cropped area of 172.18 km^2s and net sown area of 123.87 km^2s. In the area, 48.31 km^2s of agricultural land are sown more than once in a year. Region's agro-climatic conditions make it favourable for the cultivation of various crops like rubber, tea, coffee, cardamom, pepper, paddy, tapioca, ginger and turmeric. The area shows a cropping intensity of 139%.

Kattappana block panchayat of the basin has a total area of 343.23 km^2s. The area has a gross cropped area of 173.39 km^2s and net sown area of 124.74 km^2s. In the area, 48.65 km^2s of agricultural land are sown more than once in a year. Kattappana block panchayat, known for its diverse agricultural activities, which in turn benefitted from the region's favourable climate and terrain, comprises the Kattappana, Ayyappan Kovil, Chakkupallam, Kanchiyar, Erattayar, Upputhara and Vandanmedu grama panchayats. The region is renowned for its spice cultivation, mainly cardamom and pepper. Tea, rubber, paddy, tapioca and various vegetables are also grown in the region. The area shows a cropping intensity of 139%. This block panchayat has a cropping pattern dominated by spices and plantation crops, supplemented by short-term crops and mixed farming.

Nedumkandam block panchayat of the basin has a total area of 349.93 km^2s. The area has a gross cropped area of 329.18 km^2s and net sown area of 236.82 km^2s. In the area, 92.36 km^2s of agricultural land are sown more than once in a year. Nedumkandam, which is renowned for its rich agricultural landscape due to its fertile soil and favourable climate, is the major producer of cardamom and pepper. Coffee,tea, nutmeg, ginger, coconut and clove are also cultivated in the region. This region shows a cropping intensity of 139%. The cropping pattern in the Nedumkandam block panchayat is predominantly mixed, with a heavy emphasis on intercropping. This system combines perennial plantation crops with shorter-duration crops to maximize land use and income, reflecting the high-range, rain-fed conditions of the Idukki district.

4.2. Cropping Pattern and Intensity in the Thrissur district

Mixed cropping is the dominant agricultural practice in Chalakudy, Mala, Mathilakam, Irinjalakuda, and Vellangallur Blocks. This indicates that farmers cultivate more than one type of crop on the same land, either simultaneously or in rotation, to maximize land use, reduce risk, and improve soil health (*Source - Principal Agricultural Office, Thrissur*).

Thrissur, a city renowned for its rich cultural legacy and fertile plains, has a comparatively high cropping intensity because of its good agro-climatic conditions and large extent of cultivable area. Intensive agriculture is supported by the level topography of the land in many areas including Chalakudy, Irinjalakuda, Mala, and Mathilakom which are very "active" in terms of agriculture related activities. Several cropping techniques help to maximize land utilization and boost yield. In contrast to Idukki's forest-dominated terrain, Thrissur has relatively less forest cover, which permits more land use and agricultural growth.

Based on data from the Department of Agriculture Development and Farmers' Welfare (2018), cropping intensity (%) in different Blocks in the Thrissur District within the Periyar River Basin is presented in Table 5. The ratio of gross cropped area to net sown area, or cropping intensity, shows how intensely agricultural land is used. Among the Blocks, Mala exhibits the highest cropping intensity (112.46%), reflecting significant multiple cropping, with 17.23 km² of land sown more than once. Chalakudy follows with 103.58%. The other Blocks Irinjalakuda, Vellangallur, and Mathilakom show cropping intensities slightly above 100%, ranging from 100.25% to 101.01%, suggesting limited reuse of agricultural land.

Table 6 Cropping intensity (%) of the Periyar River Basin - Thrissur District

(Source: Department of Agriculture Development and Farmers' Welfare, 2018)

Block	Total Geographical Area (km²)	Gross Cropped Area (km²)	Net Sown Area (km²)	Area Sown more than once (km²)	Cropping Intensity (%)
Chalakudy	710.12	158.36	152.89	5.47	103.58
Irinjalakuda	94.925	91.94	91.02	0.92	101.01
Mala	154.44	155.51	138.28	17.23	112.46

Vellangallur	105.08	94.38	93.88	0.5	100.53
Mathilakom	96.324	91.77	91.49	0.28	100.31

4.3. Cropping Pattern and Intensity in the Ernakulam district

Ernakulam, a District marked by its blend of urban expansion and agricultural landscapes exhibits moderate cropping intensity across various Grama Panchayats. Despite having limited forest cover compared to the highland Districts, the availability of cultivable land is uneven due to urbanization and land use for non-agricultural purposes. Regions such as Angamaly, Parakkadavu, Vazhakkulam, Koovappady, and Kothamangalam reveal varying degrees of agricultural activity, with cropping intensity mostly above 100% indicating that while most land is cultivated once a year, a small portion is used for growing an additional crop.

In Ernakulam District, 12.18 sq.km. of land is sown more than once. Koovappady Grama Panchayat (GP) has the highest cropping intensity at 111.56%. High cropping intensities are also observed in Vazhakkulam (109.24%) and Njarakkal Grama Panchayats (107.31%), suggesting a robust multiple cropping practice. These are closely followed by Parakkadavu GP (105.32%), Angamaly GP (105.26%), and Edappally GP (102.59%). Kothamangalam GP has the lowest cropping intensity at 100.88%, suggesting very less acreage under more than one crop. Alangad (102.25%) and Paravur (102.44%) GPs also have modest amounts of multiple cropping. The cropping intensity of Ernakulam District is continuously above 100%. Details pertaining to land utilization, including gross cropped area (GCA), net sown area (NSA), and cropping intensity (CI) of Ernakulam District (within the Periyar River Basin) are presented in Table 7.

Table 7 Cropping intensity (%) of the Periyar River Basin - Ernakulam District

(Source: Department of Agriculture Development and Farmers' Welfare, 2018)

Grama Panchayat	Total Geographical Area (km²)	Gross Cropped Area (km²)	Net Sown Area (km²)	Area sown more than once (km²)	Cropping Intensity (%)
Angamaly	400.454	100.13	95.13	5	105.256
Parakkadavu	117.95	80.21	76.16	4.05	105.318
Vazhakkulam	122.45	56.87	52.06	4.81	109.239
Edappally	112.422	359.85	350.75	9.1	102.594

Njarakkal	54.13	33.48	31.17	2.31	107.411
Koovappady	182.53	117.57	105.39	12.18	111.557
Kothamangalam	966.5	257.16	254.92	2.24	100.879
Paravur	75.29	50.45	49.25	1.2	102.437
Alangad	85.09	42.28	41.35	0.93	102.249

5. Irrigated land and major irrigation sources with groundwater drawdown information

Irrigation, which is essential for ensuring consistent crop growth, especially in areas with insufficient rainfall. It provides a reliable water supply, boosting agricultural productivity and food security by preventing crop failure during dry periods. Irrigation is also inevitable in reducing soil erosion, supporting livestock farming, and enabling the cultivation of diverse crops, improving both economic outcomes and climate resilience. By using water more efficiently, modern irrigation techniques contribute to sustainable farming practices and the expansion of arable land.

The districts, Idukki, Ernakulam and Thrissur, which have areas belonging to the Periyar River Basin, obtains significant amounts of water through different irrigation methods.

5.1. Irrigated Land Area in Idukki District - Periyar River Basin

Idukki district, has an area of 53127.33 ha irrigated from different sources and methods. In the Idukki district, an area of 785.74 ha was irrigated using small streams/canals, out of which 785.7 ha were irrigated by Government owned canals and the rest 0.04 ha were irrigated by privately owned streams/canals. An area of 0.25 ha was irrigated with the help of Government owned ponds whereas an area of 23049.83 ha was irrigated with the help of privately owned ponds. 7345.43 ha of land in the district was irrigated using privately owned dug wells, and an area of 13021.65 ha was irrigated utilizing borewells/tubewells. 1325.5 ha area was irrigated from the rivers and lakes using methods like pumping from the river and other methods. The remaining 7598.93 ha was irrigated using other sources and methods. Fig 2 shows the distribution of irrigated lands in Idukki and the major water sources supporting them.

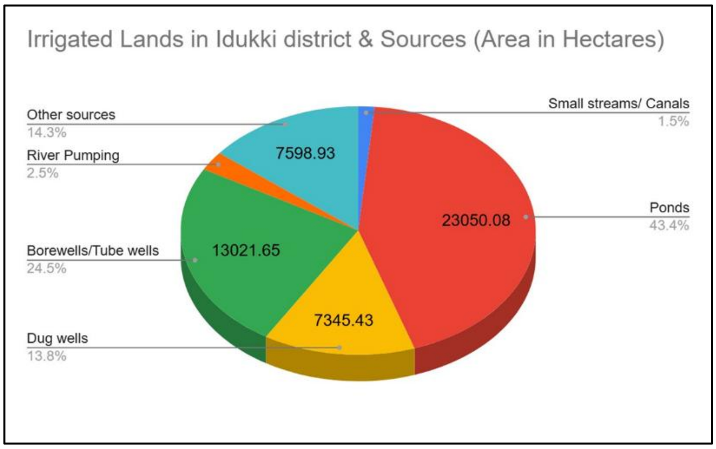

Fig 2 Schematic representation of irrigated lands in Idukki and their sources

Table 8 Block wise groundwater levels in Idukki district – PRB *(Source: Kerala State Groundwater Dept)*

Groundwater Levels - Idukki District (Periyar River Basin Area)			
Block Panchayat	**Observation Locations**	**Average Depth to Water Table (MBGL) - 2004**	**Average Depth to Water Table (MBGL) - 2024**
Adimali	Konnathady	--	5.57
	Bison Valley 1	--	9.36
	Bison Valley 2	--	10.40
	Vellathooval	--	5.81
	Pallivasal	17.54	17.53
	Mannamkandam	1.95	2.13
Azhutha	Peermade 1	3.14	2.86
	Kumily 1	2.83	2.4
	Elappara 1	1.66	1.63
	Peruvanthanam	1.91	2.87
	Periyar	--	1.46
	Peermade 2	--	14.9
	Kumily 2	--	1.62
	Manjumala	--	4.06
	Elappara 2	--	1.27
	Kokkayar	--	5.38
	Elappara 3	--	3.6
Devikulam	Santhanpara	0.93	0.57
	Munnar 1	--	1.86
	Marayoor	1.6	1.78
	Munnar 2	3.91	3.94
	Vattavada	--	6.01
	Chinnakanal	--	3.23
	KDH Village	6.65	7.75
	Pooppara	10.32	25.9
	Kanthalloor	19.01	17.3
Elamdesam	Vannappuram 1	5.04	4.78
	Karimannoor 1	5.13	4.83
	Karimannoor 2	--	7.73
	Udumbannoor 1	--	5.99

	Vannappuram 2	--	7.27
	Kudayathoor 1	4.17	3.04
	Kudayathoor 2	7.6	7.98
	Udumbannoor 2	1.51	1.5
	Kudayathoor 3	4.37	4.07
	Velliyamattom	2.37	3.9
Idukki	Arakulam 1	4.57	5.83
	Idukki 1	--	6.83
	Arakulam 2	--	4.25
	Kanjikuzhy	--	8.9
	Vathikudy 1	--	13.5
	Idukki 2	--	10.41
	Thankamani	--	4.18
	Vathikudy 2	15.16	14.72
Kattappana	Chakkupallam 1	0.86	0.84
	Ayyappankovil 1	8.27	7.66
	Kattappana	7.97	7.08
	Chakkupallam 2	--	7.98
	Kattappana Muncipality	--	3.6
	Ayyappankovil 2	--	2.86
	Upputhara 1	--	5.85
	Kanchiyar	9.89	4.47
	Vandanmedu	4.6	21.46
	Upputhara 2	6.28	8.44
Nedumkandam	Kalkoonthal 1	3.44	3.26
	Rajakkad 1	--	8.69
	Kalkoonthal 2	--	2.57
	Pampadumpara	--	8.94
	Rajakumary	--	8.4
	Karunapuram	--	3.64
	Udumbanchola	5.4	7.91
	Parathodu	2.22	--
	Rajakkad 2	32.31	32.72

Between 2004 and 2024, groundwater levels in the Periyar River Basin portion of Idukki District show an overall decline, with notable site-specific variations. Pooppara (10.32 → 25.9 m) and Vandanmedu (4.6 → 21.46 m) exhibit severe depletion, likely due to over-extraction and poor recharge in steep, plantation-dominated areas. In contrast, locations such as Santhanpara, Ayyappankovil, and Mannamkandam show stable or slightly improved levels, reflecting better recharge conditions. Shallow aquifers in Elappara, Kumily, and Udumbannoor indicate sustained groundwater availability near riverine systems. Overall, the data reveal a declining trend with localized variability, underscoring the need for improved recharge, regulated withdrawal, and catchment conservation to maintain groundwater sustainability.

Table 9 Major irrigation sources – Idukki district *(Source: Principal Agricultural Office Idukki)*

Block Panchayat	Major irrigation sources with groundwater drawdown information		
	Surface Irrigation (canal based/ tanks/ ponds/reservoirs)	**Ground Water (tube wells, open wells, bore wells)**	**Other Sources (including traditional water harvesting system)**
Adimali	Ponds, canals, streams	Dug wells, shallow / tubewells	Rain water harvesting, pits
Azhutha	Ponds, streams	Open wells, shallow/tubewells	-
Devikulam	Surface water, reservoir/streams	wells, tubewells	Rain water harvesting, pits, small streams
Elamdesam	Ponds, streams, minor irrigation	Wells, tubewells, minor irrigation	Rain water harvesting, pits, small streams
Idukki	Ponds, streams	Open wells	Rainwater harvesting
Kattappana	Surface water, streams/reservoir	Open wells, tube wells	Rain pits
Nedumkandam	Streams, minor surface schemes	Open wells, tube wells	-

5.2. Irrigated Land Area in Thrissur District - Periyar River Basin

In Thrissur District, within the Periyar River Basin, Chalakkudy Block has the largest irrigated area, covering about 9,798 ha, followed by Mala (8,675 ha) and Irinjalakuda (6,728 ha). Mathilakam and Vellangallur Blocks also have considerable irrigated extents of 5,592 ha and 4,698 ha, respectively. Altogether, the total irrigated area across all Blocks amounts to 35,491 ha. This distribution highlights the significant dependence on irrigation for agricultural activities in the region and underscores the importance of water management in ensuring groundwater sustainability (District Irrigation Plan, Thrissur, 2017).

5.3. Irrigated Land Area in Ernakulam District - Periyar River Basin

In Ernakulam District, within the Periyar River Basin, Angamaly Block records the largest irrigated area, covering about 5,691 ha, followed by Nedumbassery (3,682 ha) and Perumbavoor (2,536 ha).

Other Blocks such as Kothamangalam (1,743 ha), Keezhmadu (1,485 ha), Aluva (1,372 ha), and North Paravur (1,289 ha) also contribute notably to the district's irrigated extent. Kalamassery (549 ha) and Njarackal (116 ha) have comparatively smaller irrigated areas. Altogether, the total irrigated area across all Blocks amounts to 18,463 ha. This distribution illustrates the variation in irrigation dependency across the region and provides valuable insight into the management of groundwater resources and agricultural sustainability (District Irrigation Plan, Ernakulam, 2017).

5.4. Major irrigation sources with groundwater drawdown information - Thrissur District

The major irrigation sources in Thrissur District fall under three broad categories: surface irrigation, groundwater irrigation and irrigation from traditional water harvesting systems. Details are briefly summarised in Table 10.

Irrigation practices in the Blocks of Chalakudy, Mala, Mathilakam, Irinjalakuda, and Vellangallur reveal a diverse mix of surface and groundwater sources. In Chalakudy, irrigation is supported by river-fed canals, borewells, open wells, ponds and traditional rain pits, indicating balanced use of surface and groundwater resources. Mala Block relies heavily on groundwater through open wells and borewells, supplemented by canal systems and ponds, with occasional use of rain pits for rainwater harvesting. In Mathilakam, ponds are the dominant surface water source, while tube wells and open wells are widely used for groundwater extraction. The presence of filters in some wells suggests concerns about water quality. Irinjalakuda shows a strong dependency on ponds, supported by open wells and borewells, highlighting moderate groundwater reliance. Vellangallur demonstrates a well-balanced irrigation pattern with the presence of canal-based systems, ponds and reservoirs for surface irrigation and open wells and borewells for groundwater needs. While surface sources like ponds and canals play a significant role across all Blocks, the increasing use of borewells and open wells highlights growing dependency on groundwater. Traditional water harvesting methods like rain pits are still in practice, particularly in Chalakudy and Mala. Overall, the irrigation landscape in the basin reflects a mixed dependency on canals, significant groundwater extraction and a renewed interest in traditional water conservation practices. To prevent the overexploitation of groundwater and to secure long-term agricultural sustainability, it is vital to implement sustainable water management strategies such as rainwater harvesting, aquifer recharge and the adoption of micro-irrigation systems.

Table 10 Major irrigation sources – Thrissur district

(Source: Principal Agricultural Office Thrissur)

Block	Major irrigation sources with groundwater drawdown information		
	Surface Irrigation (canal based/ tanks/ ponds/ reservoirs)	**Ground Water (tube wells, open wells, bore wells)**	**Other Sources (including traditional water harvesting system)**
Chalakudy	River, Irrigation Canals	Open wells and Borewells	Ponds, Rain pits
Mala	Canal based, Ponds	Open wells and Borewells	Ponds, Rain pits
Mathilakam	Ponds	Tube wells, Open wells, Filters, Borewells	Rain pits, Ponds
Irinjalakuda	Ponds	Open wells and Borewells	Ponds
Vellangallur	Canal based, Ponds, Reservoirs	Open wells and Borewells	-

5.5. Major irrigation sources with groundwater drawdown information - Ernakulam District

The total groundwater availability in Ernakulam District is 6.912 million cubic metres (MCM). Groundwater resources differ significantly among Blocks due to variations in hydrogeology, recharge potential, and physiographic setting (Table 11). Kothamangalam Block has the highest groundwater availability, followed by Parakkadavu and Vazhakkulam, which reflect favourable aquifer conditions that support both agricultural and domestic uses. In contrast, Koovappady Block has the lowest groundwater availability, highlighting the need for targeted recharge interventions and careful groundwater management. The total volumetric availability reported for each Block is also influenced by its geographical area; larger Blocks tend to accumulate greater groundwater volumes even when recharge characteristics are similar. Therefore, lower groundwater availability in a smaller Block may result from its limited areal extent rather than aquifer depletion or inadequate recharge. Other Blocks, such as Alangad, Edappally, Vypin, Paravoor, and Angamaly, demonstrate moderate availability. These patterns indicate the necessity for area-normalised assessments and Block-specific water management strategies to enhance recharge in low-availability zones and ensure sustainable use where reserves are higher.

Table 11 Groundwater Availability - Ernakulam District

(Source - District Irrigation Plan, Ernakulam, 2017)

Block	Ground Water (MCM)
Vypin	0.365
Paravoor	0.382
Kothamangalam	2.410
Edappally	0.291
Alangad	0.166
Angamaly	0.375
Parakkadavu	0.833
Koovappady	0.056
Vazhakkulam	0.535
Total	6.912

6. Irrigation pattern in the Periyar River Basin

Irrigation pattern refers to the distribution and types of water sources used for agricultural activities in a region. The irrigation system being adopted in a location is influenced significantly by the hydrology of the Periyar River Basin and the topography of the place. The Periyar River supports various irrigation infrastructure including dams and barrages, government and private canals, ponds, wells, and borewells.

6.1. Irrigation Pattern in the Periyar River Basin – Idukki District

The irrigation pattern of the Idukki mainly depends on surface irrigation and localized irrigation. Surface irrigation is the application of water directly to the soil surface with the help of gravity. Basin irrigation, which is practiced in the district, is an example of this method. Several micro irrigation methods which utilize the use of drippers, foggers, sprinklers and similar emitters, to irrigate on or below the earth's surface are also observed in the irrigation supply system of Idukki district. This micro irrigation method was officially introduced in the country as a Centrally Sponsored Scheme on Micro Irrigation (CSS), in January, 2006. Fertigation method, which is a method of artificial fertilizer application through irrigation water is also followed in the district. The irrigation pattern in the area is based on the seasons and the crops grown with respect to each season and regions, and is represented in the table 12 below.

Table 12 Irrigation Pattern, Idukki district *(Source: Principal Agricultural Office Idukki)*

Block Panchayat	Season / Crop Group	Irrigated (ha)	Rainfed (ha)
Adimali	Kharif & Rabi (Pulses)	250	390
	Horticulture & Plantation	4500	3000
Devikulam	Kharif (Veg. & Tubers)	72	319
	Rabi (Pulses, Veg., Tubers)	228	519
	Summer (Pulses, Veg., Tubers)	50	639
	Oilseeds	35	160
	Horticulture & Plantation	4581	22648
Kattappana	Kharif (Veg. & Cereals)	—	545
	Rabi (Vegetables)	264	110
	Summer (Pulses & Vegetables)	97	16
	Horticulture & Plantation	8690	24807
Azhutha	Kharif & Summer (Vegetables)	230	—
	Horticulture & Plantation	—	36212.5
Nedumkandam	Kharif (Cereals, Pulses, Veg., Tubers)	72	520
	Rabi (Pulses, Veg., Tubers, Cereals)	228	581
	Summer (Cereals, Pulses, Veg., Tubers)	50	649
	Horticulture & Plantation	4581	22648
	Kharif (Cereals, Pulses, Oilseeds)	20	50

Idukki	Rabi (Cereals, Pulses, Tubers, Veg.)	40	290
	Summer (Oilseeds, Veg., Tubers)	100	230
	Horticulture & Plantation	1850	6800

Table 13 Existing Irrigation Methods in the Periyar River Basin – Idukki District

(Source: Principal Agricultural Office, Idukki)

Block	Existing irrigation pattern
Adimali	Drip / micro-sprinkler, limited basin/flood irrigation
Devikulam	Drip and sprinkler irrigation
Nedumkandam	Drip/micro sprinkler, localized flood/basin
Elamdesam	Basin Irrigation, Flood irrigation, Drip irrigation, Sprinkler irrigation
Idukki	Lift/command irrigation, drip/sprinkler irrigation
Kattappana	Drip/sprinkler irrigation
Azhutha	Drip / micro-sprinkler, very limited basin/flood irrigation

6.2. Irrigation Pattern in the Periyar River Basin - Thrissur District

Table 14 below outlines the existing irrigation practices across the Blocks in Thrissur District that fall within the Periyar River Basin. While flood irrigation remains the most commonly used method across all the Blocks, drip and sprinkler irrigation systems have also been adopted in areas like Mala, Mathilakam, Irinjalakuda, and Vellangallur. Additionally, basin irrigation is practiced in Mathilakam and Irinjalakuda. Adoption of different irrigation methods reflects the efforts to improve water use efficiency and adapt to varying crop and soil conditions in the region.

Table 14 Existing Irrigation Pattern in the Periyar River Basin – Thrissur District

(Source: Principal Agricultural Office, Thrissur)

Block	Existing irrigation pattern
Chalakudy	Flood irrigation
Mala	Flood irrigation, Drip irrigation, Sprinkler irrigation

Mathilakam	Basin Irrigation, Flood irrigation, Drip irrigation, Sprinkler irrigation
Irinjalakuda	Basin Irrigation, Flood irrigation, Drip irrigation, Sprinkler irrigation
Vellangallur	Flood irrigation, Drip irrigation, Sprinkler irrigation

6.3. Irrigation Pattern in the Periyar River Basin - Ernakulam District

The irrigation system in the portion of the Periyar River Basin in Ernakulam district, is largely influenced by the hydrology of the Periyar River, the availability of surface and groundwater sources, and the topography of the basin. While rainfed cultivation is predominant in several blocks such as Narakkal, North Paravur, Aluva, Nedumbasserry, Kalamasserry, and Vyttila, other blocks also make use of irrigation infrastructure. Perumbavoor and Angamaly adopt both rainfed and irrigated practices, whereas Keezhmadu utilizes a combination of rainfed and surface irrigation. Poothrikka relies mainly on surface irrigation. In Kothamangalam block, diverse sources such as ponds, reservoirs, rivers, the Periyar Valley Canal, and open wells contribute significantly to irrigation (*Source: Principal Agricultural Office, Ernakulam).*

7. Crop Production and Average Yield in the Periyar River Basin

Crop production and average yield are very often considered as the major outcome of every agricultural activity happening in an area. It depends on various factors such as agricultural manpower, fertilization of agricultural lands, pests' control, proper management of water resources etc. Here, the crop production and average yield are discussed in detail as two time periods, 2013-2018 and 2018-2023, discussing a five-year variation in production and average yield for the major crops cultivated in the Periyar River basin.

7.1. Crop Production and Yield in Idukki District (2013–2018)

Idukki district, the largest district in Kerala, contributes a lot into the state agricultural productivity as well as to the regional economy of the state. Between 2013 and 2018, crop production in Idukki was dominated by perennial crops and spices, in particular cardamom, pepper, tea and coffee, which continued to define the district's agricultural profile. Cardamom remained the main contributor to total agricultural production, with Idukki representing more than four fifths of Kerala production during the period. Pepper production, although extensive, showed moderate fluctuations and declined after 2015-16 due to adverse weather and pesticides. Tea and coffee farms maintained stable production levels, strengthening Idukki's position as the leading tea production district and a major contributor to coffee production. The production of coconuts and nuts showed slight variations, with Elamdesam, and Nedumkandam maintaining consistent performance. Food crops such as tapioca, banana, and plantain showed varying production trends, with banana production increasing until 2016–17 before becoming stable. Ginger and turmeric production varied annually, reaching its peak in 2014–15 and 2015–16 respectively, while pineapple and cashew contributed marginally. Cocoa and nutsmeg production gradually increased during the period, reflecting the district's continuous diversification towards high-value crops.

The yield patterns in Idukki show moderate interannual variation between 2013–14 and 2017–18. Cardamom maintained consistent high yields, especially in Kattapana, Nedumkandam and Devikulam blocks, supported by favourable climatic conditions in medium and high-altitude areas. Pepper yields were relatively stable until 2015–16 before decreasing slightly in subsequent years. Coconut production remained moderate throughout the district, with Elamdesam and Adimali registering higher production per hectare. The arecanut production improved gradually, while the nutmeg and cocoa production remained stable with incremental gains. Food crop yields showed greater variability — tapioca yields decreased slightly, while banana and plant yields improved until mid-decade before stabilizing. The yields of ginger and turmeric reached their peak in 2014–15 and 2015–16, respectively, after which they showed a slight decline. Overall, the period marked a transition to sustainable productivity of high-value-permanent crops and a gradual reduction in yields from short-term food crops, which underscored Idukki’s transition towards plantation-based agricultural resilience.

7.2. Crop Production and Yield in Idukki District (2018–2023)

From 2018–19 to 2022–23, tapioca cultivation in Idukki showed fluctuating trends in area, production, and yield, with the highest yield recorded in 2021–22. Blocks like Idukki, Elamdesam, and Devikulam performed well, though production declined notably in 2022–23. Arecanut cultivation varied across years, with better yields in Devikulam and Idukki blocks and a production spike in Kattapana. Coconut cultivation remained widespread and consistently productive, with Elamdesam recording the highest area and yield, followed by Idukki and Nedumkandam; Adimali and Azhutha maintained stable yields. Banana cultivation fluctuated, peaking in yield in 2019–20 but gradually declined in 2020–21. Plantain cultivation varied yearly, improving in 2019–20, peaking in 2020–21, declining in 2021–22, and recovering in 2022–23. Ginger cultivation remained steady, with highest area and production in Kattapana, Nedumkandam, and Idukki; yields peaked in 2020–21 before slightly declining in 2022–23. Cured turmeric maintained consistent production, with Elamdesam, Adimali, and Nedumkandam leading; Elamdesam had the highest consistent yield (Agricultural Statistics 2018-23).

Black pepper cultivation showed spatial variation and moderate yield fluctuation, with Nedumkandam consistently leading in area and production. However, a decline in area and output was observed post-2020. Raw cashew cultivation declined in area, yield, and production over five years, from initially high outputs to modest levels; 2021–22 had the highest yield. Elamdesam dominated pineapple cultivation, but production declined in 2020-21 and recovered by 2022-23, while other blocks showed low-yield production in other blocks. Jackfruit cultivation was large-scale with consistent land use. Adimali led in production, while Kattapana and Nedumkandam had highest productivity. Elamdesam and Kattapana showed high yields. Betel leaf cultivation was limited and inconsistent, with only minor entries in Nedumkandam and Devikulam. Cocoa cultivation varied across blocks, with Idukki and Adimali achieving the highest production and Elamdesam recording consistently top yields. Nutmeg cultivation remained stable, with Adimali and Idukki leading in productivity. Elamdesam and Azhutha performed moderately, while Devikulam and Kattapana showed slight improvements; Nedumkandam had inconsistent yield trends (Agricultural Statistics 2018-23).

7.3. Crop Production and Yield in Ernakulam District (2013–2018)

Between 2013–14 and 2017–18, agriculture in Ernakulam district reflected a strong diversification, combining extensive coconut, nutmeg and banana cultivation with significant rubber, paddy and vegetable production. Coconuts continued to dominate the landscape, especially in the Aluva and Paravur blocks, placing Ernakulam as a major contributor to Kerala's total coconut production. Nutmeg emerged as the district's high-value crop, with constant increases in both area and production, placed second in the state. The cultivation of Paddy continues in dispersed areas such as Edappally and Vadavucode, while bananas and plantains show periodic increases, especially in Vazhakulam and Koovappady. Rubber production remained stable in the highlands, while pineapples, vegetables and spices such as pepper and turmeric were produced in moderate quantities, mainly in the eastern blocks adjacent to Idukki.

The yields on major crops in Ernakulam district showed stable to improved patterns during 2013–18. Coconut production remained among the highest in the state, especially in the middle and coastal areas with better soil moisture and management. Nutmeg has consistently achieved high yields throughout the period, supported by favourable market trends and intensive care practices. Paddy yields improved slightly due to mechanization and better irrigation management in the lowlands. The harvest of bananas and plantain grew until 2016–17 before stabilizing. Rubber production remained stable, while pineapple and vegetable crops showed moderate seasonal variations. Overall, the yield model reflects Ernakulam's transition to highly valuable perennial and horticultural crops, with stable productivity supported by well-developed irrigation, market access and mixed agricultural systems (Agricultural Statistics 2013–18).

7.4. Crop Production and Yield in Ernakulam District (2018–2023)

Arecanut cultivation maintained stable area coverage across the district. Koovappady, Kothamangalam, and Vadavucode recorded higher yields. Coconut was widely cultivated, with high production in most blocks. Edappally had the highest yield, while Koovappady and Kothamangalam showed moderate productivity. Banana was extensively grown across blocks such as Alangad, Angamaly, Koovappady, Kothamangalam, Parakkadavu, Vadavucode, Paravur, Edappally, and Vypin, with generally high yields. Plantain was cultivated across multiple blocks, with Angamaly and Parakkadavu recording higher yields. Other blocks showed moderate area and yield. Tapioca cultivation was noted in many blocks. Koovappady and Parakkadavu led in area and production. Alangad and Edappally had limited cultivation. Cured ginger was cultivated mainly in Koovappady, Kothamangalam, Parakkadavu, and Vadavucode. Alangad, Edappally, Vazhakkulam, and Paravur also contributed. Cured turmeric was cultivated on a small scale. Angamaly and Kothamangalam reported the highest yields, while other blocks had low to moderate production. Black pepper was mainly cultivated in Kothamangalam, Angamaly, and Vazhakkulam. Other blocks such as Vadavucode and Edappally had smaller extents of cultivation. Raw cashew cultivation was observed in Angamaly, Parakkadavu, and some other blocks. Vypin and Vadavucode reported moderate yields. Pineapple was cultivated primarily in Kothamangalam, Vadavucode, Koovappady, and Vazhakkulam. Angamaly and Parakkadavu had moderate production. Jackfruit was produced across the district. Angamaly had the highest production, followed by Kothamangalam, Koovappady, Vadavucode, and Vazhakkulam. Coastal blocks had lower outputs. Betel leaf was cultivated mainly in Vadavucode, with Koovappady, Kothamangalam, Vazhakkulam, Alangad, and Edappally also contributing in small areas. Cocoa cultivation was prominent in Kothamangalam, followed by Koovappady, Vadavucode, and Angamaly. Other blocks such as Alangad, Edappally, and Paravur had limited cultivation. Nutmeg was grown widely, especially in Angamaly, Koovappady, and Parakkadavu. Vazhakkulam, Vadavucode, and Kothamangalam also recorded significant production. Sesamum cultivation was minimal and limited to blocks like Parakkadavu, Angamaly, Kothamangalam, and Vazhakkulam, with very low area and production. Sugarcane cultivation was negligible. Blocks Edappally and Vazhakkulam reported small-scale cultivation, with Vazhakkulam showing the highest production (Agricultural Statistics 2018-23). Figures 3 and 4 compare pepper production in the Periyar River Basin from 2013 to 2023, whereas Figures 5 and 6 illustrate changes in coconut production during the same period. Collectively, these figures indicate significant changes in the production of major plantation crops over the past decade.

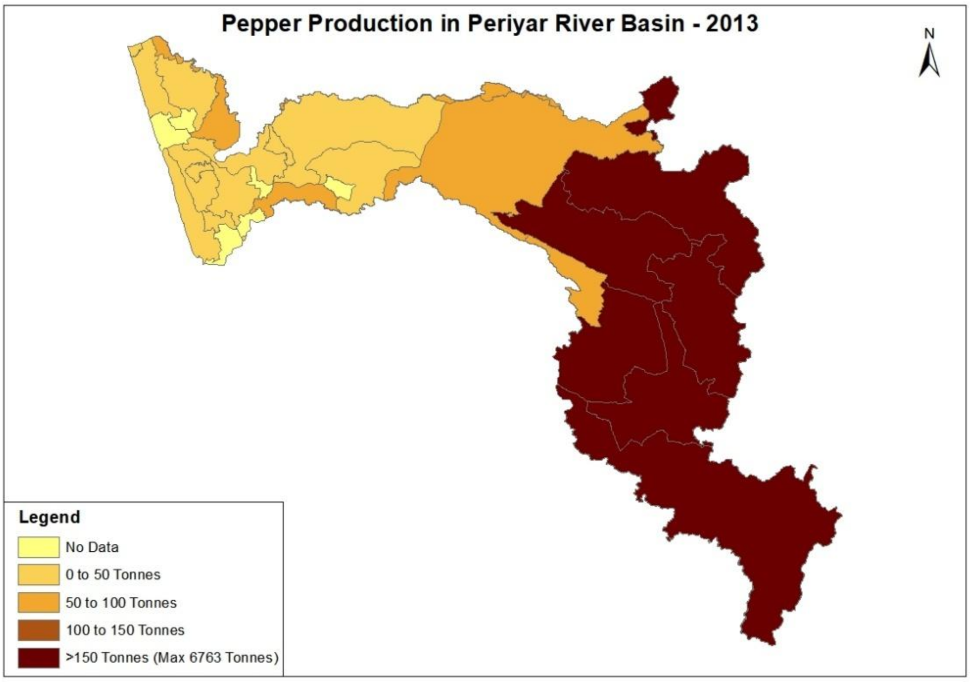

Fig 3 Pepper production (in tonnes) in the Periyar River Basin (2013) *(Source: Kerala Agricultural Statistics Report, 2013)*

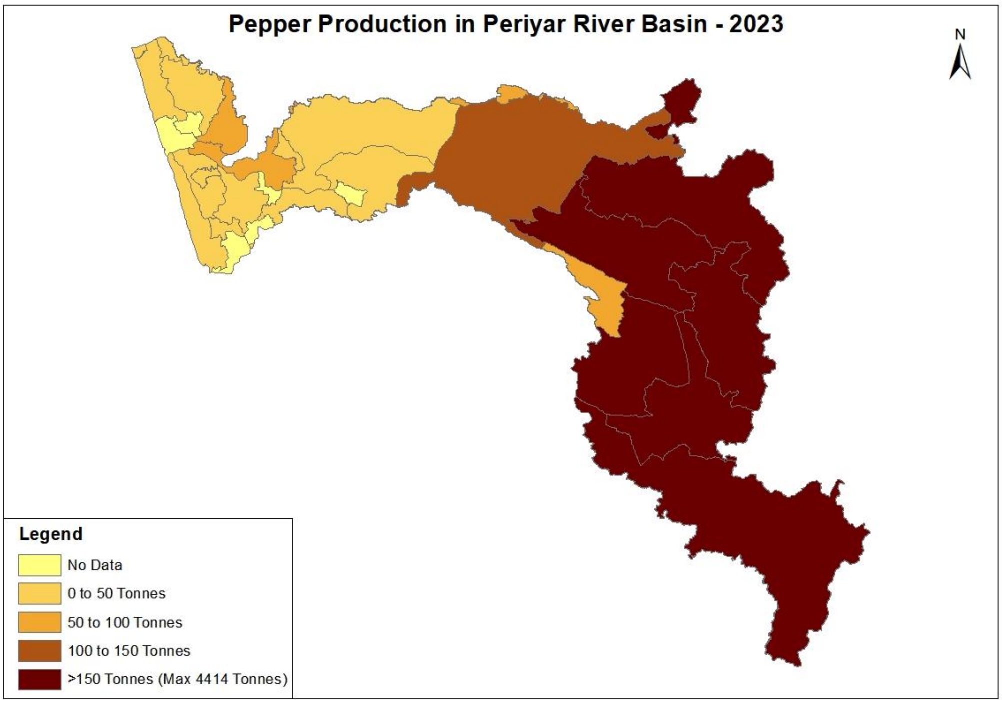

Fig 4 Pepper production (in tonnes) in the Periyar River Basin (2023) *(Source: Kerala Agricultural Statistics Report, 2023)*

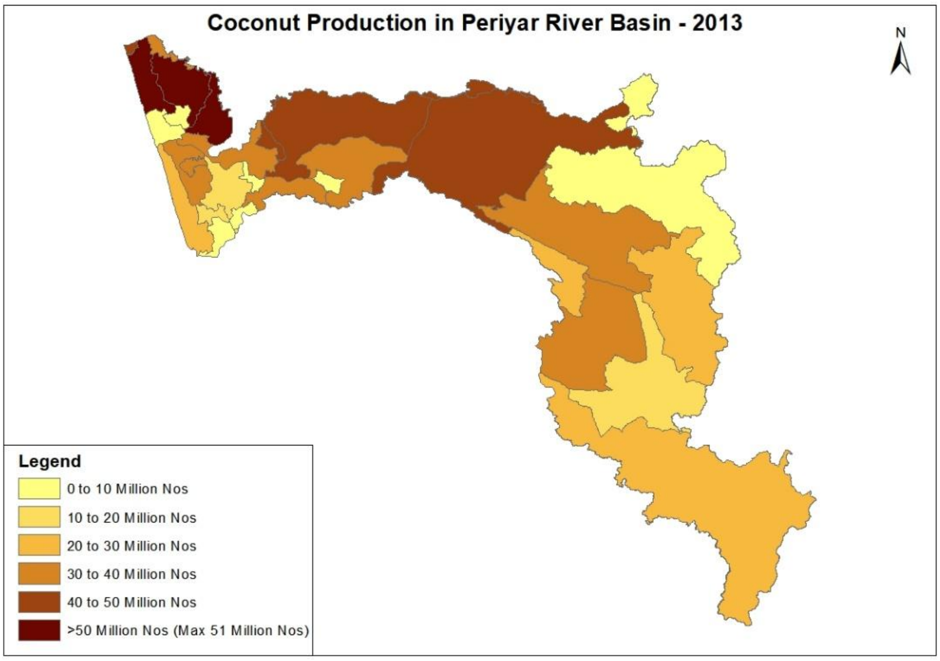

Fig 5 Coconut production (in Million Nos) in the Periyar River Basin (2013) *(Source: Kerala Agricultural Statistics Report, 2013)*

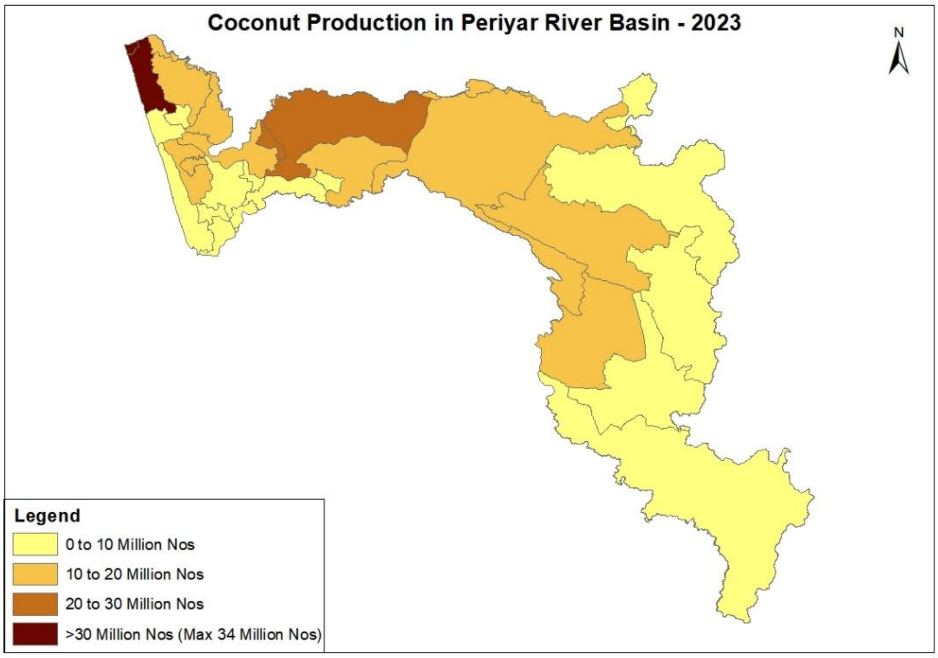

Fig 6 Coconut production (in Million Nos) in the Periyar River Basin (2023) *(Source: Kerala Agricultural Statistics Report, 2023)*

7.5. Crop Production and Yield in Thrissur District (2013–2018)

From 2013–14 to 2017–18, Thrissur maintained a balanced agricultural profile, combining extensive cultivation of paddy and coconuts with significant spice, fruit and vegetable production. Paddy remains the main food crop in the district, concentrated in Kole wetlands, which together contributed to a large share of Kerala's rice production. These areas show two and sometimes three paddy seasons (locally known as Mundakan, Puncha and Virippu) under guaranteed irrigation and high fertility. Coconuts occupied large areas in Chavakkad, Mala and Irinjalakuda blocks, making Thrissur one of Kerala's best coconut production districts. Banana and plantations were intermittently expanded in Chalakudy and Vellangallur, reaching their peak around 2015-16 before falling slightly. Tapioca and vegetables were grown mainly in small-scale systems in Mala, maintaining moderate but stable production. Among the spices, black pepper and nutmeg dominated, particularly in Chalakudy and Vellangallur blocks, where mountain slopes supported mixed perennial cropping. Rubber production remained stable in eastern highlands such as Mala and Chalakudy, while cocoa and arecanuts were maintained as small inter crops throughout the midlands.

Crop yields in Thrissur showed sustained performance during the period 2013–18, supported by irrigation infrastructure and diversified agricultural and eco-climatic conditions. The harvest of coconuts remained consistent, with a gradual improvement in Mala, assisted by replanting and fertilizer management. Banana and plantain yields fluctuated over years, strongly in Vellangallur and Chalakudy but affected by wind damage and leaf spots in 2016–17. Tapioca yields remained moderate in Irinjalakuda, while vegetable yields showed stable production. Black pepper and nutmeg maintained moderate to high productivity in highland and midland blocks, with nutmeg performing particularly well in Chalakudy block panchayat. Rubber yields remained stable throughout the period, reflecting maturity and consistent absorption intensity in the highlands. Overall, block-level trends in Thrissur highlight stable production and yield stability in both food and seasonal crops, supported by the district's favourable soil-water regime and intensive mixed agricultural systems (Agricultural Statistics 2013-18).

7.6. Crop Production and Yield in Thrissur District (2018–2023)

From 2018 to 2023, crop trends in Thrissur District showed varying patterns across different crops. Arecanut cultivation showed significant fluctuations, while coconut farming showed a steady rise in yield and production. Banana production varied from Block to Block but generally increased in areas like Mala and Irinjalakuda. Plantain showed a more consistent rise in yield and production across most Blocks. Black pepper cultivation was comparatively robust and stable, while coconut stood out for its sustained expansion. Raw cashew cultivation was largely stable, with Mathilakom, Thalikulam, and Vellangallur achieving high yields. Pineapple cultivation showed dynamic growth, especially in Chalakudy and Irinjalakuda. Jackfruit cultivation remained consistently high across many Blocks;

yields were mostly stable. Betel leaf cultivation was limited and inconsistent, with significant production observed in Chalakudy, Mala, Mathilakom, and Vellangallur. Cocoa cultivation remained marginal, with yields typically under 1 t/ha. Nutmeg cultivation expanded notably, with increasing area and stable yields. Sesamum was grown in very few areas and in small amounts. Its cultivation was irregular over the years, and the yield remained low throughout (Agricultural Statistics 2018-23).

8. Chemical fertilizer & plant protectant distribution and utilization

Chemical fertilizers and plant protection products are essential in boosting the crop productivity of the area. Fertilizers can supply important nutrients like nitrogen, phosphorus, and potassium that plants need for growth, especially in places with nutrient-depleted soils. By replenishing these nutrients, fertilizers help crops grow more efficiently, resulting in higher yields. Similarly, plant protection products help to safeguard crops from pests, diseases, and weeds that could otherwise damage them. These products ensure that crops grow in optimal conditions, reducing the risk of crop loss and improving food security, particularly in regions where pests and diseases are widespread.

The distribution and utilization of chemical fertilizers and plant protection products (such as pesticides, fungicides, and herbicides) significantly affect agricultural productivity, soil health, environmental sustainability, and economic viability. These inputs are crucial for increasing yields and protecting crops, but their overuse or misuse can have adverse long-term consequences.

While chemical fertilizers and plant protection products are integral to modern agriculture, their overuse and mismanagement can lead to long-term environmental damage, soil degradation, and human health risks. The key to sustainable agriculture lies in balancing the consumption of these inputs with practices that protect soil health, reduce environmental impact, and ensure the health of farmers and consumers. Strategies such as integrated nutrient management, sustainable pest management, and organic farming offer viable alternatives that can help mitigate the negative effects of chemical inputs while ensuring continued agricultural productivity.

8.1. Chemical fertilizer & plant protectant distribution and utilization in Idukki District

Idukki district forms the largest portion of the Periyar River Basin, and its agricultural system is supported by a well-structured network for distributing fertilizers and plant-protection materials. The state administration ensures the smooth supply of these inputs through an extensive network of fertilizer depots and Plant Protection Code (PPC) depots spread across the district. This system involves both private and cooperative institutions, reflecting a strong public–private coordination in agricultural service delivery.

Across Idukki, 347 fertilizer depots operate, of which 290 are privately owned and 57 function under cooperative institutions. Complementing this, the district hosts 512 PPC depots, with 485 under private ownership and 27 managed through public-private partnership arrangements. Together, these distribution centres form the backbone of agricultural input delivery in the district, ensuring that farmers in even the most remote highland areas have timely access to essential plant nutrients and plant-protection materials. Figure 7 presents a schematic overview of plant protectant and fertilizer consumption in Idukki, highlighting the distribution of major input categories throughout the district.

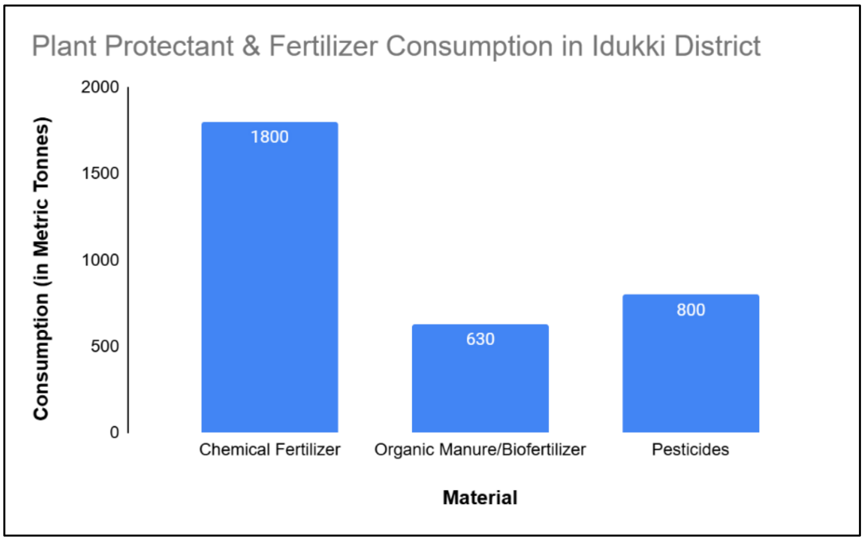

Fig 7 Schematic representation of plant protectant and fertilizer consumption in Idukki (2024)

Idukki district, which is also the largest district in the state, consumes a significant portion of the total fertilizer and pesticide reserves of the state. This huge consumption is due to the huge gross agricultural production of the district and its influence in total agricultural production of the state. Fertilizers, organic manure (biofertilizer) and pesticides are the most consumed commodities related to agriculture in the district. In Idukki, an approximate amount of 1800 Metric Tonnes of chemical fertilizers are consumed each year. These fertilizers include Urea, Calcium Ammonium Nitrate (CAN), phosphate fertilizers, Monoammonium phosphate etc. An approximate amount of 630 Metric Tonnes of organic manure (biofertilizer) is consumed in the district each year, and these mainly involves the usage of organic fertilizers like azotobacter, vermicompost, plant growth-promoting rhizobacteria (PGPB), bio potash etc. Even though organic fertilizers underperform when compared to chemical fertilizers, it is used as an alternative aimed at long term fertility and productivity of the soil. Regarding the usage of pesticides, 800 Metric Tonnes of pesticides are utilized in the district every year to get rid of plant affecting pests and to ensure proper and healthy growth of the crops. Organophosphorus, pyrethroids, pyrazole, thiophosphorus, chlorpyrifos etc. are the major pesticides used in the district aiming at critical plant protection.

8.2. Chemical fertilizer & plant protectant distribution and utilization in Ernakulam District

Ernakulam District has 32 fertilizer depots and 93 PPC (Plant Protection Code) depots in the co-operative sector, while in the private sector there are 94 fertilizer depots and 93 PPC depots. The total chemical consumption and bio-fertilizer consumption is 20,802.80 tonnes and 8,259 kg respectively. Total organic manure usage in the district is 29,100 tonnes and total pesticide usage is 293.054 tonnes. The distribution and utilization of chemical fertilizers and plant protectants in Ernakulam District are presented in Table 15.

Table 15 Chemical fertilizer & plant protectant distribution and utilization in Ernakulam District (2024)

(Source: Principal Agricultural Office, Ernakulam)

Number of Fertilizer depots in the Co-operative sector	Number of PPC depots in the Co-Operative sector	Number of Fertilizer depots in the private sector	Number of PPC depots in the Private sector	Total Chemical Consumption (t)	Total Organic Manure (t)	Total Bio-Fertilizer consumption (kg)	Total Pesticide usage (t)
32	93	94	93	20,802.80	29,100	8,259	293.054

8.3. Chemical fertilizer & plant protectant distribution and utilization in Thrissur District

In Thrissur District, Vellangallur Block has the highest number of fertilizer depots in both Co-operative (9) and private sectors (13). Irinjalakuda Municipality has the highest number of PPC depots (4) in the Co-operative sector while in the private sector Vellangallur Block leads with 6 PPC depots. Among the Blocks, chemical (71,000 T) and organic manure (1,19,000 T) consumption, and pesticide usage (2.6 T) is the highest in Mala Block. The distribution and utilization of chemical fertilizers and plant protectants in Thrissur District are presented in Table 16.

Table 16 Chemical fertilizer & plant protectant distribution and utilization in Thrissur District

(Source: Principal Agricultural Office, Thrissur)

Block / Municipality	Number of Fertilizer depots in the Co-Operative sector	Number of PPC depots in the Co- Operative sector	Number of Fertilizer deposits in the private sector	Number of PPC depots in the Private sector	Total Chemical Consumption (t)	Organic manure/ Bio-Fertilizer consumption (t)	Total Pesticide usage (t)
Chalakudy	3	0	3	1	38600	32500	1.5
Mala	3	0	3	1	71000	119000	2.6
Mathilakam	1	1	7	4	934	106750	1.80
Irinjalakuda	2	1	0	0	50	2000	0.3
Vellangallur	9	2	13	6	172	8400	1.15
Kodungallur Municipality	1	1	5	3	30	150	0.2
Irinjalakuda Municipality	4	4	4	4	50	1800	0.3

9. Agricultural manpower, land and livestock holdings in the Periyar River Basin

In the decades following the formation of Kerala State, agriculture served as the primary livelihood for most households. During 1955–1956, more than 53% of the working population was directly engaged in farming, supported by Kerala's highly favourable agro-climatic conditions. The agricultural landscape was remarkably diverse, combining staple food crops such as paddy and tapioca with major commercial crops like coconut, rubber, tea, coffee, pepper, and cardamom.

Over time, however, the sector witnessed a gradual but persistent decline in its workforce. Economic diversification and the emergence of better-paying opportunities in construction, services, and industry prompted many workers to move away from farming. Census data show that between 2001 and 2011, the number of cultivators dropped by 7.4%, while agricultural labourers declined by 18.4%. Interestingly, this period also recorded a marginal rise in the number of female cultivators and an increase in the urban share of agricultural workers, a trend likely linked to the rapid expansion of urban areas and the conversion of rural regions into urban local bodies. The number of agricultural labourers' in the 2001 census and 2011 census in the State are presented in Table 17.

Table 17 Number of agricultural labourers in Kerala State *(Source: Census 2001 & 2011)*

	Agricultural labourers (2001 census)			**Agricultural labourers (2011 census)**		
	Total	**Male**	**Female**	**Total**	**Male**	**Female**
Total	1620851	1078354	542497	1322850	857995	464855
Rural	1507081	1003265	503816	1083003	690294	392709
Urban	113770	75089	38681	239847	167701	72146

Agricultural manpower forms the backbone of the Periyar River Basin's functioning, directly shaping food productivity, water-resource management, and environmental stewardship. This workforce is composed primarily of agricultural labourers and cultivators, each playing complementary but essential roles within the basin's agricultural system.

Agricultural labourers are central to maintaining crop health and ensuring successful harvests, particularly in regions where river-fed irrigation is the primary or only dependable water source. Their work helps secure local food supply and contributes significantly to the regional economy. Beyond crop production, labourers play a critical role in soil conservation efforts, preventing erosion and degradation along the riverbanks, which is vital for maintaining the stability and fertility of riparian landscapes. By adopting and practicing sustainable farming methods, they help preserve the ecological balance of the basin, indirectly supporting its biodiversity.

Cultivators, in turn, provide the structural and economic support that sustains this labour force. They ensure access to financial resources, technical inputs, machinery, maintenance, and fair wages. Through this support system, cultivators not only facilitate efficient agricultural operations but also uphold the livelihoods of the surrounding communities that depend on farming as a primary source of income and social wellbeing.

9.1. Livestock for Sustainable Agriculture

Sustainability in agriculture, including food security and nutrition, is crucial in a changing environment. India's livestock sector plays a significant role in providing sustainable livelihoods (Sethumadhavan, 2016). Mixed farming systems that include livestock offer numerous benefits over 'crops-only' agriculture. These systems produce a wider range of products, reduce risks, and are more productive than those relying solely on crops or animals. Livestock can be fed on crop residues and other waste, reducing waste disposal issues. The integration of livestock and crop production allows for more efficient nutrient recycling, as manure serves as a valuable natural fertilizer. Draught animal power is widely used in developing countries, reducing the need for expensive tractors and fuel. Cow dung is a valuable fuel used for cooking and heating, and manure can be used to generate methane or biogas (World Food Summit, 1996).

9.2. Agricultural manpower, land and livestock holdings in the Idukki district

Agricultural manpower in Idukki district is mainly classified into two categories: Main sector and Marginal sector. As per the Census of India 2011, in the Main sector, there are 85,723 cultivators in the district, out of which 16,047 are female and the remaining 69,676 are male. In the same sector, there are 1,12,391 agricultural labourers, out of which 46,539 are female and the remaining 65,852 are male. In the Marginal sector, there are 15,194 cultivators across the district, out of which 8,061 are female and the remaining 7,133 are male. In the same sector, there are 33,307 labourers in total, out of which 19,093 are female and the rest 14,214 are male. Figure 8 presents the distribution of agricultural manpower in Idukki district, based on Census 2011 data and records.

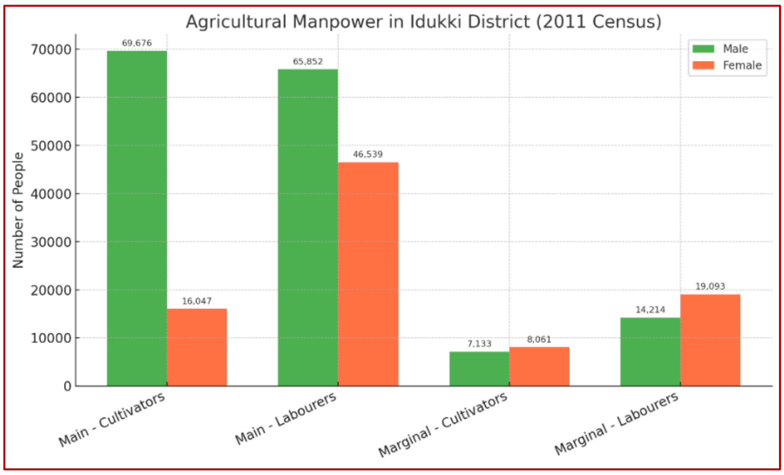

Fig.8. Agricultural manpower in Idukki district *(Source: Census 2011, Principal Agricultural Office Idukki)*

Livestock holdings of Periyar River Basin are important to the social, economic and ecological development of the basin area. The rural areas within the basin, which mainly depends on agriculture, the animals diversify the income sources and provide an important contribution to the local economy by marketing meat, milk and similar byproducts. Livestock ensures that essential components like vitamins, minerals and proteins are supplied to the local diet within the basin area. In an ecological point of view, properly managed grazing of livestock increases the fertility of the soil by generating manure, which increases the quality of the soil and thus a higher agricultural productivity. It also aids in nutrient cycling, improving the ecosystem health.

As per the Livestock Department of Govt. of Kerala, in the Idukki district of the Periyar river basin, there are 7 types of species which belong to the Livestock category. They are poultry, duck, pig, goat, cow (Indigenous), cow (Hybrid) and buffalo. The quantities of each species are given in the table 18 below.

Table 18 Distribution of livestock in the Idukki District

(Source: Principal Agricultural Office Idukki, 2024)

Type of Livestock	Quantity (Count)
Poultry	3,96,322
Goat	1,00,713
Cow (Hybrid)	78,616
Pig	15,084
Duck	13,275
Cow (Indigenous)	10,842
Buffalo	1,992

9.3. Agricultural manpower, land and livestock holdings in the Thrissur district

Block-wise details of agricultural labourers in Thrissur District, categorized by gender are presented in Table 19. The data indicates that in most of the Blocks, the number of female agricultural labourers significantly exceeds the number of males.

Table 19 Agricultural Labourers in the Periyar River Basin - Thrissur District

(Source: Principal Agriculture Office, Thrissur (March, 2023))

Name of Block	Agricultural labourers		
	Females	Males	Total
Mathilakam	18963	9933	28896
Mala	16190	6910	23100
Irinjalakuda	9547	14321	23868
Vellangallur	11741	6767	18508
Chalakudy	19195	7976	27171

Daily wages for male labourers generally range between ₹900 to ₹1000, while that for females' wages range from ₹600 to ₹750, with slight variations among different local bodies. The data indicates that land in most areas is under private ownership. This information reflects the prevailing labour cost dynamics and land distribution structure in the region.

Across the block panchayats of Thrissur District, agricultural labour wages show moderate variation but follow a consistent pattern. On average, male labourers earn about ₹950 per day, while female labourers earn around ₹675 per day. Wages are generally higher in areas like Vellangallur and Irinjalakuda, where male wages reach ₹1000 and female wages average ₹700–750 per day, compared to Chalakudy and Kodungallur Municipality, where rates are slightly lower at ₹900 for men and ₹600–650 for women. Land ownership in these regions is predominantly private, indicating that most agricultural labour operates within privately owned holdings.

Thrissur District has a total agricultural land area of 567.56 km², covering five Blocks within the Periyar River Basin. Among the Blocks Chalakudy has the largest agricultural land area (152.89 sq.km), followed by Mala (138.28 sq.km) and Vellangallur (93.88 sq.km). Irinjalakuda and Mathilakam have agricultural areas of 91.02 sq.km and 91.49 sq.km respectively (Source- CGWB, 2019)

In Thrissur District, Mala has the highest total livestock population among the Blocks. Poultry, followed by goats (under the category of small animals) have the highest population. Among large animals, the cattle population is the highest. The population of draft animals is almost nil in the district. The biomass and livestock population of Thrissur District within the Periyar River Basin are presented in Table 20.

Table 20 Biomass and Livestock in the Periyar River Basin - Thrissur District
(*Source: District Irrigation Plan, Thrissur, 2017)*

Small Animals						Large Animals					
Block	Poultry		Small	Large		Large				Small	Draft animal (Buffalo/ yak/ bulls/an y other Nos)
	Poultry (No)	Ducks (No)	Pigs (No)	Goats (No)	Sheep (No)	Cattle (No.)	Buffalo (No.)	Elephant (No.)	Horse (No.)	Rabbits (No.)	
Mathilakam	98934	0	3	10220	3	5986	2867	0	0	1092	0
Mala	124875	3147	210	10264	0	8111	2655	0	4	1844	0
Iringalakuda	75825	555	313	5639	0	6272	1304	0	0	1053	0
Vellangallur	65942	3153	32	6918	0	5082	2602	0	0	1065	0
Chalakudy	104263	8347	1111	7895	0	8007	2198	0	0	2354	0

9.4. Agricultural manpower, land and livestock holdings in the Ernakulam district

Ernakulam District has a total agricultural land area of 795.23 km², covering seven Blocks within the Periyar River Basin. Among the Blocks, Kothamangalam has the largest agricultural land area (254.92 km²), followed by Koovappady (105.39 km²), Angamaly(95.13 km²), Parakadavu (76.16 km²), Vazhakulam(52.06 km²) and Alangad(41.35 km²). Edapally Block has the lowest agricultural land area (35.07 km²), (Source- CGWB, 2019).

The number of agricultural labourers in different Blocks of Ernakulam District is presented in Table 21. Some Blocks such as Kothamangalam and Koovappady have high numbers of workers, while others such as Alangad and Edapally reported very low or no labourers. This reflects variations in agricultural activity across the district.

Table 21 Agricultural Labourers in the Periyar River Basin - Ernakulam District

(*Source - Census of India 2011, District Census Handbook – Ernakulam*)

Name of Community Development Block	Agricultural labourers		
	Females	Males	Total
Angamali	2390	3346	5736
Edapally	1	0	1
Koovappady	3254	4126	7380
Kothamangalam	5287	8128	69796
Parakkadavu	986	1509	2495
Paravoor	53	63	116
Vazhakkulam	464	865	1329
Vypin	172	425	597

Poultry, followed by ducks have the highest population under the category of small animals. Among large animals, Hybrid Cow has the highest population. Kalamassery has the highest total livestock population in the district. The only Block with draft animals is Perumbavoor. Table 22 presents an overview of the biomass and livestock of Ernakulam District within the Periyar River Basin.

Table 22 Biomass and Livestock in the Periyar River Basin - Ernakulam District
(Source: District Irrigation Plan, Ernakulam, 2017)

Block	Small Animals (Number)					Large Animals (Number)						Total
	Poultry	Ducks	Pigs	Goats	Sheep	Indigenous Cow	Hybrid Cow	Nondescript Buffalo	Hybrid Buffalo	Any other milch or meat animal	Draft Animal	
Aluva	44148	14997	138	4473	2	481	3460	1014	346	5192	-	74251
Angamaly	45000	9500	2000	9000	0	2500	2000	-	90	20	-	70110
Kalamassery	90524	6090	259	4156	1	98	2394	556	147	39	-	104264
Keezhmad	23500	4066	93	2115	-	9	2992	173	335	112	-	33395
Kothamangalam	26400	1210	2400	6800	0	349	3142	435	-	468	-	41204

Njarakkal	18533	6475	2408	2408	0	37	1158	129	0	0	-	31148
Paravur	33612	11396	0	5105	0	36	3107	924	219	363	-	54762
Perumbavoor	48584	1323	210	10054	0	80	11957	132	169	20	10	72539

10. Operational government schemes for sustainable agriculture in the Periyar River Basin

The Periyar River Basin is critically important for agriculture due to its multifaceted contributions to farming practices, water management, and community livelihoods. One of the primary benefits of the basin is its role as a reliable source of irrigation. The river provides essential water resources that enable farmers to cultivate crops throughout the year, especially during dry spells. This consistent water supply is vital for ensuring agricultural productivity and food security in the region, as it supports the growth of various crops, from staples like rice to cash crops such as spices and fruits.

In addition to its water resources, the Periyar River Basin is characterized by highly fertile alluvial soils. These soils, enriched by sediments deposited by the river, create an ideal environment for diverse agricultural practices. Farmers benefit from this natural fertility, which enhances crop yields and supports a variety of agricultural systems. The basin's favorable climatic conditions allow for a wide range of crop production, enabling farmers to diversify their outputs and reduce reliance on single crops, which can be risky in changing market conditions.

Agriculture in the Periyar River Basin also plays a crucial role in supporting local livelihoods. The agricultural activities not only provide food for local communities but also create employment opportunities in related sectors, such as processing and distribution. The economic impact of agriculture extends beyond the immediate farming community, contributing to the overall development of the region. Moreover, sustainable agricultural practices are increasingly being adopted in the basin, which enhances its ecological health. Techniques such as crop rotation, agroforestry, and mixed cropping are promoted to improve soil health and manage water resources more effectively. These practices help mitigate the negative impacts of climate change and environmental degradation, making the agricultural systems more resilient to fluctuating weather patterns and pests. Sustainable management of agricultural resources ensures that the benefits of the river basin can be enjoyed by future generations.

Operational government schemes play a crucial role in promoting sustainable agriculture in the Periyar River Basin. They provide farmers with financial support, modern tools, and eco-friendly technologies while reducing economic barriers to adoption. These initiatives also focus on farmer education through training in organic farming, integrated pest management, and agroforestry. Research support helps develop climate-resilient, low-input crop varieties suited to Kerala's conditions. Market linkage programs ensure fair prices for sustainably produced crops, encouraging wider adoption. Additionally, schemes emphasize water conservation, efficient fertilizer use, and community-based approaches, fostering collective action and knowledge sharing. Aligned with broader environmental policies, these schemes create an enabling framework that makes agriculture both economically viable and environmentally sustainable.

10.1. Paddy Development

The Rice Development Program (2024–25) aims to strengthen paddy cultivation in Kerala through sustainable practices and farmer support, with a total outlay of ₹9360 lakh. The scheme focuses on enhancing productivity across the state's seven rice-growing agroecological units while ensuring both environmental conservation and livelihood security.

A major component is input assistance, provided at ₹5500 per hectare, along with a royalty of ₹3000 per hectare to paddy landowners as an incentive for conserving paddy fields. Support includes quality seeds, AEU-based inputs, bio-control agents, and targeted measures for soil and root health management, with ₹2660 lakh allocated for lime application and soil improvement.

The program also prioritizes infrastructure development in paddy fields, implemented in project mode and converging with schemes like RKVY, RIDF, CSS, and LSGD. An allocation of ₹200 lakh is provided for these initiatives, which are identified at the block level and approved by the Director of Agriculture. Institutional collaboration with Primary Agricultural Credit Societies (PACS) ensures effective implementation and farmer participation.

Social inclusion is built into the scheme, with at least 33 percent of beneficiaries reserved for women farmers. By combining financial incentives, scientific farming practices, infrastructure improvements, and institutional partnerships, the program seeks to create a more resilient, productive, and sustainable rice sector in Kerala.

10.2. Vegetable Development through Department & VFPCK

The Vegetable Development Programme (2024–25) aims to enhance vegetable production in Kerala in a safe and sustainable manner, moving the state toward self-sufficiency. Implemented in mission mode with the involvement of the Agriculture Department, VFPCK, Horticorp, SHM, PACS, FPOs, Kerala Agricultural University, and LSGDs, the scheme emphasizes a phased shift from cash subsidies to subsidies in kind for greater efficiency.

To boost productivity, the program promotes high-yielding and hybrid varieties, with ₹500 lakh allocated for distributing seed kits and seedlings. Precision farming in open fields, homestead cultivation with perennial crops, and innovative methods such as rooftop farming, vertical units, and hydroponics are encouraged with technical support. Commercial cultivation follows a cluster-based approach, focusing on 15 agroecological units with high potential. Clusters of 3–5 hectares will be organized based on block-level crop calendars, with priority given to women, youth, and student groups.By combining household-level initiatives with commercial clusters, the program seeks to ensure safe-to-eat vegetables, higher productivity, and inclusive participation, making Kerala more self-reliant in vegetable production.

10.3. Development of Production and Technology Support

The scheme aims to deliver farm-level technologies through demonstrations and strengthen Farmer Producer Organisations (FPOs) under a farm plan-based approach, with an allocation of ₹650 lakh in 2024–25. A key component is the creation of a digital platform, developed with the support of the Digital University of Kerala, to build a comprehensive database capturing pre-production, production, and post-production data of farm units for continuous monitoring and updates.

The program supports the formation of new FPOs by aggregating farm units from 2–3 neighboring panchayats, while also assisting existing FPOs (within 3 years of formation) in product development, branding, labeling, and marketing. Institutional linkages with local self-governments will further strengthen these organizations. FPOs are envisioned as business-oriented collectives that act as catalysts for rural development and farmer empowerment.

To ensure effective implementation, a Technical Resource Team comprising qualified experts in agriculture, animal husbandry, fisheries, and irrigation will provide ongoing handholding and capacity building for FPOs. Through this integrated approach, the scheme seeks to foster stronger farmer collectives, enable better market access, and enhance the overall resilience of the farming sector.

10.4. Coconut Development

The Coconut Development Strategy (2024–25) focuses on enhancing production and productivity through replanting with high-yielding palms and the integrated development of coconut farming using improved management practices. An allocation of ₹6895 lakh has been made for these programs during the year. The scheme emphasizes scientific and timely adoption of soil test–based nutrient application, irrigation, pest and disease management, and multiple cropping systems to ensure higher yields and long-term sustainability.

A comprehensive Coconut Rejuvenation and Planting Program will be implemented under the Coconut Mission, covering healthy palms across the state. Key interventions include basin opening, crown cleaning, lime application, integrated nutrient management, and pest and disease control, carried out in a campaign mode. Use of green manures, bio-control agents, and micro and secondary nutrients will be promoted, with support from Keragramam initiatives, LSGDs, and Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGS) for effective resource use and implementation. The strategy also encourages mechanization of farm operations and greater involvement of the Karshika Karma Sena to address labor shortages. Together, these measures are designed to create a resilient and sustainable coconut sector, improving both farmer incomes and the productivity of Kerala's iconic crop.

10.5. Development of Spices

The Spice Development Programme (2024–25) focuses on strengthening the cultivation of major spices such as black pepper, ginger, turmeric, nutmeg, and clove, with an allocation of ₹460 lakh. Implementation follows an agroecological unit–based approach, giving priority to suitable areas, with special emphasis on Idukki district, which falls within the Periyar River Basin. To avail support, farmers must have a minimum cultivable area of 10 cents (excluding buildings). Assistance for pepper includes the promotion of improved varieties, better crop management practices, nursery support, supply of secondary and micronutrients, soil ameliorants, and prophylactic spraying through Government Agro Service Centres. The scheme also promotes bio-inputs such as Vesicular Arbuscular Mycorrhiza (VAM) to improve soil health and productivity.

In addition to pepper, the program supports pure and intercropping of nutmeg and clove, while also encouraging area expansion of annual spices such as ginger and turmeric. By integrating varietal improvement, scientific management, and area expansion, the scheme aims to increase spice productivity, diversify farmer incomes, and strengthen Kerala's traditional spice economy.

10.6. Supply chain/Value chain Development & Integration under FPD program

The Farm-based Supply Chain Integration Scheme (2024–25) addresses one of the key challenges of Kerala's agriculture, small and fragmented production leading to inefficient supply chains and high intermediary margins. To overcome this, the scheme proposes a hub-and-spoke aggregation model, where crop-specific local collection points (spokes) are linked to centralized hubs for marketing and distribution.

At the local level, farmer groups and FPOs will collect produce and manage supply for local markets, while surplus production will be moved to central hubs. These hubs will, in turn, connect with major traders, exporters, processors, and demand centers to ensure wider market reach and faster clearance of produce. A digital registration system, accessible via mobile applications, will record the supply commitments of farmers and the demand requirements of buyers, ensuring transparency and efficiency.

FPOs will serve as key agencies at the spoke level, supported by a federated structure at the panchayat, block, and district levels. To ensure prompt payments to farmers, corpus funds will be provided to FPOs as one-time assistance for digital transactions. Major institutional partners in strengthening local and inter-district supply chains include Vegetable and Fruit Promotion Council Keralam (VFPCK), Horticorp, Cooperatives, Kudumbashree, and FPOs. For the year 2024–25, a budget allocation of ₹500 lakh has been earmarked for the scheme.

10.7. Development of Fruits, Flowers and Medicinal Plants

The Fruit and Floriculture Development Scheme (2024–25) seeks to expand the area under cultivation of indigenous, exotic, and high-value fruits, while also promoting floriculture as a viable livelihood option. With an allocation of ₹1892 lakh, the scheme aims to enhance both production and productivity, ensuring that 25 percent of beneficiaries are women, thereby supporting gender-inclusive growth.

For fruits, the scheme emphasizes area expansion, irrigation support, establishment of hardening units, and promotion of fruit plants for both homestead and commercial cultivation, with special thrust on exotic and high-value varieties. Implementation will be led by the Department of Agriculture Development and Farmers' Welfare, with support from Kerala Agricultural University, VFPCK, Horticorp, and FPOs.

In floriculture, project-based assistance will be provided for new nurseries, tissue culture units, grading and packing centers, and market intelligence support. The scheme also envisions the creation of Flori-villages, along with dedicated markets and tie-ups with Ayurvedic pharmaceutical companies in both government and private sectors, ensuring stable demand channels. Selected districts will be prioritized for implementation, enabling localized interventions with strong market linkages.

10.8. Crop Diversification, intensification and introduction

The objective of the scheme is to promote crop diversification through crop rotation, multiple cropping, or intercropping and thereby enhance productivity. Seasonal rice fallows and interspaces of coconut plantations are targeted without affecting the main crop. Thrust will be given to the area expansion of millets. Pulses like grain cowpea, green gram, black gram and oilseeds, sesamum, and groundnut will also be promoted. An amount of ₹ 300.00 lakh is set apart for the scheme during 2024-25.

10.9. Soil and Root Health Management & Productivity Improvement

The scheme aims to strengthen farm productivity by enhancing soil health, with a particular focus on promoting soil test–based nutrient application and integrated nutrient management in non-paddy crops. For the year 2024–25, an allocation of ₹550.00 lakh has been set aside to support its implementation.

Under this programme, farmers receive assistance in accessing quality inputs for integrated nutrient management. This includes soil ameliorants, and essential secondary and micronutrients identified through soil-analysis reports to improve crop performance. Krishi Bhavan officials play a central role by guiding farmers on the type and quantity of nutrients required for their fields based on scientific recommendations.

The scheme also supports the distribution of secondary and micronutrients according to soil test data, ensuring precise and efficient nutrient use. Efforts are being intensified in collaboration with local self-governments (LSGs) to promote the cultivation and incorporation of green manure crops, which enrich soil organic matter and enhance long-term soil fertility. In addition, the programme encourages cultural practices that improve root growth and plant vigour, along with seed treatment using biofertilizers and biopesticides.

State-wide soil-testing campaigns will be organised through coordinated efforts between the Department of Agriculture Development & Farmers' Welfare and the Department of Soil Survey & Soil Conservation, ensuring accurate soil-health assessment and informed nutrient management across Kerala.

10.10. Crop Health Management

The approach of crop health management is to bring together management towards sustainable ecosystems and people's health through Good Plant Protection Practices (GPPP). During 2024-25, an amount of ₹ 1300.00 lakh is allocated under this scheme. Advisories will be provided to the farmers based on systematic surveillance. New Plant Health Clinics will be established at the Local Self Government level. The parasite breeding stations functioning under the department will be strengthened to promote parasite breeding and the production of bio-control agents. Wild animal attack is a major menace in the cropped areas in the river basin area, especially in the districts of Ernakulam and Idukki, affecting the farmers bear huge loss due to crop damage. During 2024-25, thrust on activities for the management of wild animal attacks in cropped areas through technology support will continue and rodent control will also be conducted in campaign mode across the State.

10.11. Organic Farming and Good Agricultural Practices

The objective of the scheme is to promote safe-to-eat food production through organic practices and good agricultural practices. Empowerment of existing GAP clusters, promotional assistance for new GAP clusters, green manuring, model units for scientific organic manure preparation, and Safe to Eat food production is supported in this scheme. During 2024-25, an amount of ₹ 600.00 lakh is set apart for the scheme. It is envisaged that 10 percent of the beneficiaries of the project will be women.

10.12. Production and Distribution of Quality Planting Materials and Improvement of departmental farms

The main objective of the scheme is to ensure the timely availability of good quality planting materials in the required quantity to the farmers of the State. Modernization of departmental farms and their development as centers of demonstration of advanced agricultural technology like Hi-Tech farming, precision farming, high-density planting, aquaponics, and Integrated Farming system models are envisaged under the scheme. An amount of ₹ 1725.00 lakh is allocated for the scheme during the year 2024-25.

10.13. Strengthening Agricultural Extension

The Agricultural Extension Strengthening Scheme (2024–25) is designed to enhance the adoption of modern technologies and scientific practices among Kerala's farming community, with a budget allocation of ₹3028 lakh. The scheme emphasizes public participation, supporting activities such as *Karshika Vikasana Samithies*, seminars, farmers' days, review meetings, farm melas, *Karshaka Sabhas*, *Njattuvela chanthas*, and agro festivals, including those organized by Farmers Producer Organisations (FPOs) and Primary Agricultural Credit Societies (PACS).

To strengthen technical support, Block-Level Agriculture Knowledge Centers, with scientists from the Kerala Agricultural University as nodal officers, will provide guidance to Krishi Bhavans and farmers for effective program implementation. The scheme will also continue the KISSAN Kerala project, developed with the Digital University of Kerala, which delivers ICT-enabled extension services through weekly television programs.

In parallel, the scheme advances the transformation of Krishi Bhavans into Smart Krishi Bhavans, aimed at modernizing service delivery through e-governance and technology integration. By combining public participation, ICT-based outreach, and institutional modernization, the program seeks to ensure efficient, timely, and farmer-friendly services across the state.

10.14. Farm Information and Communication

During 2024-25, an amount of ₹ 600.00 lakh is set apart for circulating scientific knowledge to farmers at the right time and to provide information on the activities of the departments of Agriculture and Fisheries through various mass and electronic media including web-based services across the state. The activities include printing of Kerala Karshakan, digital copy printing, honorarium to authors of Kerala Karshakan journal, farm photography competition, essay writing competition, short film competition, awards (excluding officials), stationary expenses, campaigns, exhibitions, cyber extension and other communication initiatives including radio programmes.

10.15. Human Resource Development

Capacity building of officials on the latest updates in agriculture sector is imperative for efficient transfer of technology to the farming community and its adoption. The scheme of this programme includes specialized training to officials in eminent institutions at state and national level to upgrade the technical and managerial competence. An amount of ₹ 335.00 lakh is allocated for the scheme during 2024-25. On farm trainings on advanced technologies envisaged through SAMETI to Department officials at block level will be entrusted to Kerala Agricultural University. Participation of department officials in the various certificate courses on advanced subjects offered by Kerala Agricultural University is also envisaged under the scheme.

10.16. Support to Farm Mechanization

Farm mechanization is the key to scientific crop and produce management. The objective of the scheme is to overcome the shortage of labour and to develop single point delivery system through strengthening of Agro Service Centres, Karshika Karma Senas and Custom Hiring Centres which are part of mechanization activities across the state. It is also envisaged to bring convergence of these three institutions as sustainable Self Help. An amount of ₹ 1991.00 lakh is allocated under the scheme during 2024-25.

Groups in the farm sector like "Krishisree Centres", to facilitate a single window service delivery to farmers under the coordination of Kerala State Agricultural Mechanization Mission (KSAMM). This will be done through a project approach.

10.17. State Crop Insurance Scheme

The State crop insurance scheme against crop loss due to natural calamity is planned in 2024-25 for the benefit of farmers. The Crop Insurance Fund is operated with contributions from the participating farmers by way of registration fee and premium and Government contribution. An amount of ₹ 3000.00 lakh is set aside for the scheme during 2024-25.

10.18. Contingency Programme to meet Natural Calamities and Pests and Endemic Disease

In order to meet the contingency due to natural calamity and pest and disease endemic and amount of ₹ 750.00 lakh is set apart during 2024-25. The activities covered will be creation of buffer stock of short duration varieties of paddy, pulses and vegetables for distribution to affected farmers in the event of natural calamities and resultant crop damages, assistance for strengthening of bunds against breaches and removal of debris and support for crop health management in the event of pest and disease endemic.

10.19. Development of Agriculture Sector in Kuttanad & RIDF

An amount of ₹ 1700.00 lakh is set apart for development of agricultural sector in Kuttanad during 2024-25. Dewatering, being the major activity undertaken as part of crop production in Kuttanad region, thrust will be given on replacing the conventional '*Petti*' & '*Para*' with Vertical Axial Flow pump/submersible pumpsets of 10-50 HP, in Kuttanad region including construction of raised platforms for installation, free of cost. The department will take efforts to ensure adoption of approved crop calendar in Kuttanad region. Availability of short duration rice varieties and related operations will also be facilitated.

10.20. Support for marketing of agricultural products

The Agricultural Marketing and Price Stabilization Scheme (2024–25) aims to address challenges of price fluctuations, weak marketing systems, and post-harvest losses, with an allocation of ₹4115 lakh. The scheme focuses on strengthening market infrastructure, improving coordination across collection, transportation, storage, and processing systems, enhancing market intelligence, and adopting innovative technologies in agricultural marketing.

A key component is the provision of real-time market information through a dedicated website accessible to farmers, enabling informed decision-making. At the panchayat level, Farmer Friends will coordinate the movement of surplus produce from farms to collection and marketing centers, ensuring better market access and income stability.

The scheme also supports the development of supply chains and cold chain systems, recognizing their critical role in reducing losses and improving marketability. To maximize efficiency, it leverages convergence with Central Schemes such as MIDH and SMAM for funding activities related to marketing and storage infrastructure. In addition, provisions for market development and price stabilization interventions are built in to protect farmers against market volatility and safeguard their livelihoods.

10.21. Post-harvest Management & Value Addition

The objective of the scheme is to promote medium, small and micro agro processing/value addition units ensuring income increase to farmers, revamping Farmer Producer Organisations and generating employment opportunities in the state. Promotion of innovative technologies in value addition and entrepreneurship in agriculture is also supported. Small Farmers Agri Business Consortium (SFAC) will implement these activities performing the role of a nodal agency. An amount of 2000 Lakhs is allocated for the scheme in 2024-25.

The support for apiculture and honey production will be continued for the benefit of honey growers and promotion of value-added honey products through State Horticulture Mission with the involvement of FPOs in integration with MIDH and Honey Mission. A considerable amount is also set apart as support to small and medium agro processing initiatives through FPOs.

10.22. Rural Infrastructure Development Fund

An amount of ₹ 1000.00 lakh is earmarked under RIDF exclusively to Kerala State Warehousing Corporation for construction of Smart agri warehouses to facilitate the storage of produce.

10.23. Umbrella Scheme on Krishi Unnathi Yojana and other CSS

Krishi Unnathi Yojana is the umbrella scheme under Agriculture with 60% central share and 40% state share. The central share of ongoing centrally sponsored schemes like National Food Security Mission (NFSM), Mission on Integrated Development of Horticulture (MIDH), National Mission for Sustainable Agriculture (NMSA), National Mission on Agriculture Extension and Technology Management (NMAET), Rashtriya Krishi Vikas Yojana (RKVY), Paramparagath Krishi Vikas Yojana (PKVY), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Sub Mission on Agricultural

Mechanisation (SMAM), Sub Mission on Plant Protection and Plant Quarantine, Information Technology, Integrated scheme on Agriculture Marketing and GOI supported Crop Insurance scheme are included under the scheme. The outlay under RKVY is utilised for the infrastructure development activities for rice development, vegetable development, promotion of organic farming, strengthening of market infrastructure in wholesale markets, district procurement centres etc.

11. Major Agroecosystem Concerns of the Periyar River Basin

The Periyar river basin is a prime example of the severe agro-ecosystem issues that can arise due to the interplay of industrial pollution, agricultural methods and unsustainable resource use. Though the river sustains widespread farming, these same activities are damaging it, setting up a vicious cycle that imperils the ecosystem and regional subsistence.

11.1. Water Contamination

The most critical agro-ecosystem concern in the Periyar river basin is the widespread water contamination, which directly impacts agricultural productivity and ecosystem health. Reports from the Kerala State Pollution Control Board (KSPCB) and the Central Pollution Control Board (CPCB) have consistently documented that the water quality in the lower stretches of the river is unfit for both human consumption and agricultural use (National Green Tribunal, 2025; The Hindu, 2025). Aditya et al. (2023) assessed the impact of the COVID-19 lockdown on the Periyar River, focusing on the industrialized Eloor–Edayar stretch in the southern Western Ghats. The study reported a substantial improvement in water quality during the lockdown, with 93 % of samples classified as excellent to good under the Water Quality Index (WQI). In contrast, post-lockdown assessments showed a decline, with only 47 % of samples meeting drinking-water standards. Elevated concentrations of heavy metals, nutrients, and organic pollutants rendered the lower reaches of the river poor to unsuitable for human use, emphasizing the strong influence of industrial effluents on downstream water quality.

11.2. Agricultural Runoff and Non-Point Source Pollution

Intensive agricultural practices in the basin are a major contributor to water pollution. The use of chemical fertilizers and pesticides on crops like paddy, coconut, rubber, and spices leads to significant agrochemical runoff, especially during the monsoon season. A study by the India Environment Portal documented that the intensive agricultural practices along the banks and watershed area have been enriching the river water with huge amounts of pesticides and fertilizers (India Environment Portal, 2012). This excess nutrient load, known as eutrophication, leads to dense algal blooms that deplete dissolved oxygen, causing large-scale fish kills and threatening aquatic biodiversity, including endangered species. The high levels of faecal coliform from domestic sewage and animal waste further exacerbate this issue, posing public health risks to communities that rely on the river for irrigation and drinking water (National Green Tribunal, 2025).

11.3. Industrial Effluents and Their Impact on Agriculture

While agricultural runoff is a significant issue, it is compounded by the massive discharge of untreated industrial effluents. The Eloor-Edayar industrial belt, with its concentration of chemical, pesticide, and fertilizer industries, is a major hotspot for toxic waste dumping. A CPCB report noted that multiple contaminants, including heavy metals like manganese, zinc, and chromium, as well as persistent organic pollutants like DDT and endosulfan, were found in the soil, groundwater, sediments, and surface water (Down to Earth, 2016). This industrial pollution directly impacts the agro-ecosystem in two ways:

- **Soil Contamination**: The heavy metals and chemical compounds present in the polluted water are absorbed by the soil, reducing its fertility and potentially contaminating crops grown using this water. This creates a risk of food chain contamination, where these toxins accumulate in agricultural products (Bhumipublishing, 2021).
- **Crop and Livestock Health**: The use of polluted water for irrigation can damage crops and harm livestock that drink from the river, leading to reduced yields and economic losses for farmers (Down to Earth, 2016).

11.4. Land Use and Ecosystem Degradation

Beyond water quality, the Periyar river basin's agro-ecosystem is under stress from widespread changes in land use and direct physical degradation.

11.5. Deforestation and Soil Erosion

The systematic deforestation in the Periyar's high-range catchment areas, a result of colonial-era timber extraction and the expansion of plantation crops like tea and rubber, has led to significant soil erosion. The removal of forest cover and undergrowth destabilizes the soil, causing it to be washed into the river. This sedimentation raises the riverbed, reduces its water-carrying capacity, and makes the basin more prone to floods (Centre for Development Studies, 2009). The Irrigation Department, Government of Kerala has also documented significant silt deposits in the tributaries of the Periyar, highlighting the scale of this issue (Irrigation Department, Government of Kerala, 2022).

11.6. Unsustainable Resource Exploitation

The basin's resources are also being exploited in a way that harms the agro-ecosystem. Illegal sand mining is a rampant issue, which scientific studies have shown is occurring at a rate far exceeding what is sustainable (Subha Lekshmi et al., 2021). Sand mining destabilizes riverbanks, lowers the water table, and disrupts the natural flow and nutrient-carrying capacity of the river, which is crucial for floodplain agriculture. A study on the impact of sand mining on the Periyar basin found that it leads to a significant decrease in groundwater levels in nearby areas and alters the river's flow patterns, causing bank erosion (Subha Lekshmi et al., 2021).

The construction of numerous dams, while providing power and irrigation, also alters the river's natural flow regime. A report by the Irrigation Department, Government of Kerala, confirms that these structures impact downstream ecosystems and the availability of water for agriculture during dry periods (Irrigation Department, Government of Kerala, 2022).

11.7. Research and Studies

Several academic and governmental studies have been conducted to understand the scope of these issues and propose solutions.

- **Water Quality Studies**: The Kerala State Pollution Control Board (KSPCB), in collaboration with the Central Pollution Control Board (CPCB), has been a primary source of data on the severity of industrial and agricultural pollution. Their reports and filings with the National Green Tribunal provide key metrics on parameters like dissolved oxygen, biochemical oxygen demand, and fecal coliform levels (National Green Tribunal, 2025).
- **Geochemical Analyses**: A study on the soil geochemistry of the basin documented the presence of heavy metal contamination and its potential impact on agriculture and public health. This research used advanced analytical techniques to determine elemental concentrations and assess the pollution load index. Divya et al. (2021) examined the soil geochemistry of the Periyar River Basin and reported elevated concentrations of Pb, Zn, Cu, Cd, Cr, and Ni, particularly in the industrial and downstream regions. The Pollution Load Index and Geoaccumulation Index indicated moderate to severe contamination, primarily linked to industrial effluents and agricultural runoff. The study highlighted potential risks to soil fertility and public health, emphasizing the need for regular monitoring and sustainable land-use management.
- **Hydrological Modelling**: Researchers from institutions like the National Centre for Earth Science Studies (NCESS) have used hydrological models to assess the impact of land use changes and climate extremes on the basin's water cycle. These studies, as published in journals like Water Science & Technology, have shown how erratic rainfall patterns and floods impact groundwater regimes, which is critical for irrigation (Aneesh & Roy, 2024).
- **Ecosystem Services Valuation**: Research has also used geospatial analysis to assess the impacts of pollution on the river's ecosystem services, showing a significant decline in the monetary value of provisioning services like fisheries due to pollution and land-use changes (Ganga Knowledge Portal, 2023).

In conclusion, the agro-ecosystem of the Periyar river basin is facing a multifaceted crisis driven by a combination of unsustainable agricultural practices, industrial pollution, and land-use changes. The scientific community and government agencies have been instrumental in documenting these issues, providing crucial data on water and soil contamination, and modelling the hydrological impacts. Addressing these concerns will require an integrated river basin management approach that prioritizes pollution abatement, sustainable farming techniques, and ecological restoration.

12. Existing or potential measures of sustainable agriculture and their economic viability in the Periyar River Basin

Sustainable agriculture is always a much-discussed topic in recent decades. Sustainable agriculture aims at ensuring proper distribution of agricultural produce without compromising the quality of the produce, as well as ensuring the proper management of soil, water and nutrients. The sustainable agricultural methods practiced in the Periyar River basin are necessary for maintaining the ecological balance of the basin as well as ensuring the long-term sustainability in agriculture. Since the Periyar river is the vital source for the nearby communities, the adoption of sustainable agriculture measures like organic farming, soil health management, water conservation etc. help to prevent soil erosion, reduce the contamination of water and the preservation of biodiversity. These measures safeguard the environment, also influences the improving farmer livelihood by promoting climate resilience, non-compromising food security and also protecting the health of the river and the ecosystem for the upcoming generations.

There are many sustainable agricultural practices followed in the basin across different fields. These measures are adopted in the fields of soil conservation, water management, integrated pest management, integrated nutrient management and integrated farming system. Agricultural methods which are more sustainable and are suitable for those fields were carefully selected and were practiced in a proper manner with supervision from the experts.

12.1. Measures for Soil Conservation

There are mainly four practices which are followed in regard to the soil conservation in the basin. They are:

1. Crop rotation
2. Intercropping
3. Reduced/No-till farming
4. Cover cropping

Crop rotation is the practice of cultivating different crops in the same area of land over different growing seasons. It is a very common practice of farmers, and can also be used by people who have limited areas of croplands or small-scale gardens. This practice helps to enhance the nutrients, organic matter and fertility of the soil. Crop rotation in the basin is practiced mainly for paddy and tuber crops. It is also seen in areas where pulses and vegetables are cultivated. This method also reduces the likelihood of developing resilient weeds and pests. This method increases crop yield which in turn reduces the financial risks.

Intercropping is the method of cultivating two or more crops in an area at the same time. It can help in increased yield and output without increasing the input like fertilizers. This technique results in increased soil coverage, fertility and microbial diversity. In Idukki district, intercropping technique is commonly followed among coconut cultivators.

Reduced/ No till farming involves minimum disturbance of the soil and hence the soil becomes capable of preventing soil erosion up to a greater extent. This is a very time saving and economically viable method of soil conservation, which can be widely practiced in sloppy terrains and hill slopes. Cardamom, coffee, tea, pepper and rubber are the major crops which are grown in this manner in the Idukki district. Rubber is also grown in cover cropping method in the Idukki, which is a technique in which the growing plants are used as a cover for the soil. This method can help in reducing the excess soil nutrient loss and help in retaining the water content in the soil.

Studies of humid tropical agroecosystems identify Sesbania aculeata, Crotalaria juncea (sunnhemp), and Vigna unguiculata (cowpea) as among the most suitable cover crops for the Periyar River Basin. Sesbania species demonstrate rapid biomass accumulation, robust nitrogen fixation, and effective erosion control in high-rainfall environments (Pandey & Singh, 2020; Biswas & Ghosh, 2019). Crotalaria juncea improves soil organic matter, enhances infiltration, and increases slope stability, which aligns with the needs of the basin's steep, erosion-prone uplands (Ramesh et al., 2017). Short-duration legumes such as cowpea perform consistently under Kerala's monsoon conditions and integrate well with the plantation-based systems prevalent in the basin (Central Plantation Crops Research Institute [CPCRI], 2018). These species are likely to be suitable due to their rapid establishment, compatibility with perennial crops, and demonstrated benefits for soil cover, nutrient cycling, and runoff reduction.

12.2. Water Management Measures

Water management in agriculture is a very important practice to follow to ensure that sufficient water is available for the cultivation of the required quantity and also to ensure that necessary amounts of water is available for the future production. There are many water management measures which are prevalent in the world and each of these are constructed according to the local geography and the area wise characteristics. Rain water harvesting, drip and sprinkler irrigation and mulching are the major water management techniques followed in the Idukki district.

Rain water harvesting ponds (*Paduthakulam*) is a major rainwater harvesting method followed in the area. These ponds are constructed as lined ponds and are used for domestic use of water post monsoon, in areas where water is scarce during summer season. The water from these ponds is also used for irrigation and agricultural purposes. This method constitutes an efficient method of water storage without seepage loss. These ponds can be used as a source of water for irrigating household vegetable gardens and also in small agricultural projects within a small area.

Drip and sprinkler irrigation systems are also set up in the Idukki district for proper irrigation of the cultivated lands. Drip irrigation applies water slowly and directly to the roots of the plants to efficiently deliver water and nutrients to the plants. Several tubings and water emitters are equipped in this method. This method is well suited for small flowerbeds, trees and plants which are deep rooted into the ground. This method can save quantity of water, energy, fertilizer and other crop protectant products. In the sprinkler irrigation method, water is sprayed into the air, like natural rainfall. Pipes are used in this technique to distribute water into the fields. This method can improve the physical condition and composition of the soil. This method can also be used in areas with very less rainfall and uneven ground conditions. This technique is mainly used for irrigation in plantations, flower farms and grasslands.

Mulching is a method of covering the cultivable soil with a layer of material, which are usually made from organic materials like straw, leaves and inorganic materials like plastic, to protect and improve the soil health. Mulching helps in retaining the soil moisture and also prevents erosion by allowing the rainwater to infiltrate into the soil pores. It reduces the surface temperature of the soil by insulating and can suppress weeds growing in the soil. This method is widely used in plantation crops like tea, coffee and cardamom which are growing in the Periyar river basin.

12.3. Integrated Pest Management (IPM) Methods

Integrated pest management is a very efficient and sensitive method to pest control which involves many common-sense practices. This method uses the life cycle of the pests and their environmental interactions to develop pest specific control methods to restrict the pest damage by the most economical way and by least hazard to people, property and the environment. This method can be applied to both agricultural and non-agricultural settings like home, gardens and workplace etc.

Use of natural enemies for getting rid of pests is an important step in integrated pest management techniques followed in Idukki district. Use of lady bugs which are efficient in destroying aphids and dung beetles which are natural predators of fly larvae etc. are examples of natural enemy-based pest management method in integrated pest control practiced in the basin. Changing the farming practices to reduce the risks of pests are also an important takeaway point in the integrated pest management method. Judicious usage of pesticides is another method of pest control. The usage of pesticides only when needed, that too in the safest way possible ensures to restrict pesticide resilient growth of pests.

Cultivation of pest resistant plants like Bacillus thuringiensis tomato (Bt tomato), Bacillus thuringiensis brinjal (Bt brinjal) etc. helps in greater yield when compared to traditional varieties of crops.

12.4. Integrated Nutrient Management (INM) Methods

Integrated Nutrient Management technique in the Periyar river basin involves the usage of a variety of nutrients to improve the health of the soil and thereby increase the crop yield. It mainly aims at meeting the nutrient needs of crops grown in a specific land area. It depends on different sources of nutrients, inorganic and organic, to make sure that the nutrient needs of the crops are met. This method helps to improve the soil structure, porosity and water holding capacity of the soil. This technique also targets to reduce the environmental pollution and also to reduce the greenhouse gas emissions to the atmosphere.

Integrated Nutrient Management Methods mainly concentrate in the utilisation of organic manures in the agricultural sector for enhancing the crop production without chemically breaking down the real composition of the soil and by maintaining their actual properties as it is. Crop residues and green manures are widely used in the Periyar River Basin as organic manures. Utilising bio fertilizers like blue green algae (cyanobacteria) and azolla are also promoted under the integrated nutrient management. This helps in nitrogen fixation in the soil, improving the soil quality and producing the plant growth regulators which are inevitable in their growth. Soil test based nutrient application is another approach in integrated nutrient management where soils which are deficient in certain nutrients are identified on the basis of mass sampling and testing. Areas which lack necessary nutrients are studied and are provided with suitable nutrients in the form of fertilizers and manures to overcome the nutrient deficit in the areas. Distribution of organic manures and fertilizers in subsidised rates are a common scene in the Idukki district to overcome the nutrient deficiency.

12.5. Integrated Farming System

Sustainable farming practices which combine the various components of agriculture like crops, livestock, aquaculture etc. together constitute integrated farming systems. The primary goal of the system is to maintain the ecological balance of the biosphere and to replicate a natural feedback mechanism, where each of the components support each other. This system mainly aims at sustainable, productive, profitable and diverse agricultural practices which finally creates a situation where no waste is created and nothing is wasted.

Various Integrated Farming Systems models are made and followed across the country with an aim of achieving sustainable existence of the agricultural sector. Agroforestry, crop management and post-harvest management of resources are widely monitored in this technique. The National Mission for Sustainable Agriculture (NMSA) and other government schemes promote the inclusion and adoption of Integrated Farming System in the agricultural sector, which in turn becomes a more sustainable and economically viable option of cultivation, where people can depend on different sources of income rather than depending on a single source of income like it is in the traditional method of cultivation.

12.6. Existing/ potential measures of sustainable agriculture and their economic viability Idukki District

Table 23 Existing or potential measures of sustainable agriculture and its economic viability
(Source: Principal Agricultural Office, Idukki)

Block/ Municipality	Soil conservation measures	Water management measures	Integrated pest management methods	Integrated nutrient management methods	Integrated farming system
Adimali	Contour bunding, intercropping, cover cropping	Mulching, drip irrigation, rainwater harvesting	Followed	Followed	Followed
Devikulam	Terracing, cover cropping, agroforestry	Drip, mulching, sprinkler, rainwater harvesting	Followed	Followed	Followed
Idukki	Contour bunding, intercropping, cover cropping	Mulching, drip, rainwater harvesting	Followed	Followed	Followed
Kattappana	Crop rotation, intercropping, mulching	Drip irrigation, mulching, rainwater pits	Followed	Followed	Followed
Nedumkandam	Contour farming, cover cropping	Drip, sprinkler irrigation, water harvesting	Followed	Followed	Followed
Azhutha	Terracing, intercropping, vegetative barriers	Drip, sprinkler irrigation, mulching	Followed	Followed	Followed
Elamdesam	Intercropping, crop rotation	Drip, sprinkler, mulching, water harvesting	Followed	Followed	Followed

12.7. Existing/ potential measures of sustainable agriculture and their economic viability Ernakulam District

The sustainable agricultural practices adopted across different blocks of Ernakulam District, as presented in Table 24, reflect a strong emphasis on soil conservation, water management, and integrated approaches. Common soil conservation measures include crop rotation, intercropping, cover cropping, and mulching, while water management practices such as drip irrigation, sprinkler systems, rainwater harvesting, and mulching are widely applied. Integrated pest management, integrated nutrient management, and integrated farming systems are consistently followed in most blocks, demonstrating a commitment to sustainable and eco-friendly cultivation. Notably, Poothrikka stands out with unique soil conservation measures such as geotextile application and tree planting, while also combining both organic and chemical methods for pest and nutrient management. Overall, the data highlights the district's active pursuit of sustainable agricultural practices with variations tailored to local conditions.

Table 24 Existing or potential measures of sustainable agriculture and its economic viability

(Source: Principal Agricultural Office, Ernakulam)

Block/ Municipality	Soil conservation measures	Water management measures	Integrated pest management methods	Integrated nutrient management methods	Integrated farming system
Narakkal	Inter cropping	Mulching	Followed	Followed	Followed
North Paravur	Crop rotation, intercropping, cover cropping	Drip, mulching, rain water harvesting, sprinkler	Followed	Followed	Followed
Aluva	Crop rotation, intercropping, cover cropping	Drip and Mulching	Followed	Followed	Followed
Nedumbasserry	Crop rotation, intercropping	Sprinkler irrigation, rain water pits, mulching, rain water harvesting	Followed	Followed	Followed
Kalamasserry	Crop rotation, intercropping	Mulching, Drip, Rain water harvesting	Followed	Followed	Followed
Vyttila	Inter cropping	Irrigation, mulching	Followed	Followed	Followed
Perumbavoor	Crop rotation, intercropping	Drip, Sprinkler, Mulching, Water harvesting	Followed	Followed	Followed
Angamaly	Inter cropping,crop rotation	Drip, Sprinkler Mulching, Water harvesting	Followed	Followed	Followed
Keezhmadu	Intercropping, crop rotation	Drip, Sprinkler, Mulching, Water harvesting	Followed	Followed	Followed

Poothrikka	Geotextile measures, planting trees, mulching	-	Organic & Chemical methods	Organic & Chemical methods	Followed
Kothamangalam	Inter cropping	Drip, Sprinkler, Mulching, Water harvesting	Followed	Followed	Followe d

12.8. Existing/ potential measures of sustainable agriculture and their economic viability Thrissur District

The LSGIs including 5 Blocks and 2 municipalities in Thrissur District have adopted sustainable agricultural practices to promote environmental conservation and improve productivity. Crop rotation, inter-cropping, cover cropping, mulching, etc, have been practiced across various Blocks/ Municipalities as part of soil conservation efforts. To improve water-use efficiency, water management techniques such as rainwater harvesting, mulching, rain pits, micro irrigation, drip irrigation, etc. have been employed. Chemical control, biocontrol agents, bio-pesticides, traps, mechanical pest control measures, etc. are the common integrated pest management methods adopted. Integrated nutrient management methods include use of organic manure, chemicals, and biofertilizers. Additionally, an integrated farming system which supports sustainable agriculture and boosts the region's economy is promoted. The existing and potential measures of sustainable agriculture along with their economic viability are presented in Table 25.

Table 25 Existing or potential measures of sustainable agriculture and its economic viability

(Source: Principal Agricultural Office, Thrissur)

Block/ Municipality	Soil conservation measures	Water management measures	Integrated pest management methods	Integrated nutrient management methods	Integrate d farming system
Chalakudy	Crop Rotation, inter cropping, cover cropping, mulching	Mulching, Micro irrigation	Chemical and biocontrol agents, mechanical pest control measures	Fertilizers, organic manures, biofertilizers	12 IFS Unit
Mala	Crop Rotation, intercropping, cover cropping, mulching, geo fencing	Rain pit, mulching, natural ponds maintenance, drip irrigation, micro irrigation	Chemical control, biocontrol agents, bio-pesticides, traps, mechanical pest control measures	Organic manures and biofertilizers	73 IFS Unit

Mathilakam	Crop Rotation, intercropping, cover cropping, mulching, reduced/no- till farming	Rain water harvesting, mulching, rain pits micro irrigation	Bio-pesticides, fungicide, biocontrol agent, traps, mechanical pest control measures	Organic manures, chemical fertilizers, biofertilizers	27 IFS Unit
Irinjalakuda	Crop Rotation, intercropping, cover cropping, mulching	Mulching, Micro irrigation	Traps, biocontrol agents, mechanical, biological pesticides	Organic manures, chemical fertilizers, biofertilizers	10 IFS Unit
Vellangallur	Mulching, crop rotation, intercropping, cover cropping	Mulching, drip irrigation, crop rotation, rain pits micro irrigation	Chemical pesticides, bio pesticides, organic pesticides, mechanical traps, physical methods	Organic manures, chemical fertilizers, biofertilizers	31 IFS Unit
Kodungallur Municipality	Crop Rotation, intercropping, cover cropping, mulching	Mulching, rain pits, Micro irrigation	Bio-pesticides, biocontrol agent mechanical pest control measures	Organic manures and biofertilizers	3 IFS Unit
Irinjalakuda Municipality	Crop Rotation, intercropping, cover cropping, mulching	Mulching, Micro irrigation	Bio-pesticides, biocontrol agent mechanical pest control measures	Organic manures, chemical fertilizers, biofertilizers	

13. Nutrients and Sediment Loads in the Periyar River Basin

The Periyar river supports a diverse range of ecological habitats and serves as a primary source of water for drinking, agriculture, industry, and hydroelectricity. However, recent decades have witnessed a substantial increase in nutrient and sediment loads in the Periyar, driven by a combination of anthropogenic and natural factors, leading to degraded water quality, ecological imbalance, and threats to public health.

13.1. Nutrient Loads

Recent hydro-geochemical studies have confirmed widespread nutrient enrichment in the Periyar River. Arun et al. (2024) conducted a comprehensive analysis of water and sediment samples along the Eloor–Vypin industrial belt and found elevated levels of ammonia (4.4–894 µg/L), phosphate (28.7–132.4 µg/L), nitrate (50–852 µg/L), and nitrite (3.1–30 µg/L). These concentrations are significantly above acceptable thresholds, especially for drinking and bathing waters, suggesting chronic contamination from industrial and domestic effluents. The proximity of this stretch to one of Kerala's largest industrial hubs, the Eloor-Edayar Industrial Zone, which houses more than 250 chemical and petrochemical factories, is a primary contributor to the elevated nutrient loads (Harikumar et al., 2009).

Urban runoff and sewage discharge further exacerbate the problem. According to the Kerala State Pollution Control Board (KSPCB, 2018), the Biochemical Oxygen Demand (BOD) load entering the Periyar from Ernakulam and Aluva urban zones ranges between 12–15 tons/day. A recent report by the Times of India (2025) revealed that faecal coliform counts reached as high as 11,000 MPN/100 mL in the urban stretch, indicating severe microbial contamination and the discharge of untreated domestic waste. The situation is compounded during the monsoon when runoff from unlined drains and septic tanks further increases nutrient concentrations.

In the highland regions of the Periyar basin, intensive cultivation of tea, cardamom, pepper, and vegetables contributes significantly to non-point source nutrient pollution. Ramesh et al. (2011) found that nitrate concentrations in surface water adjacent to tea estates in Munnar exceeded WHO standards, ranging from 4 to 14 mg/L. Similarly, Joseph et al. (2007) reported substantial orthophosphate concentrations linked to fertilizer application and leaching in vegetable farms. This agricultural runoff, enriched with urea, DAP, and potassic fertilizers, is transported into tributaries like the Muthirapuzha and Perinjankutti during rainfall events.

13.2. Sediment Loads

The sediment dynamics of the Periyar River are influenced by topography, rainfall intensity, land use practices, and human interventions such as deforestation and sand mining. Narayana and Ramachandran (2010) highlighted that the erosivity index in the Western Ghats region of the Periyar often exceeds 8000 MJ mm ha^{-1} h^{-1} yr^{-1}, indicating a high potential for soil erosion, especially during the southwest monsoon. Aditya et al. (2023) confirmed seasonal variations in sediment transport, with turbidity and Total Dissolved Solids (TDS) levels reaching up to 15,366 mg/L in pre-monsoon periods due to sediment mobilization.

Deforestation and unscientific land use changes have destabilized slopes, particularly in Idukki and Pathanamthitta districts. Nair and Soman (2012) estimated soil loss rates of over 35 tons/ha/year in disturbed landscapes. Quarrying for lateritic rock and road construction near Vandiperiyar and Adimali has further exposed fragile geological formations to erosion. According to Padmalal and Maya (2005), sand mining in the lower reaches of the Periyar has led to the extraction of nearly 500,000 m^3 of sediment annually, far exceeding natural replenishment rates. This not only deepens riverbeds but also undermines riverbank stability, leading to channel incision and habitat loss.

Additionally, the construction of major dams such as Mullaperiyar, Idukki, and Cheruthoni has significantly altered sediment transport patterns. Studies by CWRDM (2015) indicate that up to 85% of upstream sediments are trapped behind reservoir walls, leading to sediment starvation downstream. This disruption contributes to downstream erosion, delta shrinkage, and siltation of irrigation canals. During extreme flood events, such as those in 2018, 2019, and 2021, accumulated sediments are remobilized, dramatically increasing downstream turbidity and reducing water clarity.

13.3. Heavy Metals and Organic Loading

The Periyar is also heavily contaminated with trace metals due to decades of industrial discharge. A 2024 sediment quality assessment by the KSPCB revealed alarmingly high levels of iron (77,203 mg/kg), zinc (14,022 mg/kg), manganese (675.6 mg/kg), copper (1,040 mg/kg), and chromium (750.6 mg/kg) in bottom sediments near Eloor and Kalamassery. These concentrations far exceed sediment quality guidelines and point toward long-term bioaccumulation risks in aquatic food webs.

Organic pollution, often measured as total organic carbon (TOC) in sediments, is also a pressing concern. Saraladevi et al. (1992) investigated organic carbon distribution in surface sediments from nine stations along the lower Periyar River, covering Thottumugham, Pathalam, Edayar, Eloor, Varappuzha, and adjacent Cochin backwater zones. Total organic carbon (TOC) values ranged from 1.19 to 29.6 mg g^{-1}, with the highest concentrations recorded near the Eloor–Edayar industrial stretch. The study attributed this enrichment to continuous inputs of sewage, agricultural runoff, and industrial effluents, which elevated BOD and COD levels, promoting anoxic conditions and recurrent fish mortality in the downstream reaches.

13.4. Ecological and Health Impacts

The consequences of elevated nutrient and sediment loads are far-reaching. Algal blooms, especially in the Vembanad Lake, have been frequently reported by Menon et al. (2010), driven by excessive nitrate and phosphate levels. Such eutrophication depletes dissolved oxygen, resulting in hypoxia and the collapse of aquatic ecosystems. Endemic and migratory fish species such as Tor khudree (Mahseer) are under stress due to sediment smothering and poor water quality.

Moreover, chronic microbial contamination poses significant public health risks. Frequent gastroenteritis outbreaks in Kochi and Aluva have been linked to the use of contaminated Periyar water (TOI, 2025). Sediment deposition in reservoirs also reduces their effective storage capacity, impacting hydropower and irrigation services.

13.5. Water and Sediment Quality Monitoring in the Kochi Harbour Region

The Periyar River’s discharge into Kochi Harbour faces stress from sewage, sand mining, deforestation, dams, and urbanization. To assess impacts, CESS (2006–2007) monitored seven harbour sites for water and sediment quality. Results showed seasonal shifts in pH, salinity, and DO, high turbidity and suspended solids during monsoon, and heavy metal enrichment (Pb, Cd, Hg) near industrial hotspots like Eloor. The sampling locations within the harbour region are illustrated in Figure 9.

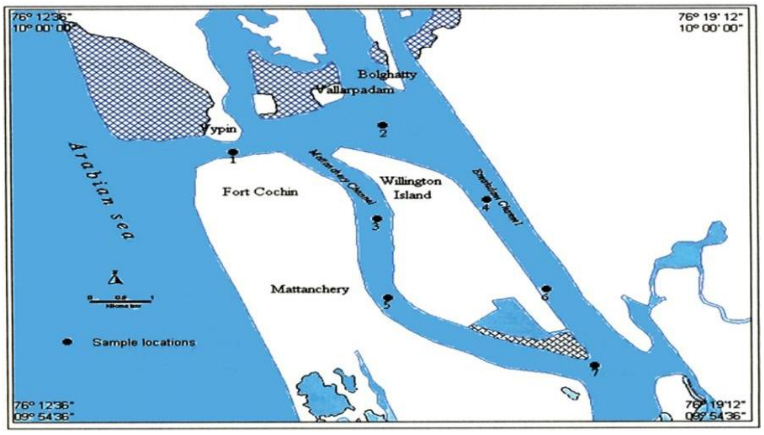

Fig. 9. Sampling locations in the Kochi harbour region, *Source: CESS Annual Report 2006-2007*

13.6. Nutrient Dynamics and Pollution Hotspots in the Periyar Lake

(Ray, Krishnan, & Vasudevan, 2012) carried out a three-year study on Periyar Lake, a man-made reservoir in Thekkady, Idukki district, Kerala, to assess nutrient dynamics and pollution. Six sampling stations were established, with shore-based stations more exposed to human activities like boating and tourism, and offshore stations covering deeper, less disturbed zones. Monthly water samples were collected from both surface and bottom layers between April 2002 and April 2005. Shore based stations consistently showed higher nutrient levels, including Nitrate, Phosphorus, and Oil and Grease, indicating localized anthropogenic pollution from Kumily township runoff and boat activity, whereas offshore stations recorded the lowest pollutant and microbial levels, reflecting minimal disturbance. This spatial variation helped identify nutrient-loading hotspots and ecologically sensitive areas, providing a basis for comprehensive nutrient load assessment of the lake.

Seasonal monitoring of Periyar Lake measured nitrate nitrogen, Total Kjeldahl Nitrogen (TKN), inorganic phosphorus, and silica, with concentrations ranging from 0.1–0.6 mg/L for nitrate, 1.0–3.9 mg/L for TKN, 0.01–0.1 mg/L for inorganic phosphorus, and 0.01–0.41 mg/L for silica. Nutrient levels peaked during the pre-monsoon season due to reduced dilution and declined during the monsoon from increased inflow. Shore-based stations consistently showed the highest nutrient concentrations, marking it as a potential nutrient-loading hotspot from localized anthropogenic inputs. Although exact nutrient loads were not calculated, these spatial and seasonal patterns provide a basis for future integrated flux assessments, while the general stability across the lake reflects the relatively undisturbed watershed of the sanctuary (Ray et al., 2012).

Krishnan (2012) examined nutrient enrichment and phytoplankton dynamics in the Mullaperiyar Reservoir (Periyar Lake) using five consistent sampling stations, enabling a detailed assessment of spatial and seasonal trends. TKN concentrations ranged from 1500 to 3000 µg/L, peaking at shore-based station during the pre-monsoon, indicating significant nitrogen enrichment, while the lowest values were observed at another shore-based station during the monsoon periods. These results highlight shore-based station as a consistent nutrient hotspot, likely influenced by reduced dilution and anthropogenic inputs. In contrast, groundwater in the Chalakudy River Basin showed nutrient variations shaped by both natural mineral weathering and localized human activities, particularly agricultural runoff, reflecting the interplay between geology and land use.

13.7. Management and Mitigation Strategies

Given the complexity and scale of pollution in the Periyar basin, a multi-tiered approach is essential. Riparian buffer zones with native vegetation can significantly reduce nutrient and sediment inflow (Lowrance et al., 1984). Contour farming and vegetative barriers have proven effective in reducing hill slope erosion (Pimentel et al., 1995). Constructed wetlands utilizing aquatic macrophytes offer a natural means of nutrient filtration (Kadlec & Wallace, 2008).

Innovative, low-cost turbidity control methods using coir and rice husk ash have also shown promise. A 2022 study demonstrated that dosing 1 mg/L of these natural fibres reduced turbidity and balanced pH effectively during flood-induced sediment surges. Enforcement of Zero Liquid Discharge (ZLD) norms in industries and the expansion of sewage treatment infrastructure are vital regulatory steps. Basin-wide GIS-based monitoring systems, as proposed by Kumar et al. (2017), can help track pollution hotspots and inform adaptive watershed management.

14. Flow/Nutrient Trapping Structures in the Periyar River

The Periyar River is a lifeline for Kerala, particularly for farming communities in Idukki and Ernakulam districts. It supports not only daily water requirements but also sustains extensive agricultural activity. However, increasing nutrient loads, primarily Nitrogen and Phosphorus, are degrading the river's water quality. These nutrients primarily enter the river through agricultural runoff (from fertilizers and manure), untreated domestic sewage, industrial discharges, and urban stormwater. Unchecked, these nutrient inflows can lead to eutrophication, excessive algal growth, and deterioration of aquatic ecosystems. To counter this, nutrient trapping and flow regulation structures have been constructed at various points along the Periyar River and its tributaries.

In this scenario, Flow and nutrient trapping structures are key components in how we manage rivers and landscapes. These structures, both man-made and natural, help control how water moves through an environment and how nutrients and sediments are stored or transported. They’re commonly used in agriculture, water supply, flood control, and even to support ecosystems.

Flow regulation structures are built to manage the direction, timing, and volume of water flow. Dams and reservoirs, for example, store water during rainy periods and release it when it's dry, helping to provide a steady water supply. Weirs and barrages help maintain water levels for irrigation and navigation. In some cases, water is diverted entirely through tunnels or canals from one river basin to another. These changes can significantly affect downstream ecosystems and how rivers naturally function.

On the other hand, nutrient and sediment trapping structures are designed to slow water down, allowing sediments and nutrients like nitrogen and phosphorus to settle out before reaching downstream water bodies. Large reservoirs can trap these materials on a big scale, while smaller structures like check dams or sediment basins are often used in farming areas to reduce soil erosion and water pollution. Natural features like wetlands and vegetated riverbanks also act as effective filters, improving water quality and supporting biodiversity.

While these structures bring many benefits, they also come with several disadvantages. By altering how water and nutrients move through a system, they can disrupt natural processes and impact both people and ecosystems downstream. Understanding their roles helps us make better decisions about managing rivers and landscapes in a sustainable way. There are a number of flow and nutrient trapping structures that are present across the stretch of the Periyar river, influencing the course of the river as well as its impact on biodiversity.

14.1. Major Flow and Nutrient Trapping Structures in Idukki district

1. Mullaperiyar Dam

The Mullaperiyar Dam is a composite gravity structure, and has a height of 47.24m above the datum (river bed level), with a length of 366m. The dam's front and back faces are made of uncoursed rubble masonry in lime-surkhi combination mortar. The hearing, which makes up almost 60% of the dam's capacity, is made of lime surkhi concrete. The Mullaperiyar Dam is a flow-regulating structure, which means it controls and manages water flow for human use. This dam blocks the flow of the Periyar River, creating a reservoir. The stored water is widely used to irrigate crops in the drought-prone regions of Tamil Nadu. This ensures a consistent water supply for agriculture, even during dry seasons or locations with limited rainfall. The water held in the reservoir is also used to produce hydroelectric power. The potential energy contained in the water is converted to electrical energy when it is released through turbines. Considering that the Mullaperiyar Dam is mainly utilized for irrigation and power generation, as well as its location in a tropical environment, nutrient dynamics in the reservoir would be more associated with organic material from the catchment area than a controlled attempt to trap nutrients for ecological purposes.

2. Idukki Arch Dam

Idukki Arch Dam is constructed between the Kuravanmala and Kurathimala across the Periyar River and is the highest arch dam in Asia and the third tallest arch dam in the world. This dam was constructed along with two other dams, at Cheruthoni and Kulamavu, with a total reservoir area of 60 km^2. This dam was primarily constructed for power generation and water storage, in the Idukki reservoir, and releasing it in a controlled manner for electricity generation. This dam influences in managing the seasonal river flow, preventing floods, ensuring water availability during dry season, and hence considered as a flow regulating structure.

3. Cheruthoni Dam

Cheruthoni Dam was constructed as part of the Idukki Hydro Electric Project, across the Cheruthoni River, a tributary of the Periyar River, in Cheruthoni and is the largest straight gravity dam in Kerala, with a height of 138.2m and length of 650.90m. The spillway of the Idukki reservoir is in the Cheruthoni Dam and hence the dam acts as a flow regulating structure.

4. Kulamavu Dam

Kulamavu dam is a part of Idukki Hydro Electric Project and is located in Idukki District of Kerala State. The water stored in the Idukki reservoir is diverted through a long power tunnel of 2027m length and pressure shaft with an average length of 975m to an underground powerhouse located at Moolamattom, with a capacity of 780 MW. Kulamavu Dam is also a flow regulating structure, located across the Periyar River.

5. Thadiyampadu Chappath

Thadiyampadu Chappath is constructed across the Periyar River at Thadiyampadu, connecting Thadiyampadu and Mariyapuram regions of Idukki in Kerala State. It has a length of 170m, width of 9m and an average height of 2.5m. The chappath was damaged during the 2018 flood and the same was restored after the flood. The bed of the river in this area is rock and depositions of sand and silt depositions are seen over the rocky river bed in the area. Thadiyampadu Chappath is considered as a flow as well as a nutrient trapping structure constructed across the Periyar river.

6. Chappath at Periyar Valley

The Old chappath is across the Periyar River at the Periyar valley, built on short pillars and abutments located in the river bed, partially obstructing the flow of the river, as well as a site of sediment deposition. The bed of the river bed at the location is rock, with silt, sand and clay sedimentation, with the presence of boulders. Silt depositions with vegetation are also present in the area. This structure acts as a flow and nutrient trapping structure on the Periyar river.

7. Ponmudi Dam

Ponmudi Dam is a part of the Panniyar HydroElectric project, located at Ponmudi, across the Panniyar river. The project is in Muthirapuzha subbasin. The water from the Ponmudi reservoir is diverted to Panniyar power station, located on the left bank of Muthirapuzha river, through a water conductor system. This water, after power generation, is released back to Panniyar river. This structure acts as a flow and nutrient trapping structure in the Periyar river basin.

Table 26 lists the flow and nutrient trapping structures in the Idukki district of the Periyar River Basin, highlighting key interventions that reduce runoff, promote infiltration, and limit sediment and nutrient losses from upland catchments.

Table 26 Flow and Nutrient Trapping Structures in the Periyar River Basin – Idukki district

Sl. No.	Name of the Structure	Type of Structure	Latitude	Longitude	Grama Panchayath
1	Mullapperiyar Dam	Dam	9.528691667	77.14433	Kumily
2	Idukki Arch Dam	Dam	9.8431	76.9764	Idukki
3	Cheruthoni Dam	Dam	9.845666667	76.96703	Vazhathope
4	Kulamavu Dam	Dam	9.8028	76.8856	Arakkulam
5	Anchuruli Tunnel Outlet	Tunnel/Spill outlet	9.80345	76.87390	Ayyappancoil
6	Ponmudi Dam	Dam	9.824683116	77.15621	Konnathady

7	Kallarkutty Dam	Dam	9.980077778	77.00133	Vellathooval
8	Kundala Dam	Dam	10.14348611	77.19863	Munnar
9	Pambla Dam	Dam	9.962455556	76.95708	Adimali
10	Erattayar Dam	Dam	9.810277778	77.10583	Erattayar
11	Mattuppetty Dam	Dam	10.10636111	77.12351	Munnar
12	Mukkudil Dam	Dam	9.9467	77.1077	Kattappana
13	R.A. Headwork	Weir (Small check dam)	10.068092	77.06712	Munnar
14	Sengulam Dam	Dam	10.01088333	77.03266	Chithirapuram
15	Chappath at Periyar Valley	VCB	9.932940	76.971489	Vazhathope / Periyar Valley Project Area
16	Thadiyampadu Chappath	VCB	9.87944	76.97000	Karimannoor (bordering Thodupuzha Block)

14.2. Major Flow and Nutrient Trapping Structures in Ernakulam and Thrissur districts

In the Ernakulam District, key nutrient trapping structures include the Urulikkuzhy Check Dam and the Ananthamkudi Check Dam, both situated in Kuttampuzha Panchayat. The Koovappady Panchayat hosts three VCBs—Paadathmaly, Kotta Palam 1, and Kotta Palam 2. In Mudakkuzha Panchayat, the Mudakuzha Cross Bar serves a similar purpose, while Okkal Panchayat contains two additional irrigation-focused VCBs. Collectively, these structures contribute significantly to nutrient retention by reducing runoff velocity, facilitating the deposition of nutrient-bearing sediments, and enhancing groundwater recharge.

While some of the nutrient trapping structures also provide incidental flow regulation benefits, a few major installations in the Periyar River Basin are primarily designed for flow control, flood management, and water storage. Notably, the Bhoothathankettu Barrage, located in Pindimana

Panchayat, and the Idamalayar Dam, situated in Kuttampuzha Panchayat, are key flow regulation structures in the basin. These facilities play a crucial role in ensuring a steady water supply downstream, protecting agricultural and urban areas from seasonal flooding, and maintaining ecological flow during dry periods. Although not primarily designed for nutrient control, they offer secondary benefits by stabilizing water levels and reducing the velocity of nutrient-laden surface flows, thereby indirectly contributing to improved water quality in the Periyar River system. The flow and nutrient trapping structures in the Periyar River Basin across Thrissur and Ernakulam Districts are presented in Table 27. Fig. 10,11 and 12 shows Location Map of dams, check dams and VCB's located in the Periyar River Basin.

Table 27 Flow and Nutrient Trapping Structures in the Periyar River Basin – Thrissur and Ernakulam Districts

(Source: Irrigation Design and Research Board)

Sl. No.	Name of the Structure	Type of Structure	Lat	Long	Grama Panchayath
Nutrient Trapping Structures					
1	Urulikkuzhy Check Dam	Check Dam	10.095778	76.812917	Kuttampuzha
2	Ananthamkudi Check Dam	Check Dam	10.095556	76.783694	Kuttampuzha
3	Paadathmaly Cross Bar	VCB	10.13623300	76.47061700	Koovappady
4	Cross Bar for irrigation (Kotta Palam 2)	VCB	10.13871700	76.47063300	Koovappady
5	Mudakuzha Cross Bar	VCB	10.13938300	76.52570000	Mudakkuzha
6	Cross Bar for irrigation (Kotta Palam 1)	VCB	10.14141700	76.47046700	Koovappady
7	Cross Bar for irrigation	VCB	10.15490000	76.46571700	Okkal

8	Cross Bar for irrigation	VCB	10.15586700	76.46486700	Okkal
Flow Regulation Structures					
9	Bhoothathankettu Barrage	Barrage	10.137549	76.66198	Pindimana
10	Idamalayar Dam	Dam	10.22207222	76.70648611	Kuttampuzha

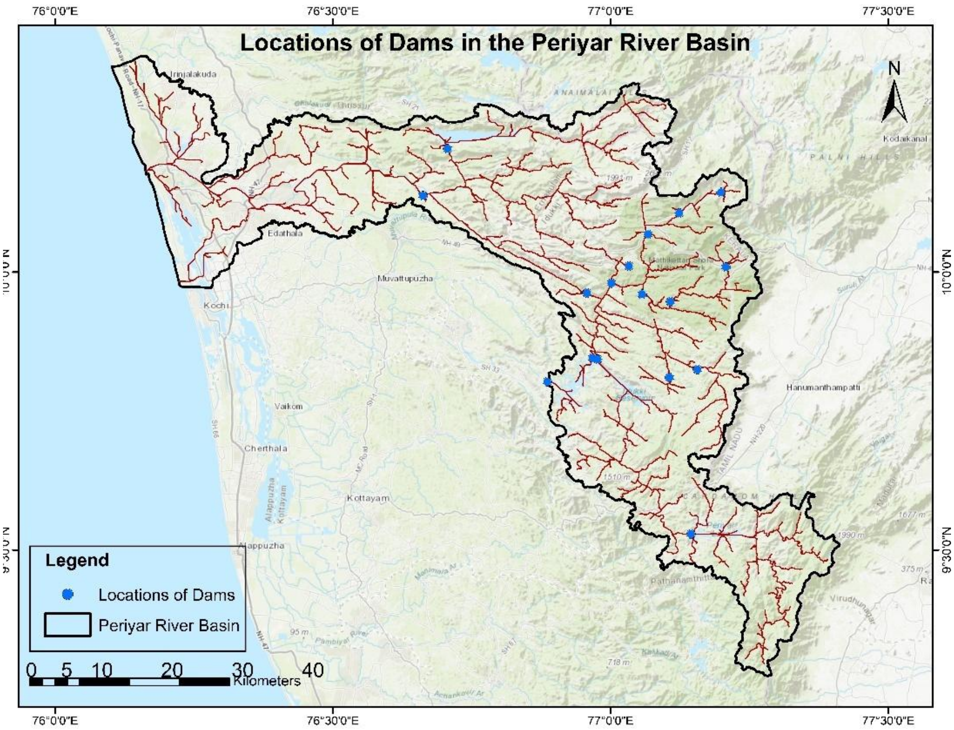

Fig 10 Locations of Dams in the Periyar River Basin *(Source: IDRB)*

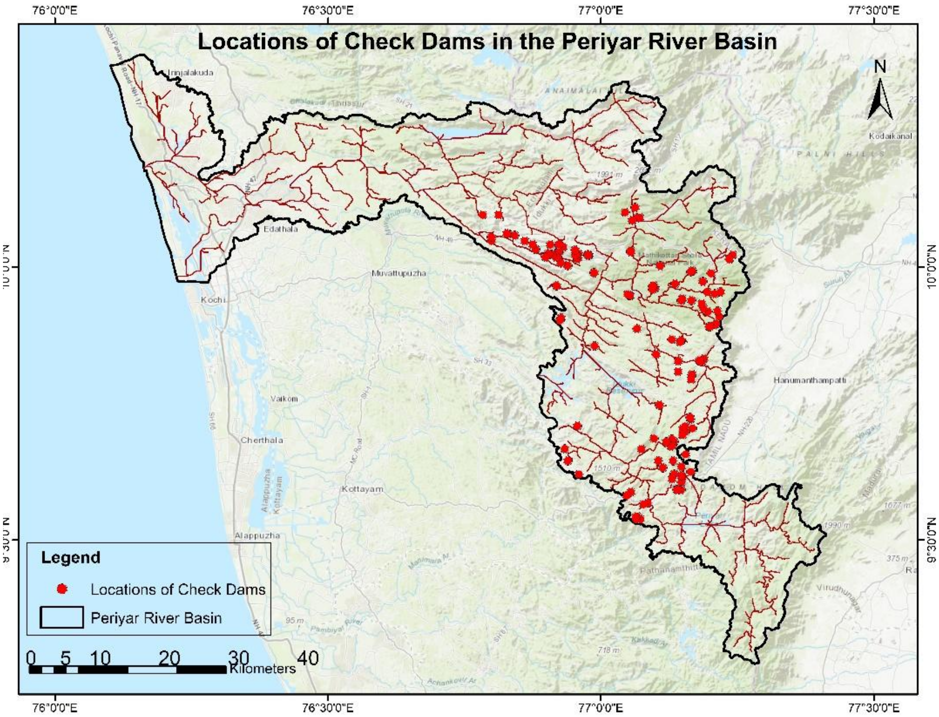

Fig 11 Locations of Check Dams in the Periyar River Basin *(Source: IDRB)*

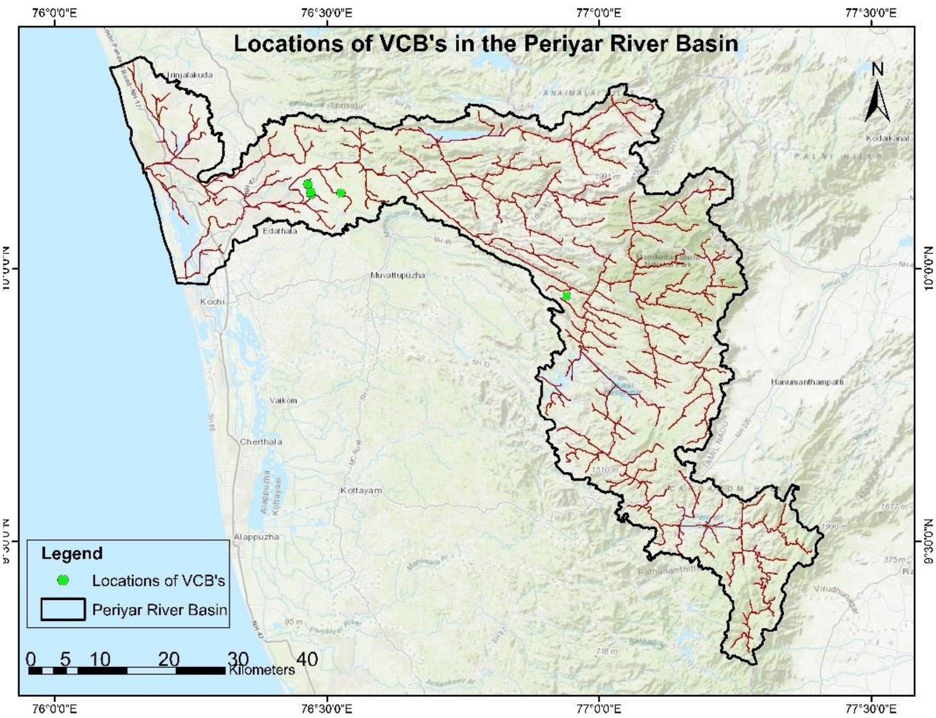

Fig 12 Locations of VCB's in the Periyar River Basin *(Source: IDRB)*

15. Agricultural Management Practices in the Periyar River Basin

Agricultural management practices in the agricultural sector are a set of unique methods aimed at improving the growth of crops and the soil health. These methods are structural and agronomic techniques which are the most effective and practical means of attaining sustainability in the primary production sector, agriculture. There are many agricultural management practices which are followed in the Periyar River Basin aimed at a more sustainable method of cultivation with enhanced soil structure, improvement in the organic matter, promotion of beneficial microorganisms, leading to healthy crops and a more resilient agricultural ecosystem. In the basin, the agricultural management practices are performed under the supervision of local agricultural institutions (Krishibhavans), controlled by the District Agricultural Directorate in each district. Proper awareness of the methodologies is provided to the local farmers to make them capable of following the necessary procedures to ensure proper health of crops and productivity during the tenure of their cultivation. Tillage and reconsolidation, no tillage and surface residues, raised bed farming, SRI in paddy cultivation, crop rotation, intercropping, irrigation supply systems, micro irrigation, manure and fertilization practices, terrace farming and pest management are some of the major agricultural management practices followed in the Periyar River Basin.

15.1. Agricultural Management Practices in Idukki district

Agricultural practices across the Idukki district of the Periyar River Basin are shaped by its rugged topography, diverse soils, and an equally diverse cropping system, resulting in a rich mosaic of land-management methods. Traditional tillage remains central to the cultivation of paddy, vegetables, tubers, and fruit crops, where loosening the soil enhances aeration, boosts infiltration, and ensures efficient mixing of fertilizers. Over time, this is naturally followed by reconsolidation, in which rain and soil texture gradually restore the land to its pre-tilled density. In the more fragile, sandy, and sloping terrains of Idukki, farmers often adopt no-tillage systems, which protect the soil from erosion, conserve moisture, and build up soil carbon levels while allowing surface residues to moderate temperature and support nutrient recycling. These no-till conditions are particularly beneficial for long-term plantation crops such as rubber, cardamom, pepper, coffee, and tea. Complementing this, raised bed farming provides improved drainage, reduced compaction, and higher planting density, making it ideal for vegetables, garlic, ginger, turmeric, and tuber crops.

Although Urea Deep Placement (UDP) has shown promise in enhancing nitrogen efficiency and reducing greenhouse-gas emissions, it has not yet been adopted within the basin. In paddy fields, the System of Rice Intensification (SRI) is practiced in select areas for demonstration, promoting wider spacing and enhanced root growth to achieve higher yields with lower seed and water requirements. To maintain soil health and break pest cycles, farmers use crop rotation extensively with paddy, vegetables, tubers, and pulses, while intercropping in coconut, cardamom, rubber, and fruit plantations maximizes land use, improves nutrient cycling, and reduces the risk of yield loss. The district's irrigation system is anchored in canals, ponds, tanks, and open wells, supplemented by the widespread use of micro-irrigation techniques such as drip systems, sprinklers, and fertigation, introduced under the national micro-irrigation programme.

Nutrient management blends traditional and modern approaches: farmers rely heavily on organic manures, including cattle manure, vermicompost, and poultry manure, alongside synthetic fertilizers applied through soil application, foliar spraying, and fertigation. In the steep highlands, terrace farming remains indispensable, carving stable benches into mountain slopes to prevent erosion and support tea and coffee plantations. To safeguard crop health, the district increasingly adopts Integrated Pest Management (IPM), which combines ecological understanding, cultural practices, biological agents, and targeted chemical use, along with pest-resistant varieties like Bt-tomato and Bt-brinjal, ensuring effective control with minimal environmental impact.

Table 28 Agricultural management practices followed in the Idukki district

(Source: Kerala agricultural statistics 2023–24)

Block Panchayat	Major Agricultural Practices
Adimali	Tillage, reconsolidation, crop rotation, terrace farming, and integrated pest management are common. Paddy, vegetables, and tuber crops dominate, with some demonstration of System Rice Intensification (SRI).
Azhutha	No-tillage farming on hilly slopes and rainfed terrains is prevalent. Rubber, cardamom, and pepper cultivation is widespread. Intercropping of cardamom and fruit trees is common.
Devikulam	Terrace farming for tea and coffee plantations is the key practice. No-tillage methods for slope stabilization and micro-irrigation systems in estates are observed.
Elamdesham	Raised bed and mixed cropping systems are practiced for vegetables, garlic, and turmeric. Manure application (cow dung, compost) and fertigation via drip systems are growing trends.
Idukki	Crop rotation and integrated pest management dominate. Paddy, pulses, and tuber crops are cultivated. SRI practices and organic manuring are promoted by local agencies.

Kattapana	Intensive vegetable and tuber crop cultivation using raised beds and fertigation. Urea deep placement is being experimented with. Terrace farming for horticultural crops is seen.
Nedumkandam	Intercropping and no-tillage methods for plantation crops like cardamom, pepper, and coffee. Rubber plantations use micro-irrigation and integrated pest management strategies.

15.2. Agricultural Management Practices in Thrissur district

Agricultural management practices in the Periyar River Basin within Thrissur District include tillage, crop rotation, soil amendment, irrigation management, pest and disease control, and integrated nutrient management. In Chalakudy Block (Kadukutty Grama Panchayat), traditional tillage is followed, and raised bed farming is practiced in suitable areas, while zero farming is uncommon. Koratty Block stands out for adopting a wide range of practices—tillage, crop rotation, irrigation, pest and disease control, and animal husbandry—covering nearly 95% of cultivated land, with zero farming practiced over 0.5 ha. In the Mala Block, Annamanada Grama Panchayat has adopted raised bed farming on 120 ha, while Mala Grama Panchayat follows crop rotation, intercropping, and tillage, with zero farming on 1.5 ha. Kodungallur Municipality practices zero farming on 0.5 ha, whereas Poyya Grama Panchayat selectively applies raised bed farming for suitable crops. In the Mathilakam Block, Kaipamangalam and Perinjanam Grama Panchayats adopt crop rotation, relay cropping, trap cropping, and multi-tier cropping to enhance productivity, while Mathilakam Grama Panchayat cultivates banana and vegetables in flood-prone areas. Eriyad Grama Panchayat follows multi-tier and integrated cropping for efficient nutrient use. Sreenarayanapuram and Edavilangu Grama Panchayats implement tillage, crop rotation, irrigation, pest and disease management, and animal husbandry, with tillage on 5 ha each; raised bed farming on 1.5 ha and 3 ha, and zero farming on 1 ha in Edavilangu. In the Irinjalakuda Block, Muriyad Grama Panchayat and Irinjalakuda Municipality practice tillage and crop rotation but not zero or raised bed farming. The Vellangallur Block, including Poomangalam, Velookkara, Vellangallur, and Puthenchira Grama Panchayats, emphasizes integrated nutrient, pest and disease management, efficient water use, livestock integration, and field-level waste management (Puthenchira) to promote sustainability. Overall, Urea Deep Placement (UDP) and System of Rice Intensification (SRI) methods are generally not practiced in the LSGIs of Thrissur District (Principal Agriculture Office, Thrissur).

15.3. Agricultural Management Practices in Ernakulam district

Agricultural management practices in the Ernakulam district within the Periyar River Basin largely focus on conventional tillage along with selective adoption of other methods. Almost all blocks consistently follow tillage as the primary practice, while no-tillage and zero farming methods are rarely adopted. Raised bed farming is followed in several locations such as Narakkal, North Paravur, Aluva, Nedumbasserry, Kalamasserry, Vyttila, Perumbavoor, Angamaly, and Keezhmadu, wherever crop and soil conditions permit. However, in many panchayats of Keezhmadu, Poothrikka, and Kothamangalam blocks, raised bed farming is either not practiced or adopted only on a limited scale.

The advanced practices of Urea Deep Placement (UDP) and the System of Rice Intensification (SRI) in paddy cultivation are not reported across the blocks of Ernakulam district. Agricultural

officers (Krishibhavans) have reported that there is no available data on agricultural management practices and their importance for the blocks of Ernakulam district (Source: Principal Agriculture Office, Ernakulam).

16. Identification of agricultural factors affecting the Periyar river and proposed corrective measures

The Periyar River, the longest river in Kerala, supports one of the most intensively cultivated regions in India. Its catchment supports cardamom plantations, paddy fields and rubber and tea estates. However, increasing agricultural intensity across the basin has resulted in nutrients being loaded, pesticide contamination and sediment flow that have damaged the ecological integrity of the river (Aditya et al., 2024). Agricultural expansion, combined with poor land management practices, exacerbates erosion and discharge, which in turn increases concentrations of nitrates and phosphates, causing eutrophication (Thomas et al., 2020). The challenge is to balance the economic importance of agriculture with the maintenance of river health.

16.1. Nutrient Loading and Fertilizer Runoff

One of the most significant agricultural effects on the Periyar River is the enrichment of nutrients by the discharge of fertilizers. In Idukki's high-range plantations, large-scale cardamom and tea cultivation requires intensive use of nitrogen and phosphate fertilisers (Gayathri et al., 2021). During the monsoon seasons, surface flow transports these nutrients to tributaries, increasing levels of nitrogen and phosphorus downstream (Rani et al., 2019). Excessive nutrient concentrations promote algae blooms that dilute dissolved oxygen and harm fish and benthic animals (Nair & Sujatha, 2022). Such eutrophication episodes have been observed especially near Mangalapuzha and Aluva, where river lines receive both agricultural and domestic waste (Krishnakumar et al., 2023). Controlled fertilizer applications and the introduction of biofertilizers can significantly reduce this nutrient load (Zhu et al., 2013).

16.2. Pesticide Contamination and Bioaccumulation

The plantation sector of the Periyar basin, particularly the cardamom farms in the Western Ghats, uses a wide range of pesticides, including organic phosphates and synthetic pyrethroids, which often enter the river through leakage and drift (Gayathri et al., 2021). Pesticide residues were found in both surface and sediment samples in the upper Periyar region, raising concerns about chronic toxicity in aquatic organisms (Menon et al., 2019). Persistent pesticides bioaccumulate in the food chain and threaten endemic fish and amphibians (Das et al., 2020). Furthermore, excessive use of pesticides can disturb the soil microbiota, which further affects nutrient cycles and long-term soil fertility. The establishment of buffer vegetation areas and the adoption of integrated pest control (IPM) strategies can reduce chemical flow into river systems (Kumar & Singh, 2018).

16.3. Soil Erosion, Sedimentation, and Land Use Change

Deforestation and terracing in the agricultural slopes of the Idukki and Munnar regions increase soil erosion, leading to high sedimentation rates in the downstream stretches (Thomas et al., 2020). Sediment inflows not only affect light penetration and primary productivity, but also cause clogging of irrigation channels and reduced water storage capacity (Prasad & Pillai, 2017). Land use mapping using satellite data shows that areas converted from forest to plantation have 2–3 times higher sediment yields (Aditya et al., 2024). Implementation of soil conservation practices such as contours bunding, mulching and agroforestry can mitigate sediment transport to the Periyar River (Zhu et al., 2013).

16.4. Wastewater from Agro-Processing Units

The agricultural processing units, including rubber sheet processing and spice washing facilities, contribute untreated organic effluents to the Periyar (Nair & Sujatha, 2022). These effluents increase the biochemical oxygen demand (BOD) and further stress aquatic life. Many of these units are located along tributaries such as the Mullayar and Periyar Valley irrigation projects, where direct discharges are common (Krishnakumar et al., 2023). The modernization of wastewater treatment facilities and the implementation of strict wastewater discharge standards can significantly reduce organic loads (The Hindu Bureau, 2024).

16.5. Irrigation Return Flows, Waterlogging, and Interaction with Industrial Pollution

Although agricultural output flows are less documented than industrial emissions, recent hydrochemical surveys in the Aluva-Kochi/Eloor industrial area show elevated levels of sodium, chloride and bicarbonate in surface and groundwater, making water in some places unsuitable for irrigation due to sodium risks (Eloor Industrial Region Study, 2025). These elevated salt ions can come partly from agriculture (fertilizers, soil salts, irrigation returns), but also from industrial and domestic sources, complicating the allocation. Mass fish deaths have been linked to low dissolved oxygen (DO), high ammonia and high sulphide levels in parts of Periyar (Edayar-Eloor, etc.), which can be caused by accumulation of organic matter, stagnation and return flows loaded with organic waste (Periyar fish kill: KUFOS, 2024). Agricultural organic waste (meat, crop residues, washing water) probably contributes to this load.

16.6. Proposed Corrective Measures

The Periyar River is increasingly affected by agricultural flow, pesticide residues, nutrient loads, and inappropriate waste management, which together threaten water quality, aquatic biodiversity and human livelihoods. To address these challenges, comprehensive correction measures must be taken that integrate sustainable agricultural practices, soil and water conservation, improved drainage, pollution control and institutional governance. The proposed interventions focus on reducing nutrients and pesticide inputs, minimizing soil erosion, treating organic and agricultural waste, and strengthening monitoring and enforcement mechanisms. Through technological, ecological and policy-based approaches, these measures are aimed at restoring the ecological health of the Periyar River, while supporting the sustainable livelihoods of communities dependent on its resources.

16.7. Nutrient Management & Fertilizer Control

To improve soil health and reduce nutrient pollution, it is essential to promote soil nutrient diagnosis through mobile testing laboratories and extension services, especially in planting areas and mixed farms. These initiatives can help estimate the nutrient requirements of crops and avoid high use of fertilizers, which often leads to nutrient imbalances and environmental pollution. The Kerala Agriculture University (KAU) provides guidelines for the application of balanced fertilizers based on soil test results, emphasizing the importance of specific nutrient management for the location to optimize crop yields and minimize environmental impact.

The adoption of split fertilization, where smaller doses of fertilizer are applied in accordance with the stages of crop growth, can prevent nutrient losses due to leakage and volatilization. Applications for fertilizers at a particular time to avoid periods just before heavy rains can further reduce the risk of nutrient spills into water sources. The use of slow-release fertilizers or controlled-release formulations can also minimize nutrient losses and improve the efficiency of fertilizer use. Research has shown that slow-release nitrogen fertilizers can improve crop growth, yield and nitrogen use efficiency, while reducing nitrogen losses under various environmental conditions.

Monitoring the results of these practices is crucial. Measurement of downstream nitrate and phosphorus levels at the end of the monsoon season can help assess the release of nutrients into water bodies.

Evaluating the crop yield per unit of applied fertilizer (fertilizer use efficiency) provides information on the effectiveness of nutrient management practices. In addition, the monitoring of the frequency of algae blooms or dissolved oxygen downs in small tributaries can serve as indicators of nutrient enrichment and degradation of water quality.

16.8. Pesticide Management, Reduction & Substitution

It is vital to implement regulations prohibiting the use of toxic or prohibited pesticides for the protection of human health and the environment. The Government of Kerala has identified and banned several highly dangerous pesticides, including Aldicarb, Aldrin and Benzene Hexachloride, in accordance with national guidelines. Strengthening border and supply chain checks can help reduce the smuggling and sale of inappropriately labelled pesticides and ensure that only approved and safe products enter the market.

Training in integrated pest management (IPM) is essential to sustainable agriculture. IPM includes the use of a combination of biological, cultural, mechanical and chemical tools to manage parasitic populations in an environmentally and economically sustainable manner. In the Idukki cardamom belt, pilot programmes focused on IPM can help farmers reduce dependence on chemical pesticides and adopt safer alternatives. These programmes have been organized by various agencies, including the DPP GIZ-AVT McCormick project, which has conducted training sessions on sustainable cardamom cultivation practices.

The establishment of pesticide residue monitoring protocols is necessary to ensure food safety and environmental protection. Regular sampling of small streams, plantation drainage, soil and market products, especially spices and leafy vegetables, can help to detect pesticide residues. The Kerala Agriculture University conducts pesticide residue analysis of vegetables, fruits and food products, providing valuable data to guide consumers and farmers to ensure safe food.

16.9. Soil Conservation, Erosion Control, and Land Cover Management

Implementation of soil and water conservation measures is essential to prevent soil erosion and maintain soil fertility. The Department of Soil Survey and Soil Conservation in Kerala has implemented various soil and water conservation measures on arable land, such as soil bunds, stone-cut contour bunds, vegetative fences, contour or stubby caves and moisture conservation pits. These measures intercept rainfall where it falls and reduce the likelihood that discharge water is obtained at erosive speeds in arable land.

The use of remote sensing and Geographic Information System (GIS) technologies can help map erosion-prone sub-catchments and focus interventions accordingly. Studies have shown the effectiveness of GIS-based approaches to assess soil erosion risk and guide conservation efforts in Kerala's mountainous regions.

16.10. Improved Drainage, Return Flows, and Water Flow Management

Modernisation of drainage infrastructure in agricultural areas is essential to prevent water logging and promote healthy crop growth. The management of irrigation return flows to ensure that they pass through treatment systems, such as ponds or constructed wetlands, before entering the rivers can reduce the risk of water pollution. Maintaining a light flow during dry periods and regulating the sudden release or unblocking of buffers and regulators can prevent sudden floods that reduce dissolved oxygen levels downstream.

Monitoring salinity, sodium absorption ratio (SAR) and electrical conductivity (EC) is important to detect salt accumulation in soil and water used for irrigation. These parameters may indicate the need for potential soil degradation and corrective measures.

16.11. Treatment of Organic and Market/Farm Processing Waste

The construction of low-cost wetlands or biofilters near producers and markets can effectively treat wash water, effluents and reduce the risk of water pollution. Proper management of fertilizers through composting or other methods can prevent excessive nutrient loads in water bodies. The application of setbacks for processing units from waterways and the protection of adequate containment and regular inspections can further mitigate pollution risks.

16.12. Institutional, Monitoring and Governance Measures

The establishment of a Periyar Protection Authority, as recommended by the High Court of Kerala, can provide a coordinated approach to managing agriculture, industrial and municipal pollution in the Periyar Basin. This authority can monitor the implementation of pollution control measures, enforce regulations and coordinate efforts between various stakeholders.

Expanding the water quality monitoring network to include agricultural harvests, small streams, tributaries and up/down plantation areas is essential for a comprehensive assessment of water quality. Monitoring parameters such as nutrients (nitrogen and phosphorus), pesticides, dissolved oxygen, ammonia, biochemical oxygen demand (BOD) and turbidity can provide valuable information for decision-making. Using sensors and high-frequency sampling, particularly during monsoon events, can improve the effectiveness of monitoring programmes.

Providing farmers with incentives such as subsidies, certification programs for pesticide-free or low-residue produce, improved market access, or payments for ecosystem services (PES) for planting buffer strips or reducing chemical inputs can encourage the adoption of sustainable agricultural practices. Such incentives help align farmer’s economic interests with environmental protection goals.

17. Suitable locations for forestation, orchards and organic farming in the Periyar River Basin

17.1. Suitable locations for forestation

Kerala has a total forest area of 11,524.91 km², with an additional 1,562.04 km² of plantations and 135.81 km² of ecologically fragile land. The forest and tree cover together span 24,073 km² (FSI, 2021), highlighting the state's rich forest resources and significant conservation efforts (Kerala Forest Statistics, 2021).

The Periyar River flows through significant forested regions in its upper course, particularly near the Idukki Reservoir and surrounding catchments. Both banks in several stretches are under forest or plantation cover, with notable areas managed by forest departments and KSEB. However, as the river flows downstream, forest cover gradually decreases, and the lower reaches of the river, especially from Bhoothathankettu to Munambam, show minimal to no forest presence along its banks (Room for River).

17.2. Forest cover in the Periyar River Basin

The Periyar River Basin in Idukki district is one of the most ecologically diverse and ecologically vital regions in the Western Ghats. According to the Forest Cover Map of the Periyar River Basin - Idukki District (Fig 13), the landscape is predominantly covered with moderately dense to very dense forests, especially in the central and southern parts of the Basin. These high canopy regions correspond to areas around Thekkady, Vandiperiyar, Mullapperiyar and Periyar Tiger Reserve, where the canopy density exceeds 70%. Moving outside these protected areas, the forest transitions into moderately dense (40–70%) and open forest (10–40%) areas, mainly along the mid- and low-altitude regions near Adimali, Kattappana and Nedumkandam. The vegetation and degraded areas (10% canopy density) are largely located on eastern dry slopes and near settlements, indicating areas affected by land conversion, soil erosion and human invasion. Figure 14 illustrates the forest cover distribution within the Idukki segment of the Periyar River Basin, highlighting the spatial extent of dense, moderately dense, and open forest classes. The map reflects the strong dominance of montane and mid-elevation forest systems in the upper catchment, which play a critical role in regulating hydrological processes, stabilizing slopes, and maintaining catchment-scale ecological integrity.

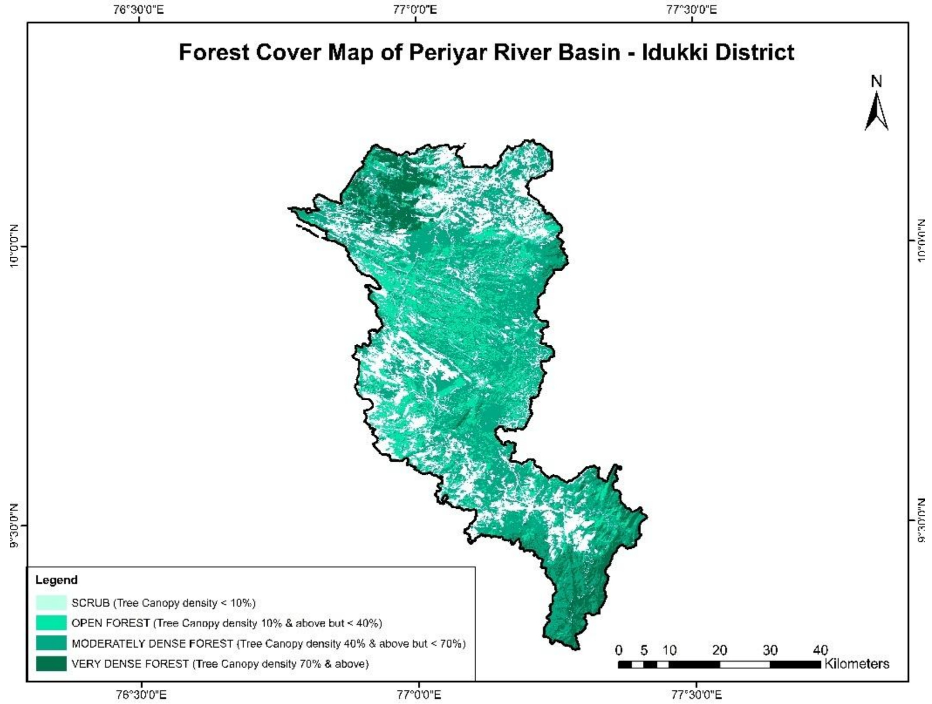

Fig 13 Forest Cover Map of the Periyar River Basin - Idukki District

The forests of the Periyar Basin form part of the moist deciduous, semi-evergreen, and evergreen forest complexes of the southern western Ghats, which form a mosaic of tropical ecosystems (Pascal, 1988; Champion & Seth, 1968). The very dense forest areas on the map correspond to tropical and semi-evergreen forests characterized by high precipitation, complex canopy stratification, and evergreen flora. Moderately dense forests usually consist of dry deciduous vegetation, which passes between green and open forest areas. These forests play a crucial role in maintaining watershed stability and serve as major watersheds for numerous tributaries feeding the Periyar River. They are essential for the recharge of groundwater, carbon sequestration and biodiversity protection and contain several endemic species of plants and animals unique to the western Ghats (Chandran et al., 2010).

Recent studies using satellite data and GIS techniques show that the Idukki region retains one of the highest canopy density percentages in Kerala (FSI, 2021; Jha et al., 2022). However, there is a gradual decline in moderately dense forest areas, particularly in areas adjacent to settlements and agricultural lands. The main drivers of this change are the expansion of cardamom, tea and rubber plantations, as well as the development of infrastructure, including road networks and hydroelectric projects (Prasannakumar et al., 2014). Despite these pressures, the southern and central parts of the basin, including Periyar Tiger Reserve and Idukki Wildlife Sanctuary, remain ecologically stable, as Rajendran et al. (2018) reported. In contrast, the northern and eastern slopes near Adimali and Munnar have experienced increased fragmentation and conversion of forests into plantation lands.

Protected areas within the basin, including the Periyar Tiger Reserve, the Idukki Wildlife Sanctuary and parts of the Eravikulam National Park, act as vital ecological corridors that maintain the continuity of forest cover in the basin. These forests provide not only hydrological benefits but also serve as climatic buffers and biodiversity reservoirs. The Kerala Forest Department (2022) has implemented participatory management programmes through Vana Samrakshana Samithis (VSS) to address deforestation and promote community-based conservation, particularly in open and wild forest areas. These initiatives focus on ecological restoration, soil conservation and reforestation, focusing on areas at risk of degradation.

According to Dudley & Phillips (2006), a forest is land above 0.5 ha with more than 10% tree crown cover and trees capable of reaching 5 m height. Identifying existing forest cover is essential for planning forestation, agroforestry, and sustainable land use. In Ernakulam District, Kothamangalam (626 km²), Chalakkudy (527.35 km²), and Angamaly (200 km²) are forest-rich and should be conserved, whereas blocks with very low or no forest cover—Koovappady, Edappally, Alangad, Vazhakulam, Parakadavu, Irinjalakuda, Mala, Mathilakam, and Vellangallur—are most suitable for future forestation (Aquifer Mapping and Management Plan for Hard Rock Terrains, Ernakulam District, 2018–19; Thrissur District, 2019–20). Fig. 14 shows Block-wise map of forest cover in the Periyar River Basin - Ernakulam and Thrissur District.

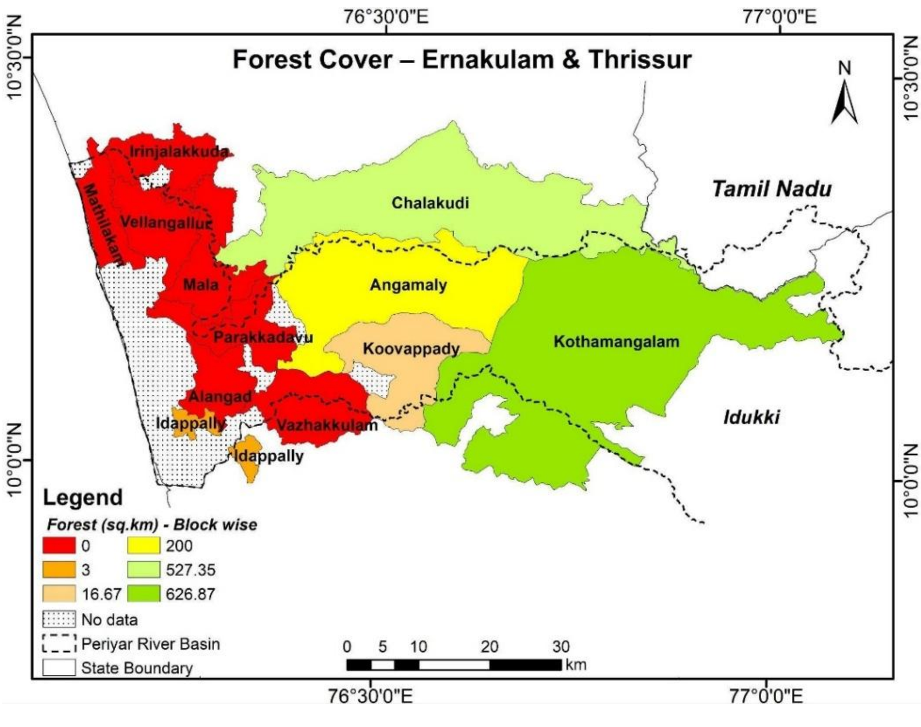

Fig. 14 Block-wise map of forest cover in the Periyar River Basin - Ernakulam and Thrissur District

In Ernakulam district, the scope for forestation development is limited, with most block panchayats reporting no suitable areas. However, a few blocks show potential. In Nedumbassery block, Chengamanadu and Nedumbassery panchayats are identified as suitable for forestation. In Kalamasserry block, Mulavukad offers scope for forestation. Angamaly block has selective potential, with Manjapra, Malayattoor-Neeleswaram, and Kanjoor suitable for forestation (Principal Agriculture Office, Ernakulam).

17.3. Orchards

An orchard is a space for cultivating trees or shrubs for food production, with strategic planning and maintenance influencing productivity. It contributes to biodiversity, soil conservation, water purification, and habitats for species. Orchards support fruit production, job creation, and community engagement. FAO (2005) classifies orchards under land under permanent crops, which include long-term crops and flowers.

In the Idukki district, the potential for the development of orchards is considerably high due to the favourable climate, altitude, and soil diversity. The moist tropical highlands of the region support fruit crops such as bananas, mangoes, guava, citrus, and jackfruit (DADFW, 2023). Among the seven block panchayats, Devikulam, Kattapana, and Nedumkandam show high adaptability due to well-drained soils and moderate slopes, making them ideal for bananas, citrus and passion fruit orchards (Kerala State Planning Board, 2023). Adimali and Elamdesham blocks are moderately suitable, especially for mangoes, guavas, and jackfruits, and have a scope for integrated fruit and vegetable systems (Kerala Agricultural University [KAU], 2022). In Azhutha, there are selective orchard areas in Vandiperiyar and adjacent areas suitable for avocado and citrus (Central Institute for Temperate Horticulture [CITH], 2020). The Idukki block has moderate potential in lower-slope Grama panchayats such as Vazhathope and Arakkulam, favouring mixed systems based on jackfruit and papaya (Principal Agriculture Office, Idukki, 2023). Overall, the expansion of the orchards in Idukki must balance productivity with soil and slope protection in the fragile landscape of the Western Ghats (Kumar et al., 2018; Rajendran et al., 2018).

In Ernakulam district, the scope for orchard development is limited, with most block panchayats reporting no suitable areas. However, a few blocks show potential. Karukutty, Mookkannoor, and Angamaly Municipality are suitable for orchards. Keezhmadu block indicates orchard suitability in Vazhakkulam. In Kothamangalam block, several panchayats such as Pindimana, Keerampara, Kottappady, Kavalangad, and Kuttampuzha are found suitable for orchard development (Principal Agriculture Office, Ernakulam).

17.4. Organic Farming

Organic farming is a sustainable, eco-friendly system that relies on natural resources and biological processes instead of synthetic inputs. It maintains soil health, biodiversity, and ecological balance through practices like composting, using farmyard manure, vermicompost, and natural formulations such as Panchgavya and EM. Rooted in the principles of health, ecology, fairness, and care, it promotes recycling of farm biomass and living soils. As an agroecological approach, it focuses on environmental protection, resource efficiency, animal welfare, food quality, and social justice ((Lampkin, Schwarz, & Bellon, 2020); National Centre for Organic and Natural Farming, 2025).

Kerala aims to become an organic state by converting at least 10% of cultivable land annually, achieving full conversion within five to ten years (Kerala State Organic Farming Policy, Strategy and Action Plan, 2009). The government promotes organic farming through the "Jaiva Keralam" movement, awareness programs, workshops, publications, and district-level Organic Melas. Traditional systems like Pokkali, Kaipad, and homestead farming, along with models such as Adat and Marappanmoola, showcase integrated organic practices. Organic farming extends beyond crops to animal husbandry, dairy, poultry, fisheries, forestry, and biodiversity conservation. Rising consumer demand for pesticide-free food has encouraged government support via women's self-help groups, organic markets, and private entrepreneurship. Policies from 2007 onwards emphasize sustainability, eco-friendliness, and large-scale adoption (Prabhu, 2021).

In Ernakulam, only a small portion of farmers rely on organic farming as their main livelihood, mostly using homestead manures like cow dung, poultry manure, and green manure. Production is insufficient for export. Traditional systems such as Pokkali cultivation have declined after the 2018 floods. In Thrissur, small-scale organic cultivation of vegetables and tubers is common, mainly for self-consumption, though some farmers mix organic and chemical methods due to contamination and pest challenges, which reduce yields. Government support through awareness programs, timely supply of quality seeds, manures, biopesticides, marketing outlets, and subsidies is essential to sustain and expand organic farming. In Idukki, nationally recognized farmers promote sustainable organic agriculture, with Udumbanchola taluk successfully cultivating cardamom using organic methods and buffer zones. The Peerumedu Development Society supports farmers by buying organic spices at premium prices and providing free inputs through soil and crop testing. Black pepper and coffee are also grown organically in Mankulam, though cardamom still relies on chemical fertilizers, risking contamination. Strengthening organic farming requires affordable bio-inputs, training and awareness programs, simplified certification, subsidies, and specialized marketing systems (Department of Agriculture Development and Farmers' Welfare, 2022).

18. Summary

The Periyar Agriculture Profiling Report (2025) offers a comprehensive analysis of agricultural dynamics across the varied landscapes of the Periyar River Basin. It delineates the basin's agricultural identity, ranging from high-range plantation systems to midland and lowland mixed farming, and examines how ecological factors, traditional practices, irrigation methods, and land-use patterns collectively influence agricultural outcomes. Through an assessment of cropping patterns, agro-ecological zones, irrigation sources, groundwater dynamics, farming techniques, and input utilization, the report provides an integrated perspective on the interaction between agriculture, natural resources, and socio-economic systems within the basin.

The report evaluates the sustainability of prevailing agricultural practices, emphasizing areas where environmental pressures are intensifying, including nutrient runoff, soil erosion, and groundwater depletion. It identifies strategies to mitigate agricultural impacts on the river system and strengthen long-term resilience, such as advancements in water management, soil conservation, and integrated farming systems. Additionally, the report documents current management frameworks and technological interventions, and highlights opportunities for future enhancement through sustainable agriculture, afforestation, and ecological restoration.

Overall, the report provides a clear narrative of how agriculture interacts with the Periyar River Basin, both supporting livelihoods and exerting pressures that require thoughtful and coordinated management. It brings together insights from agricultural, ecological, hydrological, and socio-economic perspectives into a single framework, enabling a deeper understanding of the basin as an interconnected system.

Role of Agriculture Profiling Report – Periyar in Supporting Stakeholders

This report is important because it serves as a foundational resource for managing the Periyar River Basin in a sustainable and integrated manner. It brings clarity to how agricultural practices influence the basin's ecological balance, water resources, and long-term productivity. By synthesizing diverse information into a coherent framework, the report equips policymakers, administrators, and technical institutions with the knowledge required to design interventions that protect the river while supporting agricultural livelihoods.

The report identifies pathways for farmers to adopt more sustainable and climate-resilient agricultural practices, providing insights into systems that improve productivity while minimizing environmental impact. For planners and conservation agencies, it serves as a guide for prioritizing investments in soil health, irrigation efficiency, and watershed protection. Furthermore, the report enhances public understanding of the interdependence between agriculture and river health, fostering increased community engagement in sustainable land and water management.

Ultimately, the report contributes to the development of a shared vision for the Periyar River Basin that balances economic growth with ecological stewardship. As a baseline reference for future research, planning, and policy development, it plays a critical role in shaping a more resilient and environmentally responsible agricultural landscape in the region.

References

1. Aditya, B. et al. (2023). Hydrochemical seasonal variation in the Periyar Basin. Indian Hydrological Journal.
2. Aditya, S. K., Krishnakumar, A., & AnoopKrishnan, et al. (2024). *Analysis of seasonal spatio-temporal variations in river water quality and its influencing factors in the Periyar River Basin, Southern Western Ghats, India*. *Journal of Water and Climate Change, 15*(9), 4434-4456. https://doi.org/10.2166/wcc.2024.136
3. Arun, G. et al. (2024). Hydro-geochemical characteristics of the Periyar river in the Eloor belt. Journal of Environmental Hydrology.
4. Arun, L. (2022). Livelihood security of dairy farmers affected by Kerala flood 2018. Department of Veterinary and Animal Husbandry Extension, College of Veterinary and Animal Sciences, Mannuthy, Thrissur, Kerala, India.
5. Arun, T. J., Krishna R. P., Aneesh T. D., Limisha A. T., Sreeraj M. K., & Reji S. (2019). Studies on the textural characteristics of sediments from Periyar River Basin, Kerala, Southern India. International Journal of Applied Environmental Sciences, 14(5), 495–526.
6. Arun, V., Vishnu Maya, T. M., Antony, S., Dev, V. V., Gayathri, S., Krishnakumar, A., & Anoop Krishnan, K. (2023). Assessment of hydro-geochemical indices of Periyar river in Eloor Industrial Belt (Kerala), India to identify potential environmental impacts. NCESS Annual Report 2023-24.
7. Ashraf P M., & Mukundan M K (2007, April). Seasonal variations in water quality of four stations in the Periyar river basins. Journal of Environmental Science and Engineering, 49(2), 127–132.
8. Bharathkumar, L., & Mohammed-Aslam, M. A. (2015). Crop pattern mapping of Tumkur Taluk using NDVI technique: A remote sensing and GIS approach.
9. Bhumipublishing. (2021). Soil Geochemistry of Periyar River Basin. Retrieved from the publisher's repository.
10. Birthal, P. S., & Negi, D. S. (2012). Livestock for higher, sustainable and inclusive agricultural growth. Economic & Political Weekly, 47(26–27), 89–99.
11. Central Ground Water Board. (2019). Aquifer mapping and management plan for hard rock terrains of Ernakulam District, Kerala (AAP: 2018–19). Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India.
12. Central Institute for Temperate Horticulture (CITH). (2020). Potential horticultural zones and fruit crop suitability mapping for Kerala hill regions. ICAR, Government of India.
13. Centre for Development Studies (CDS). (2009). Status Report on Periyar River. Retrieved from the CDS institutional repository.

14. Centre for Earth Science Studies (CESS). (2006-2007). Monitoring of water and sediment quality in the Cochin Harbour region. CESS Annual Report 2006-2007, 34.
15. Centre for Earth Science Studies (CESS). (2007-2008). Monitoring of water quality characteristics in the Kochi region. CESS Annual Report 2007-2008, 23–24.
16. Centre for Earth Science Studies (CESS). (2008-2009). Interstitial water chemistry of aquatic environments and its significance in nutrient dynamics: A case study. CESS Annual Report 2008-2009, 24.
17. Centre for Earth Science Studies (CESS). (2011-2012). Water and sediment quality monitoring and assessment of estuaries of Kerala: A case study from Kochi estuary and Periyar River. In CESS Annual Report 2011-2012 (pp. 23–24). CESS, Akkulam, Thiruvananthapuram.
18. Champion, H. G., & Seth, S. K. (1968). A revised survey of the forest types of India. Government of India Press.
19. Chandran, M. D. S., Ramachandran, V. S., & Sukumaran, S. (2010). Vegetation and landscape ecological studies in the Periyar Tiger Reserve, Kerala. Journal of the Bombay Natural History Society, 107(2), 108–121.
20. CPCB. 1995. Water quality status and statistics-Indicators of organic pollution-Medium and minor rivers
21. CPCB. 2000. Water quality status and statistics-Indicators of organic pollution-Medium and minor rivers
22. CWRDM (2015). Sediment Yield and Trapping Efficiency in the Idukki Reservoir.
23. Das, P., Radhakrishnan, K., & Mohan, M. (2020). *Ecotoxicological assessment of pesticide exposure in aquatic biota of South Indian rivers*. *Environmental Monitoring and Assessment, 192*(6), 398. https://doi.org/10.1007/s10661-020-08321-7
24. Department of Agriculture Development and Farmers Welfare (DADFW). (2023). District agricultural profile 2022–23: Idukki district. Government of Kerala.
25. Department of Agriculture Development and Farmers' Welfare. (2018). Soil based plant nutrient management plan for Ernakulam District (DNP Series 7). Government of Kerala. https://www.keralasoilfertility.net/en/nutrient_management_plan.jsp
26. Department of Agriculture Development and Farmers’ Welfare. (2022). Survey on organic farming and marketing in Kerala: 2021–22. Government of Kerala.
27. Department of Agriculture, Cooperation & Farmers Welfare. (2017). Pradhan Mantri Krishi Sinchayee Yojana: District Irrigation Plan – Ernakulam. Government of India.
28. Department of Animal Husbandry, Government of Kerala. (2012). Livestock population statistics (2003–2012). Thiruvananthapuram: Department of Animal Husbandry. Retrieved from https://livestock.kerala.gov.in

29. Devassi, V P, P M A. Bhattathiri. 1974. Phytoplankton ecology of Cochin backwater. Ind. J. Mar. Sci. 3:46-50
30. Down to Earth. (2016). Polluted Periyar River needs to be restored on priority: CPCB report.
31. Dudley, N., & Phillips, A. (2006). Forests and protected areas: Guidance on the use of the IUCN protected area management categories (A. Phillips, Ed.; Best Practice Protected Area Guidelines Series No. 12). IUCN – The World Conservation Union.\
32. Food and Agriculture Organization of the United Nations. (2005). A system of integrated agricultural censuses and surveys: Volume 1. World Programme for the Census of Agriculture 2010 (FAO Statistical Development Series). Rome: Author. https://www.fao.org/3/a0135e/a0135e.pdf
33. Forest Survey of India (FSI). (2021). India State of Forest Report 2021. Ministry of Environment, Forest and Climate Change, Government of India.
34. Forest Survey of India. (2015). India State of Forest Report 2015. Ministry of Environment & Forests, Government of India. https://fsi.nic.in
35. Ganga Knowledge Portal. (2023). Evaluating the Impacts of River Pollution on Ecosystem Services: A Case of Periyar River, Kerala. Retrieved from the portal's repository.
36. Gayathri, S., Dev, V. V., Raj, R. S., Krishnakumar, A., Maya, T. M. V., & Krishnan, T. K. (2021). *Spatiotemporal evaluation of hydrochemical facies and pesticide residues in the cardamom plantations of Southern Western Ghats, India. Environmental Nanotechnology, Monitoring and Management, 16*, 100599. https://doi.org/10.1016/j.enmm.2021.100599
37. Government of India. (2019). 20th Livestock Census of India – 2019. Ministry of Fisheries, Animal Husbandry and Dairying. Press Information Bureau. Retrieved from https://pib.gov.in/PressReleasePage.aspx?PRID=1813802
38. Hamidov, A., Helming, K., & Balla, D. (2016). Impact of agricultural land use in Central Asia: A review. Agronomy for Sustainable Development, 36(1), Article 6.
39. Harikumar, P. S., Nasir, U. P., & Rahman, M. P. M. (2009). Distribution of heavy metals in the core sediments of a tropical wetland system. International Journal of Environmental Research, 3(4), 627–640. https://doi.org/10.1007/s13593-015-0337-7
40. India Environment Portal. (2012). Periyar River Pollution. Retrieved from the portal's repository.
41. International Journal of Engineering Research & Technology. (2021). Impact of Sand Mining on Periyar Basin.
42. Irrigation Department, Government of Kerala. (2022). Periyar River Basin. Retrieved from the government department's official document repository.
43. IWA Publishing. (2024). Hydraulic modeling of the Periyar River using HEC-RAS: unraveling flow dynamics. Water Science & Technology, 89(10), 2676-2688.

44. Jayapalan, A P., K M. Sasidharan. And V A. Nair. 1976. Some aspects of the physico chemical and biological variations in Periyar water due to the effluent discharge from FACT. Bull. Dept. Fish. Kerala.1:47-59
45. Jha, C. S., Behera, M. D., & Roy, P. S. (2022). Forest cover and vegetation dynamics in the Western Ghats: An analysis using remote sensing and GIS. Environmental Monitoring and Assessment, 194(8), 1–18.
46. Jose J., Raj R V., Krishnakumar A & anoop Krishnan K (2019, September). Assessment of surface and ground water quality in Periyar river basin with special reference to its upper catchments, southern Western Ghats. Paper presented at the International Conference on Water Resources: Innovation in Quality and Quantity, Sustainable Development Challenges and Management, Thiruvananthapuram, India
47. Joseph, A. et al. (2007). Influence of vegetable farming on water quality in Periyar catchments. Kerala Agricultural University Report.
48. Joseph, K J., P. N. K. Nambeesan., C. S. Shynamma. and P.T. Lekshmanan.1984. Studies on phytoplankton in polluted waters. Journal of Marine Biological Association of India.26:42-46
49. Joseph, M. L. Status report on Periyar River: The declining trend of biodiversity and fish production in consequence of pollution in the lower reaches of Periyar River. Kerala Research Programme on Local Level Development (KRPLLD).
50. Joy, C M.1989. Growth response of phytoplankton exposed to industrial effluents in river Periyar. PhD Thesis. Cochin University.
51. Kadlec, R. H., & Wallace, S. D. (2008). Treatment Wetlands. CRC Press.
52. Kerala Agricultural University (KAU). (2022). Agro-climatic characterization and crop suitability mapping for the high ranges of Kerala. Directorate of Research, Vellanikkara.
53. Kerala Forest Department. (2022). Forest management and participatory conservation in Kerala. Government of Kerala.
54. Kerala State Planning Board. (2023). Economic Review 2023: Agriculture and allied sectors. Government of Kerala.
55. Krishnakumar, A., Das, R., Aditya, S. K., Anoop Krishnan, K., Gayathri, S., Dev, V. V., Raj, S. R., & Vishnu Maya, T. M. (2022). Geochemical analysis of soils and sediments in Western Ghats. NCESS Annual Report 2021–22.
56. Krishnakumar, A., Jose, J., Kaliraj, S., Aditya, S. K., & Anoop Krishnan, K. (2022). Impact of flood on groundwater hydrochemistry in the Periyar River Basin (PRB), Kerala, India. In NCESS Annual Report 2021–22. National Centre for Earth Science Studies.

57. Krishnakumar, A., Thomas, S., & Nair, A. (2023). *Water quality deterioration and ecosystem responses in the Lower Periyar River stretch, Kerala, India*. *Hydrology Research, 54*(7), 1231-1248.
58. Krishnan, R. J. (2012). Nutrient (N & P) enrichment coupled with phytoplankton dynamics of Mullaperiyar Reservoir in the Western Ghats of Kerala. Biosciences Biotechnology Research Asia, 9(1), 379–385.
59. KSPCB (2018). Water Quality Monitoring Report of Kerala Rivers.
60. KSPCB. 1981. Periyar action plan- phase1, status survey and project identification
61. Kumar, P., Sreelakshmi, B., & Thomas, A. R. (2017). GIS-based modeling for pollution hotspots in Periyar River. International Journal of Geographic Information Science, 12(3), 201–214.
62. Kumar, S., Thomas, J., & Joseph, A. (2018). Forest fragmentation and land use transitions in the Idukki highlands of Kerala. Journal of Tropical Ecology, 34(4), 217–231.
63. Kumar, V., & Singh, J. (2018). *Integrated nutrient and pest management in tropical agroecosystems: A sustainable approach*. *Sustainability, 10*(7), 2453.
64. Lakshmanan, P T., C S. Shynamma., A N. Balchand. And P N K. Nambeesan. 1987. Distribution and variability of nutrients in Cochin backwaters, south west coast of India. Ind. J. Mar.Sci.16:99-102
65. Lampkin, N., Schwarz, G., & Bellon, S. (2020). Policies for agroecology in Europe, building on experiences in France, Germany and the United Kingdom. Journal of Sustainable Organic Agriculture Systems (Landbauforschung), 70(2), 103–112. https://doi.org/10.3220/LBF1611684471000
66. Liu, L., Xiao, X., Qin, Y., Wang, J., Xu, X., Hu, Y., & Qiao, Z. (2020). Mapping cropping intensity in China using time series Landsat and Sentinel-2 images and Google Earth Engine. Guangdong Province Key Laboratory for Land Use and Consolidation, South China Agricultural University; University of Oklahoma; Chinese Academy of Sciences; Tianjin University
67. Lowrance, R., et al. (1984). Riparian forests as nutrient filters in agricultural watersheds. BioScience, 34(6), 374–377.
68. Maya K K., Babu K N., Padmalal D., & Seralathan P (2007). Hydrochemistry and dissolved nutrient flux of two small catchment rivers, south-western India. Chemistry and Ecology, 23(1), 13-27. https://doi.org/10.1080/02757540601084029
69. Menon, N. R. et al. (2010). Cyanobacterial blooms in Vembanad Lake. Indian Journal of Environmental Protection, 30(2), 135–139.

70. Menon, R., Joseph, A., & Mathew, M. (2019). *Pesticide residue analysis and health risk assessment in Kerala River systems*. *Environmental Pollution, 252*, 678-689.
71. Nair, K. K. C., & Soman, K. (2012). Land Use and Soil Erosion in the Western Ghats. Kerala Science Congress Proceedings.
72. Nair, R., & Sujatha, K. (2022). *Assessing organic pollution from agricultural and industrial sources in the Periyar River*. *Indian Journal of Environmental Protection, 42*(5), 471-480.
73. Narayana, D., & Ramachandran, K. (2010). Rainfall erosivity and soil conservation priorities. Indian Journal of Soil and Water Conservation, 38(1), 32–38.
74. National Green Tribunal. (2025). Report filed by the Chief Environmental Engineer for and on behalf of the Kerala State Pollution Control Board. Order in OA 287 of 2024.
75. NEERI, 1992. Water quality in Periyar river basin. Report NEERI, 1992. Water quality in Periyar river basin. Report
76. Padmalal, D., & Maya, K. (2005). Sand Mining: Environmental Impacts and Selected Case Studies. KSCSTE, Kerala.
77. Pan, L., Xia, H., Yang, J., Niu, W., Wang, R., Song, H., & Qin, Y. (2021). Mapping cropping intensity in Huaihe basin using phenology algorithm, all Sentinel-2 and Landsat images in Google Earth Engine. International Journal of Applied Earth Observation and Geoinformation, 102, 102376.
78. Pascal, J. P. (1988). Wet evergreen forests of the Western Ghats of India: Ecology, structure, floristic composition and succession. Institut Français de Pondichéry.
79. Paul, A.C. and K.C. Pillai.1976. Studies on pollution aspects of Periyar river. Project Report. Pradhan Mantri Krishi Sinchayee Yojana. (2017). District irrigation plan – Thrissur. Government of India.
80. Pimentel, D., et al. (1995). Environmental and economic costs of soil erosion. Science, 267(5201), 1117–1123.
81. Prabhu, B. (2021). Organic farming in Kerala. International Journal of Creative Research Thoughts (IJCRT). S.N. College, Nattika, Thrissur, India.
82. Prasad, B., & Pillai, P. (2017). *Erosion and sedimentation impacts on river health in Kerala's highland catchments*. *Geographical Review of India, 79*(3), 242-258.
83. Prasannakumar, V., Vijith, H., & Abinod, S. (2014). Forest degradation and landscape change in the Periyar basin, Kerala: An integrated remote sensing and GIS analysis. Environmental Earth Sciences, 72(1), 161–175.
84. Principal Agricultural Office, Ernakulam (2025) Principal Agricultural Officer, Thrissur (2025)
85. Principal Agriculture Office, Idukki. (2023). Annual agricultural development report 2022–23: Orchard and horticulture development. Government of Kerala.

86. Rajendran, P., Ramesh, B. R., & Chandran, M. D. S. (2018). Temporal changes in forest cover and its drivers in the Periyar–Munnar landscape. Indian Forester, 144(5), 423–433.
87. Ramani,K.N, P. Venugopal, K.Saraladevi, S.Lalitha and R.V.Unnithan.1980.Sediments of Cochin Backwater in relation to pollution. Ind. J. Mar. Sci. 9: 111-114
88. Ramesh, R., Purvaja, R., & Venugopalan, I. T. (2011). Nutrient dynamics in the Periyar River. Journal of Environmental Biology, 32(6), 649–654.
89. Rani, A., Thomas, J., & Joseph, L. (2019). *Nutrient dynamics and eutrophication potential in Periyar River Basin*. *Journal of Environmental Biology, 40*(4), 723-731.
90. Ray, J. G., Krishnan, J., & Vasudevan, S. (2012, May). Nutrients, productivity and pollution of Periyar Lake, Kerala, India.
91. Resmi, R., Krishnakumar, A., & Anoop Krishnan, K. (2021). Groundwater studies of Chalakkudy basin, southern Western Ghats. In NCESS Annual Report 2020–21. National Centre for Earth Science Studies.
92. Sankaranarayanan, V.N.and S.Z.Quasim.1969. Nutrients of Cochin backwaters in relation to environmental characteristics.2:236-247
93. Saraladevi, K. et al. (2015). Organic carbon distribution in Periyar sediments. Proceedings of the Indian National Science Academy.
94. Saraladevi, K.,P. Venugopal., K.N. Remani., S. Lalitha. And R..V. Unnithan.1979. Hydrographic features and water quality of Cochin backwaters in relation to Industrial pollution. Ind. J. Mar. Sci.8:141-145
95. Sethumadhavan, T. P. (2016). Sustainable livestock farming: Issues and concepts. In Biodiversity for sustainable development (pp. 309–314).
96. Sreelakshmi, C. D., & Chinnamma, M. A. (2018). Quality assessment of sediments in Periyar River with special reference to phosphate fractionation and metallic contamination. International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), 7(2). ISSN 2278-2540.
97. Stephen, M., Peter, K. A., Ajithkumar, C. B., & Reghunandan, K. V. (2007). Significance of socio-economic factors of farmers on the milk production of crossbred cows in Thrissur District of Kerala. Kerala Agricultural University.
98. Suresh, A., Raju, S. S., & Chauhan, A. K. (2014). Growth and structural changes in livestock sector in India. Journal of Livestock Science, 5, 57–70.
99. The Hindu Bureau. (2024, June 6). *Discharge of chemical effluents may have led to Periyar fish kill: Irrigation department*. *The Hindu.*
100. The Hindu. (2025). Water quality in Periyar river not on expected lines, says CPCB.

101. TOI (2025). Fecal contamination in Periyar River reaches alarming levels. The Times of India, April 2025.

102. World Food Summit. (1996). Food for all: Rome, 13-17 November 1996. Food and Agriculture Organization of the United Nations.

103. Zhu, Z., Chen, J., & Li, J. (2013). *Best management practices for controlling agricultural nonpoint source pollution in river basins*. *Journal of Environmental Management, 128*, 593-606. https://doi.org/10.1016/j.jenvman.2013.05.042