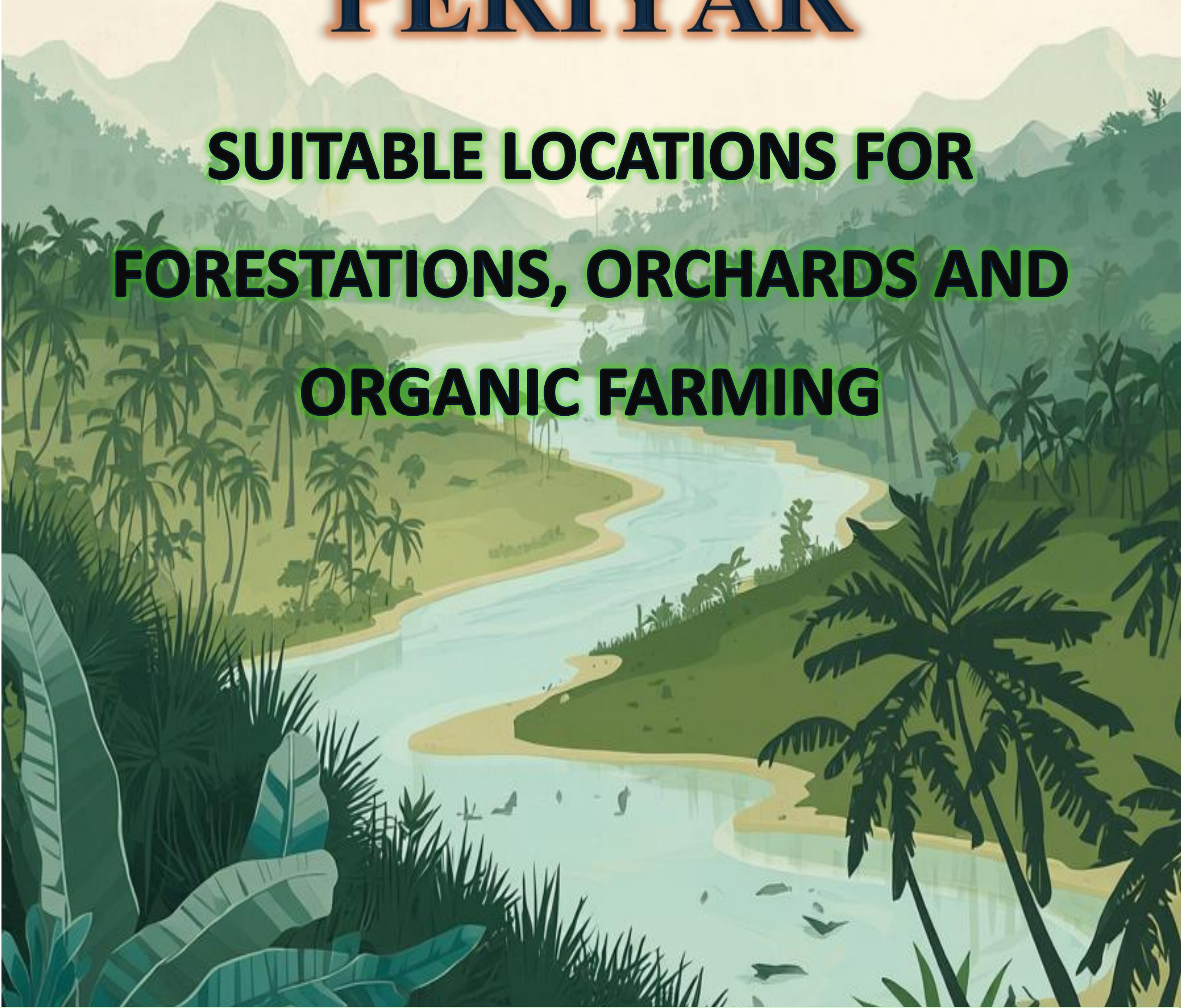
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

PERIYAR

SUITABLE LOCATIONS FOR FORESTATIONS, ORCHARDS AND ORGANIC FARMING



cPeriyar
IIT PALAKKAD
तमसो मा ज्योतिर्गमय
Centres for Periyar River Basin Management Studies
IIT Palakkad & NIT Calicut

Centre for Ganga River Basin Management and Studies

PERIYAR

Suitable Locations for Forestations, Orchards and Organic Farming

March 2026

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

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

Centre for Ganga River Basin Management and Studies (cGanga)

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

www.cganga.org

Acknowledgment

This report is a comprehensive outcome of the project jointly executed by IIT Palakkad (Lead Institute) and NIT Calicut (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It was submitted to the National River Conservation Directorate (NRCD) in 2026. We gratefully acknowledge the individuals who provided information for this report.

Suggested Citation

Periyar – Suitable Locations for Forestations, Orchards and Organic Farming by cPeriyar and NRCD

Contacts

Centres for Periyar River Basin Management Studies, cPeriyar

Indian Institute of Technology Palakkad, Kanjikode 678623, Kerala, India

Team Members

Dr. Deepak Jaiswal, cPeriyar, IIT Palakkad
Dr. Athira P, cPeriyar, IIT Palakkad
Dr. Neenu K, cPeriyar, IIT Palakkad
Saivinayak Viswanathan, cPeriyar, IIT Palakkad

Dr. Chithra N R, cPeriyar, NIT Calicut
Aditya Harikumar, cPeriyar, NIT Calicut
Nandana V, cPeriyar, NIT Calicut
Ayaz Ameer, cPeriyar, NIT Calicut

Preface

The Periyar River Basin is one of Kerala's most important river systems, supporting diverse ecosystems, extensive forest landscapes, plantation agriculture, and numerous communities that depend on its natural resources for their livelihoods. Owing to its ecological significance and increasing pressure on land and water resources, there is a growing need for scientifically informed land-use planning that promotes environmental sustainability while supporting sustainable development.

This report presents a spatial assessment of suitable locations for forestation, orchard development, and organic farming within the Periyar River Basin. The study was undertaken to identify potential areas for sustainable land-use interventions to enhance vegetation cover, improve watershed health, strengthen ecological resilience, and promote environmentally responsible agricultural practices. Using geospatial techniques and suitability analysis, the assessment integrated land-use and land-cover information, soil characteristics, climatic conditions, and other relevant spatial datasets to identify suitable intervention zones across the basin.

The study first assessed the basin's existing land-use pattern and identified underutilised lands, including marginal and barren areas, that could serve as the primary resource base for future interventions. Based on environmental suitability criteria, potential forestation zones were identified to support soil and water conservation, biodiversity enhancement, and ecological restoration. The suitability of selected orchard crops, namely coconut, banana, pineapple, cashew, and arecanut, was also evaluated using crop-specific climatic and soil requirements. In addition, suitable areas for organic farming were delineated by considering land availability and proximity to existing composting facilities to promote sustainable nutrient management and organic agricultural practices.

Beyond the spatial assessment, the report proposes an implementation framework that emphasises phased execution, institutional coordination, and stakeholder participation. The findings provide a scientific basis for prioritising sustainable land-use interventions within the basin. They are expected to support informed decision-making, improve watershed management, enhance livelihood opportunities, and contribute to the long-term environmental sustainability and climate resilience of the Periyar 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

CESS	Centre for Earth Science Studies
CPCRI	Central Plantation Crops Research Institute
DCR	Directorate of Cashew Research
FAO	Food and Agriculture Organization of the United Nations
FPO	Farmer Producer Organisation
GIS	Geographic Information System
IIHR	Indian Institute of Horticultural Research
IPCC	Intergovernmental Panel on Climate Change
KAU	Kerala Agricultural University
LSGI	Local Self-Government Institution
LULC	Land Use / Land Cover
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MIDH	Mission for Integrated Development of Horticulture
NAP	National Afforestation Programme
NMSA	National Mission for Sustainable Agriculture
NRCB	National Research Centre for Banana
NRSC	National Remote Sensing Centre
PTR	Periyar Tiger Reserve
RKVY	Rashtriya Krishi Vikas Yojana
SHG	Self-Help Group
UNEP	United Nations Environment Programme

1. Introduction & Objectives

The Periyar River is the longest river in Kerala and the second-largest river basin in the state, with a basin area approximately 5,216 km². The basin extends across major parts of Idukki, Ernakulam, Thrissur and Coimbatore (Tamil Nadu) and includes diverse physiographic regions from highland forested areas to midland agricultural zones and lowland plains. The river originates in the Western Ghats and is supported by a well-developed tributary network. The basin is environmentally vulnerable, and nearly 80% of the total area in the high ranges is affected by erosion and mass movements (CESS, 2010), indicating the importance of prioritising forestation and soil conservation interventions in the upper catchment areas. Anamudi, the highest point in the basin, has an elevation of 2,695 m.

The geographical diversity of the Periyar River Basin supports a wide range of agricultural activities. Plantation crops such as cardamom, tea, coffee, and pepper dominate the highland regions, while paddy and coconut are cultivated in the midland and lowland areas. The Periyar River system, together with its reservoirs, canals, and irrigation infrastructure, plays an important role in sustaining agricultural practices by ensuring water availability across seasons.

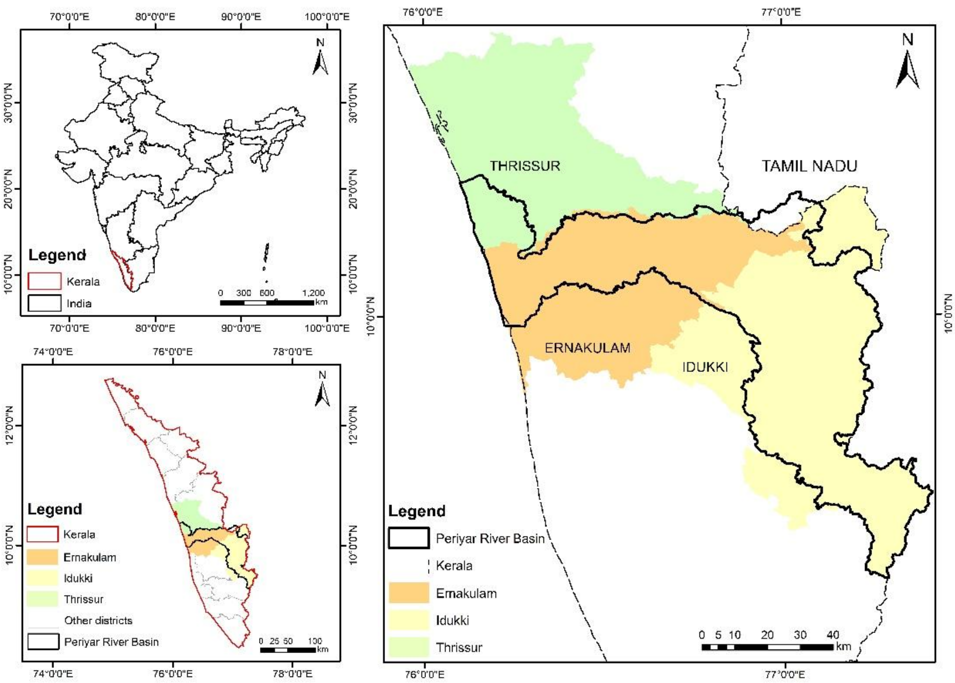


Figure 1. Boundary of Periyar Basin *(Source: River Atlas – Periyar)*

With increasing pressure on land and water resources, the need for a more structured approach to land-use planning within the basin has become evident. Identifying suitable areas for forestation, orchard cultivation, and organic farming requires a careful understanding of the spatial variability in land characteristics, existing land-use patterns, and resource availability. Rather than viewing these interventions in isolation, they must be integrated into the broader landscape by considering ecological sensitivity, soil conditions, and water resources. Approaches such as forestation can strengthen vegetation cover and reduce land degradation, while orchard systems support diversified and economically viable agriculture. Similarly, organic farming offers a pathway to reduce chemical dependency and enhance long-term soil health. Mapping these suitability zones, therefore, becomes an essential step in guiding sustainable and location-specific land-use decisions.

The relevance of such an approach is particularly pronounced in the Periyar River Basin, where the interplay between intensive agriculture and fragile ecosystems has resulted in growing environmental concerns. Agricultural runoff carrying nutrients such as nitrates and phosphates has contributed to water quality deterioration, while land-use changes, including deforestation in upper catchments, have accelerated soil erosion and sediment transport into the river system. At the same time, the basin exhibits substantial spatial variability in land utilisation that presents both challenges and opportunities for intervention. For instance, in Idukki district, although forests account for about 45.5% of the total geographical area, nearly 15,460 hectares remain as cultivable wasteland and around 2,376 hectares as fallow land, indicating scope for ecological restoration and sustainable land use. Similarly, Ernakulam district contains over 30,000 hectares of cultivable wasteland and fallow land combined, despite having a net sown area of 144,223 hectares, reflecting underutilised potential within an increasingly urbanising landscape (Ministry of Jal Shakti, 2025). These patterns highlight the necessity of systematically identifying and allocating land for forestation, orchard development, and organic farming in a manner that is both environmentally and economically viable. By aligning such interventions with existing land-use characteristics and resource availability, it becomes possible to mitigate ecological degradation while enhancing agricultural sustainability. Consequently, mapping suitable locations for these practices is not only a planning exercise but also a critical step towards achieving balanced land management and long-term resilience within the Periyar River Basin. The suitability assessment was restricted to areas outside protected landscapes; therefore, the portion of the basin falling within Coimbatore District was not considered for analysis, as it is entirely encompassed by the Anamalai Tiger Reserve. Given its protected status and ecological significance, no land-use interventions were proposed within this area.

A comprehensive assessment of land-use patterns and agricultural systems is essential for supporting informed and sustainable planning within the Periyar River Basin. This study focuses on identifying and mapping suitable locations for forestation, orchard cultivation, and organic farming based on existing land-use characteristics, environmental conditions, terrain variability, and resource availability across districts of Idukki, Ernakulam, and Thrissur. Considering the basin's physiographic diversity, ranging from plantation-dominated highlands to fragmented agricultural landscapes in the midland and lowland regions, the study aims to align land-use interventions with the specific characteristics and potential of different areas within the basin.

The study further aims to assess existing land-use patterns and delineate suitable areas for forestation, orchard development, and the promotion of sustainable agricultural practices within the Periyar River Basin. Particular emphasis is placed on addressing uneven land utilisation, including the presence of fallow and underutilised lands, through strategies that promote forestation, orchard-based cultivation, and organic farming practices. In addition, the study aims to develop an implementation framework incorporating phased interventions, community engagement, and land-use transition strategies to support sustainable basin management. The study also provides basin-specific recommendations and highlights the role of stakeholders in promoting environmentally sustainable and economically viable land-use practices within the Periyar River Basin.

2. Land Use of the Periyar River Basin

Land use within a river basin reflects the interaction between natural resources, human activities, and environmental conditions. In the Periyar River Basin, the distribution of forests, agricultural lands, plantations, water bodies, and built-up areas varies considerably across regions due to differences in topography, climate, and settlement patterns. These variations have a direct influence on agricultural productivity, water availability, ecological stability, and overall resource management within the basin. Understanding the existing land use structure is therefore essential for evaluating the suitability of different areas for sustainable land use interventions.

The Periyar River Basin spans the forested highlands of the Southern Western Ghats to the intensively used midland and lowland zones, which support dense human settlement and agriculture. The basin lies within a tropical monsoon climate and is one of the largest watersheds in Kerala (Sadhwani et al., 2022). Highland areas in Idukki and adjacent Western

Ghats districts are dominated by evergreen and semi-evergreen forests interspersed with plantation agriculture, especially cardamom, coffee, and tea, often embedded within forested landscapes (Chacko et al., 2019; Gayathri et al., 2021). Agroforestry and plantation systems based on coffee, cardamom and tea are widespread in these high-elevation landscapes (George et al., 2024; George et al., 2025). In the midland and lowland regions, paddy wetlands and mixed crop systems, including coconut-based agroforests and other homestead crops, have historically dominated but are undergoing rapid change (Zainulabdeen & Nagaraj, 2023; Mohan et al., 2022; Fox et al., 2017). Across the basin, urban and peri-urban expansion, especially around Kochi/Cochin and Thrissur, has driven increases in built-up area at the expense of agricultural lands and wetlands, contributing to land-use intensification, fallowing and abandonment (Jacob & Dwarakish, 2015; Thekkeyil et al., 2023; Prasad & Kuruvila, 2024). These spatial variations in forest cover, plantations, paddy wetlands, mixed crops, fallows, wastelands and built-up areas underpin the basin's land-use dynamics and shape the agricultural and ecological livelihoods of local communities (Sadhwani et al., 2022; Jose & Padmanabhan, 2016).

Changes in land use over recent decades have markedly reshaped the basin's environmental conditions. Rapid urban growth, agricultural conversion, and intensified use of natural resources have shifted the system from predominantly natural or agrarian landscapes toward more human-dominated ones, with consequences for hydrology, soils, and ecosystem functions (Sadhwani et al., 2022; Alagulakshmi et al., 2025). Across Kerala's river basins, expansion of built-up areas has largely occurred at the expense of agricultural and forest land, leading to landscape fragmentation and loss of natural cover (Alagulakshmi et al., 2025). Such transitions alter runoff generation, erosion, and sediment yield, with especially pronounced impacts at sub-watershed scales in monsoon-dominated systems (Sadhwani et al., 2022). Increasing built-up and impervious surfaces in midland and lowland zones tend to intensify surface runoff and stress natural drainage. They can contribute to soil erosion and reduced infiltration, thereby affecting groundwater recharge and water quality (Zeshan et al., 2021). At the same time, transitions such as abandoned or underutilised agricultural land, degraded bare land, and fragmented fields can be seen as opportunities for more sustainable land-use options, including reforestation, orchard systems, and improved agricultural management, which are widely recommended to enhance watershed stability and reduce soil and water degradation (Biru et al., 2025; Saddique et al., 2020). Accordingly, a detailed assessment of the current land use and land cover pattern forms a critical basis for identifying priority zones for afforestation, orchard development, and organic or low-impact farming, and for supporting integrated, basin-scale planning aimed at long-term resource sustainability (Halder et al., 2025).

2.1. Land Use Land Cover Map of the Basin

Understanding the distribution of land use and land cover is crucial for assessing the environmental condition of the basin and identifying areas suitable for targeted land-use interventions. Land use and land cover mapping using remote sensing and GIS techniques has become an important tool for assessing watershed characteristics, monitoring environmental changes, and supporting sustainable land management planning in river basins. Such geospatial analyses help in identifying environmentally sensitive regions, monitoring vegetation changes, and evaluating the impact of human activities on natural resources. Figure 2 shows the LULC map of the Periyar River Basin.

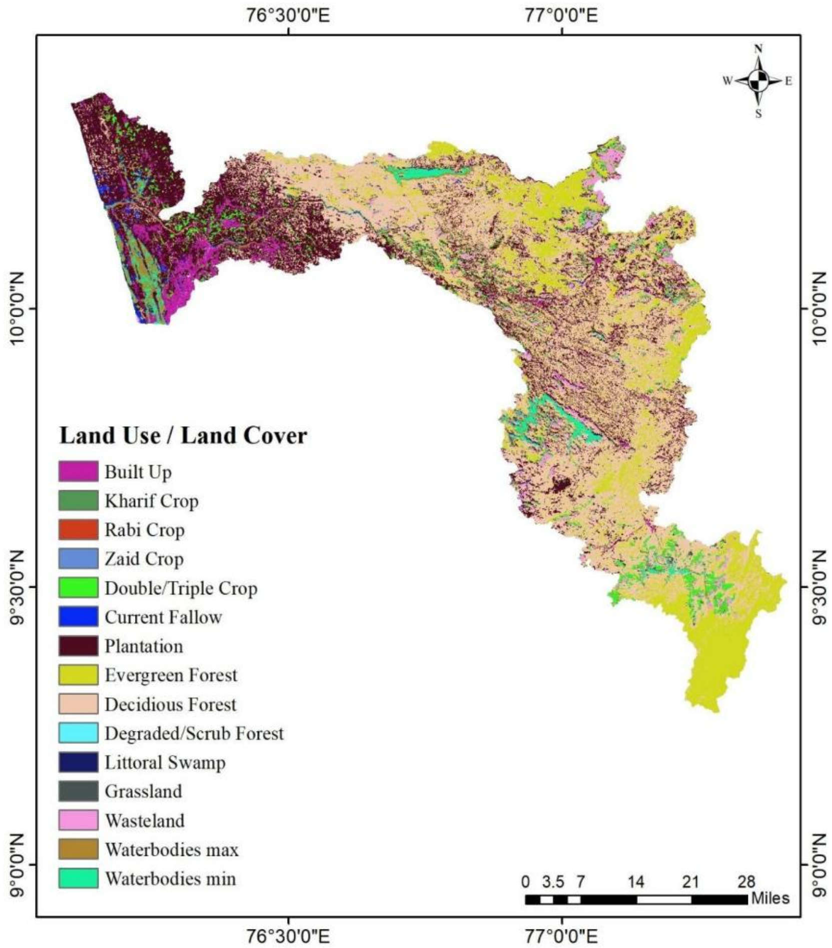


Figure 2. Land Use Land Cover map of Periyar river basin

(Source: NRSC Bhuvan Portal, LULC 2023–24 Dataset)

Table 1 shows that forests constitute the most dominant land cover category within the basin, emphasizing the ecological significance of the upper catchment regions. Deciduous forests occupy nearly 39.73% of the basin area, forming the largest single land cover class, while evergreen forests account for an additional 20.16%. Together, these forest ecosystems play a crucial role in maintaining hydrological stability, regulating runoff, conserving biodiversity, and protecting soil from erosion.

Table 1: LULC area in percentage

(Source: NRSC Bhuvan Portal, LULC 2023–24 Dataset)

Land Use/Land Cover	**Area (%)**
Deciduous Forest	39.73
Plantation	22.28
Evergreen Forest	20.16
Double/Triple Crop	4.22
Wasteland	3.52
Built Up	3.18
Waterbodies (Max Extent)	2.38
Waterbodies (Min Extent)	1.68
Current Fallow	0.96
Rabi Crop	0.91
Degraded/Scrub Forest	0.44
Kharif Crop	0.37
Grassland	0.16
Littoral Swamp	0.02
Zaid Crop	< 0.01

Dense forest cover in the upper catchment regions helps reduce soil erosion, regulate runoff, and maintain hydrological stability within the basin (Giriraj et al., 2008). The dominance of forest and plantation within the upper catchment regions plays a significant role in regulating streamflow and reducing surface runoff during intense rainfall events. Forest ecosystems in the upper catchment areas also contribute to groundwater recharge and maintenance of river flow during dry periods (Bruijnzeel, 2004). Although degraded and scrub forests represent only about 0.44% of the basin area, their presence indicates localized disturbances and gradual alteration of natural vegetation in certain regions.

Alongside forested landscapes, plantation forms another major component of land use within the basin, covering approximately 22.28% of the total area. This reflects the dominance of perennial plantation crops, particularly in the highland regions where tea, coffee, rubber, cardamom, and pepper cultivation are extensively practiced. Compared to plantation areas, seasonal agricultural land occupies a relatively smaller proportion of the basin, with Kharif crops accounting for 0.37% and Rabi crops covering around 0.91%. Areas under double and triple cropping constitute about 4.22%, indicating pockets of comparatively intensive cultivation supported by favourable water availability and agricultural inputs. Current fallow land occupies nearly 0.96% of the basin, representing agricultural areas that remain temporarily uncultivated due to seasonal or management related factors. The close interaction between plantation landscapes and natural forest ecosystems within the basin plays an important role in supporting regional ecological balance and biodiversity conservation (Giriraj et al., 2008). Plantation based agricultural systems also play an important role in supporting the regional economy and employment opportunities in the highland regions.

The influence of human activities within the basin is also evident through the presence of built-up areas, which account for approximately 3.18% of the total area. Expansion of settlements and associated infrastructure is more pronounced in the midland and lowland regions, contributing to increasing pressure on agricultural and natural landscapes. Wastelands occupy around 3.52% of the basin area, reflecting the occurrence of degraded or underutilized lands that offer opportunities for restoration and sustainable land management interventions. Smaller land cover categories such as grasslands and littoral swamp areas, though limited in extent, continue to hold ecological importance due to their contribution to habitat diversity and wetland functions. Water bodies represent another vital component of the basin landscape, with their extent varying seasonally between 1.68% and 2.38% of the total area. Rivers, reservoirs, ponds, and other water resources are integral to the functioning of the basin, supporting irrigation, domestic water supply, ecological processes, and agricultural productivity. The distribution of these water bodies, together with the surrounding land use pattern, strongly influences the environmental sustainability and resource dynamics of the basin.

The overall distribution of land use and land cover categories within the Periyar River Basin highlights significant scope for interventions related to forestation, orchard development, and organic farming. The extensive forest cover and the presence of degraded and scrub forest areas provide opportunities for strengthening ecological restoration and improving vegetation continuity in environmentally sensitive regions. Similarly, the large extent of plantation areas and perennial crop-based landscapes suggests favourable conditions for expanding orchard cultivation in suitable midland and highland zones. Areas under fallow land and wasteland also present opportunities for introducing organic farming practices, particularly in regions where low intensity cultivation and availability of natural vegetation can support reduced chemical input systems. Maintaining landscape diversity and ecological continuity within the basin is essential for achieving sustainable land management and long-term environmental conservation (Giriraj et al., 2008). Sustainable land use planning can therefore contribute to improving watershed health, conserving biodiversity, and enhancing long term agricultural resilience within the basin. The diversity in land use categories across the basin therefore creates a suitable foundation for adopting location specific and sustainable land management approaches that balance agricultural productivity with ecological conservation.

The identification of underutilised lands formed the initial step in the suitability assessment process. Marginal, barren, and other underutilised land categories were extracted from the latest NRSC Land Use/Land Cover (LULC) dataset and used as the primary land resource base for subsequent analyses. However, barren lands located within the Periyar Tiger Reserve were excluded from further consideration. These areas form part of a legally protected landscape. They are primarily characterised by steep slopes, rocky terrain, and ecologically sensitive habitats, making them unsuitable for the proposed forestation, orchard development, and organic farming interventions. After excluding protected areas and environmentally constrained locations, a total of 226.64 km² (4.35% of the total basin area) of underutilised land was identified within the Periyar River Basin (Figure 3). These lands comprise marginal, barren, and underutilised areas that offer opportunities for sustainable land-use interventions. The identified underutilised lands served as the base layer for the subsequent suitability assessments. Specific portions of these lands were subsequently allocated for forestation, orchard development, and organic farming based on environmental suitability, climatic conditions, soil characteristics, and accessibility considerations.

The resulting intervention zones, therefore, represent different land-use recommendations derived from the available pool of underutilised lands outside protected areas. This approach ensures that conservation objectives within the Periyar Tiger Reserve are maintained while directing restoration and sustainable development activities to suitable, accessible landscapes elsewhere in the basin.

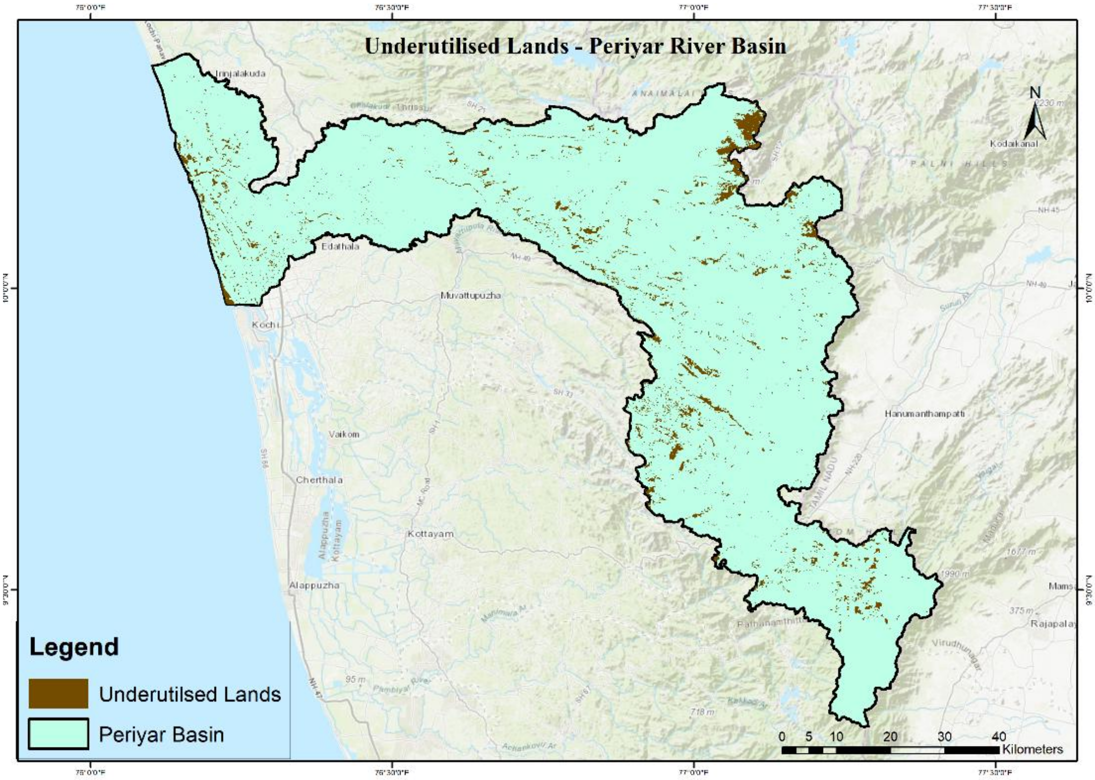


Figure 3. Spatial distribution of underutilized lands (marginal, barren, and other underutilized land categories) identified from the NRSC LULC dataset within the Periyar River Basin

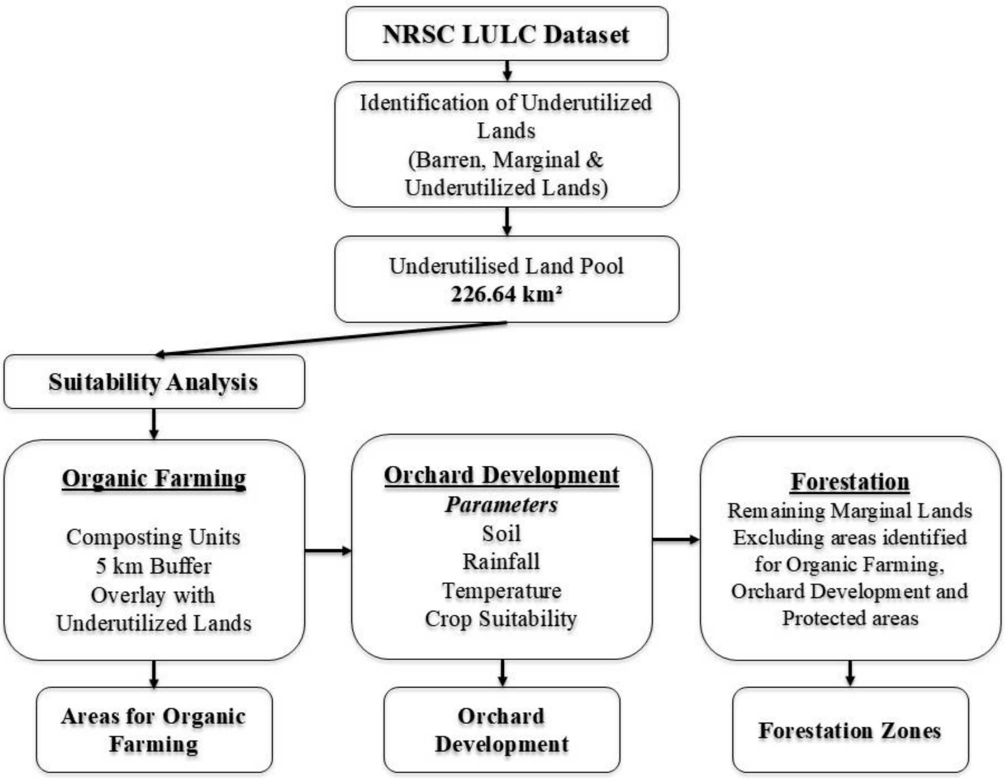


Figure 4. Methodological Framework for the Allocation of Underutilized Lands to Forestation, Orchard Development, and Organic Farming Interventions

3. Potential Forestation Zones

The spatial suitability analysis of the Periyar River Basin identified 34.20 km^2 as suitable for forestation activities. These zones predominantly comprise marginal, barren, and underutilized lands that are currently unsuitable for intensive agriculture. Nevertheless, they possess considerable potential for ecological restoration and landscape enhancement. To mitigate land-use conflicts and optimize resource allocation, the analysis excluded areas previously designated for orchard development and organic farming.

The identified forestation zones are characterized by sparse vegetation, exposed surfaces, and reduced land productivity, and are primarily located in degraded land parcels. These areas are highly susceptible to ongoing land degradation, soil erosion, and surface runoff, especially in tropical river basins with intense seasonal rainfall as in the case of Periyar Basin. Transforming these degraded landscapes into forested zones is expected to enhance infiltration, decrease sediment transport, improve slope stability, and strengthen watershed functioning. Increased vegetation cover also moderates surface temperature and improves local microclimatic conditions (Bonan, 2008).

Forestation has been widely acknowledged as a successful watershed management strategy because of its capacity to enhance hydrological regulation and minimise soil loss. Vegetative cover enhances infiltration processes, reduces runoff velocity, and promotes groundwater recharge by intercepting rainfall (Bruijnzeel, 2004). Furthermore, the restoration of forest cover in degraded landscapes makes a substantial contribution to the conservation of biodiversity by enhancing the resilience of ecosystems and ensuring the continuity of habitats (Chazdon, 2008).

The forestation zones that have been identified are also expected to be significant in the mitigation of climate change and the long-term sequestration of carbon. The reestablishment of forest vegetation in both vegetation and soil systems facilitates atmospheric carbon storage and enhances biomass accumulation (IPCC, 2006). The proposed forestation zones have the potential to significantly support sustainable watershed management and ecological restoration initiatives within the Periyar River Basin, given the ecological sensitivity of the region and the increasing pressure from land-use change. Figure 5 depicts the spatial distribution of the selected forestation zones, focusing on Mullakanam, Kannampady, Padikappu, Valara, Neendapara, Elamplassery, Mamalakandam, Inchathotty, and the neighbouring areas. The forestation zones were established after determining which regions were ideal for orchard growth and organic farming. The NRSC Land Use/Land Cover (LULC) dataset was first used to remove marginal, underutilised, and barren lands. Areas deemed suitable for organic farming and orchard development were then excluded to minimise overlap and competing land-use recommendations. The remaining marginal and barren lands were then identified as potential forestation zones. This sequential method prioritised lands with agricultural and horticultural development potential, with the remaining accessible lands used for afforestation. The designated forestation zones give potential to increase vegetation cover, restore damaged landscapes, enhance biodiversity, conserve soil and water, and strengthen the overall ecological resilience of the Periyar River Basin.

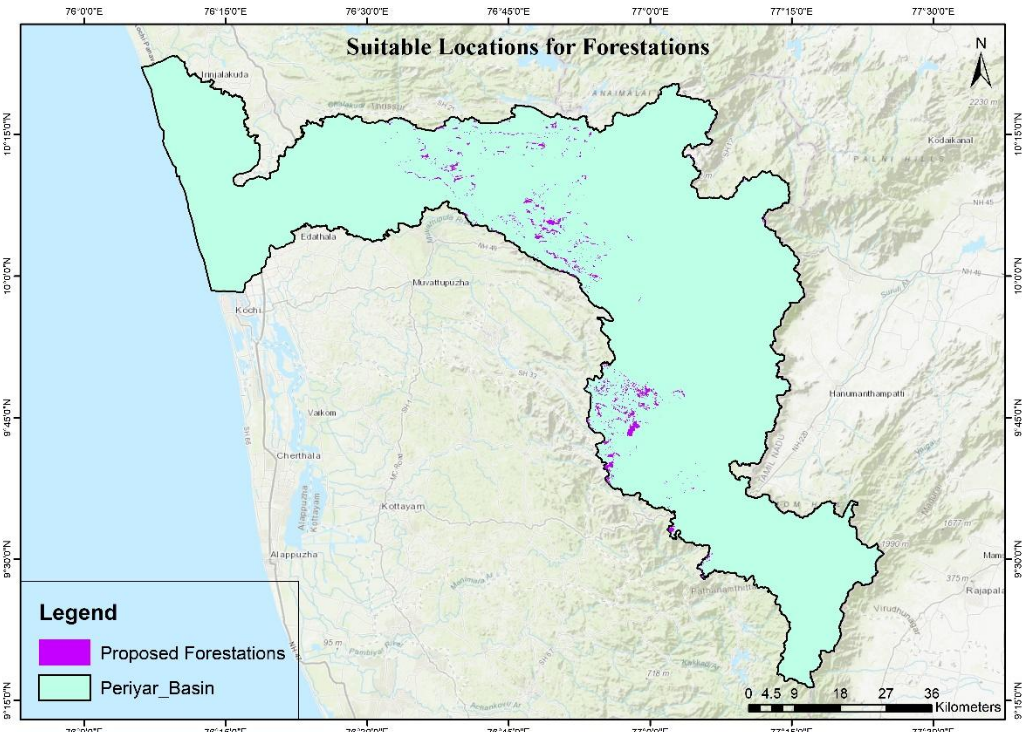


Figure 5. Suitable locations for forestations in the Periyar River Basin

The total forestation potential identified within the basin is approximately 34.20 km² (0.66% of the basin area). The relatively small extent reflects the fact that the Periyar River Basin is already predominantly forested and contains extensive protected forest areas. Therefore, additional forestation opportunities are largely confined to degraded and underutilised lands located outside existing forest ecosystems.

4. Orchard Potential Zones

The orchard suitability assessment was carried out using a GIS-based climate-envelope framework to delineate potential orchard development zones for coconut, banana, pineapple, cashew, and arecanut within the Periyar River Basin. Crop-specific environmental requirements (landuse-landcover, soil texture, annual rainfall, and temperature) were derived from published sources describing biophysical crop requirements and growth ranges (Grüter et al., 2022; Sawant et al., 2025). For each crop, climatic and edaphic thresholds representing known successful growing conditions were defined and used to construct individual suitability layers for soil texture, rainfall, and temperature (Dabesa et al., 2020; Abdelrahman et al., 2022). Mean annual rainfall data were obtained from the India Meteorological Department (IMD) gridded rainfall dataset at a spatial resolution of 0.25° × 0.25 °. In contrast, mean annual temperature data were derived from the IMD gridded temperature dataset at 1° × 1° spatial resolution. Climatic suitability was assessed using these annual rainfall and temperature datasets, and the climatic layers were resampled to a common spatial resolution, clipped to the Periyar River Basin, and reclassified into crop-specific suitability classes based on published climatic thresholds. A binary classification scheme was applied to each parameter: locations falling within the prescribed suitability range were coded as suitable, and those outside as unsuitable. For temperature, both minimum and maximum thresholds were evaluated to capture thermal limits of each crop (Burrough et al., 1992; Hebbar et al., 2022).

Final suitability maps for each crop were generated using a Boolean overlay, retaining only those areas classified as suitable for all criteria simultaneously; areas failing any criterion were excluded. This produced binary suitability outputs (suitable/unsuitable), rather than weighted or ranked suitability surfaces, in line with climate-envelope and agro-ecological zoning approaches that rely on environmental thresholds to delineate zones capable of supporting particular crops under existing climate and soil conditions (Hashim & Sayl, 2021; Nabati et al., 2020; Faraslis et al., 2025). The crop-specific suitability parameters adopted for the analysis are presented in Table 2.

Table 2. Crop-Specific Soil and Climatic Suitability Criteria Used for Orchard Development in the Periyar River Basin

S.No	Crop	Suitable Soil Texture	Temperature Range (°C)	Rainfall (mm/year)	Reference
1	Coconut (*Cocos nucifera*)	Sandy loam, Loam, Sandy clay loam	20–32	1000–3000	KAU (2016)
2	Banana (*Musa spp.*)	Loam, Clay loam, Sandy clay loam	15–35	1200–2500	NHB (2021); KAU (2016)

S.No	Crop	Suitable Soil Texture	Temperature Range (°C)	Rainfall (mm/year)	Reference
3	Arecanut (*Areca catechu*)	Loam, Clay loam	14–36	1500–4500	KAU (2016)
4	Pineapple (*Ananas comosus*)	Sandy loam, Loam	18–32	1000–2500	KAU (2016)
5	Cashew (*Anacardium occidentale*)	Sandy loam, Sandy clay loam	20–35	600–3500	KAU (2016)

The designated zones do not correspond to areas currently under cultivation with these crops. Rather, they identify areas with ideal environmental conditions for future orchard expansion. The spatial distribution of the identified orchard zones shows a distinct concentration of suitable locations in the midstream parts of the basin, mainly in the Idukki district of the Periyar River Basin. In contrast, the western side of the basin has less suitable places, especially along the river mouth and coastal plains. This spatial pattern is determined by elevation, rainfall distribution, temperature controls, soil properties, and the availability of suitable marginal lands throughout the basin. The chosen areas propose an opportunity to increase horticultural production through sustainable, site-specific orchard development practices.

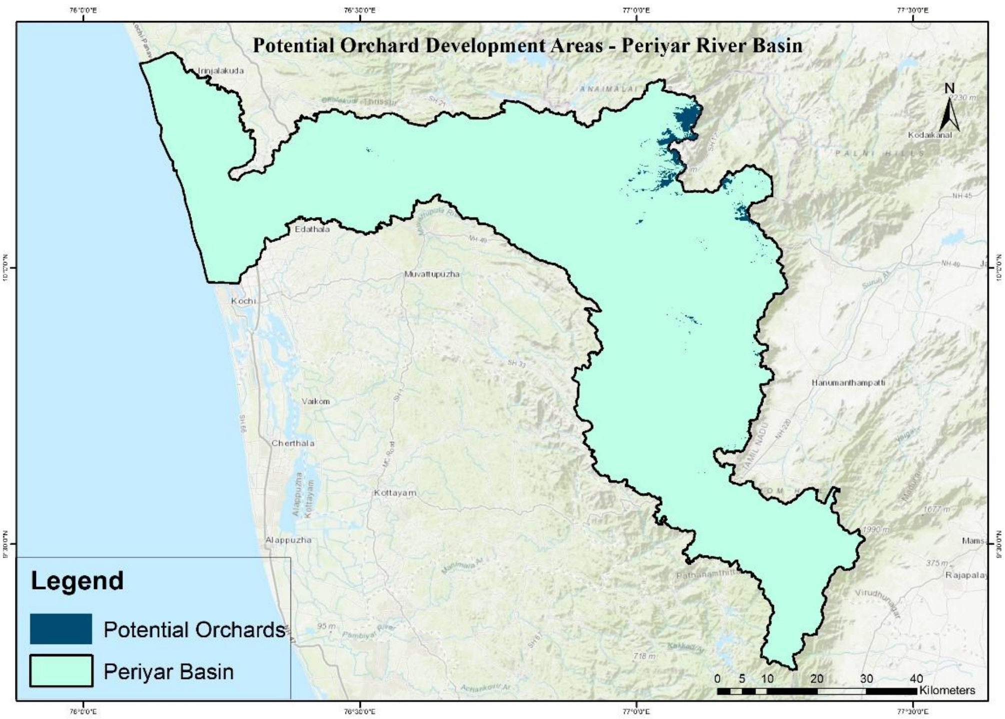


Figure 6. Potential areas suitable for orchard development in the Periyar River Basin

The orchard suitability assessment identified a total of 101 km² (1.94% of the total basin area) as suitable for the cultivation of selected perennial and horticultural crops within the Periyar River Basin (Figure 6). These areas were delineated through a GIS-based suitability analysis that integrated crop-specific climatic requirements, soil characteristics, and land availability criteria. The assessment considered coconut, banana, pineapple, cashew, and arecanut, which are among the major orchard crops cultivated in Kerala.

4.1 Suitable locations for coconut

The suitability analysis found 41 km² as suitable for coconut farming in the Periyar River Basin (Figure 7). The suitable zones are primarily distributed in the northern and central portions of Devikulam Block Panchayat, where environmental conditions are well aligned with crop requirements. These places have ideal rainfall regimes, humid climatic conditions, and suitable soils, which enable long-term coconut cultivation and productivity. Coconut production flourishes in warm tropical climates with consistent year-round moisture availability, making upland and midland zones ideal for orchard expansion (Kumar & Nair, 2006). The concentration of suitable locations in Devikulam illustrates the combined influence of climate, soil qualities, and land availability, emphasising the region's potential for developing coconut-based farming systems and multi-tier horticulture methods throughout the basin.

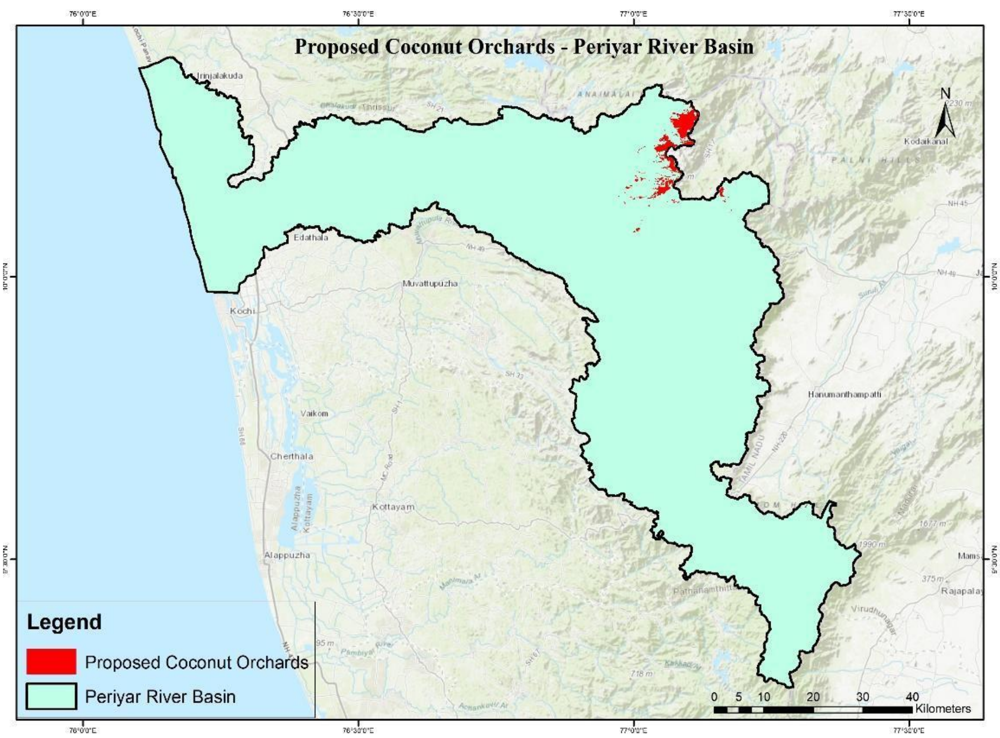


Figure 7. Suitable locations for Coconut orchards in the Periyar River Basin

4.2 Suitable locations for Pineapple

Pineapple suitability zones (Figure 8) include 44.49 km², making it one of the most widely distributed orchard crops in the analysis. Suitable lands were mostly centred in the northern and eastern parts of Devikulam Block Panchayat, where the climate and soil conditions are ideal for pineapple cultivation. The identified suitability zones are associated with favourable climatic and soil conditions that meet the environmental requirements of the selected crops. Pineapple grows well in tropical humid conditions with good drainage and moderate topography slopes, which reduce waterlogging and root stress (Bartholomew et al., 2003). Although slope and drainage were not explicitly incorporated into the suitability assessment, several of the identified areas occur within landscapes that have long supported plantation and horticultural activities, indicating the presence of generally favourable agro-environmental conditions. Consequently, the results should be interpreted as a planning-level assessment, with site-specific terrain and drainage evaluations undertaken prior to implementation. The comparatively large number of eligible areas suggests significant potential for developing pineapple farming in the upper reaches of the Periyar River Basin, notably in the Devikulam region, where environmental conditions meet the crop's agro-climatic requirements.

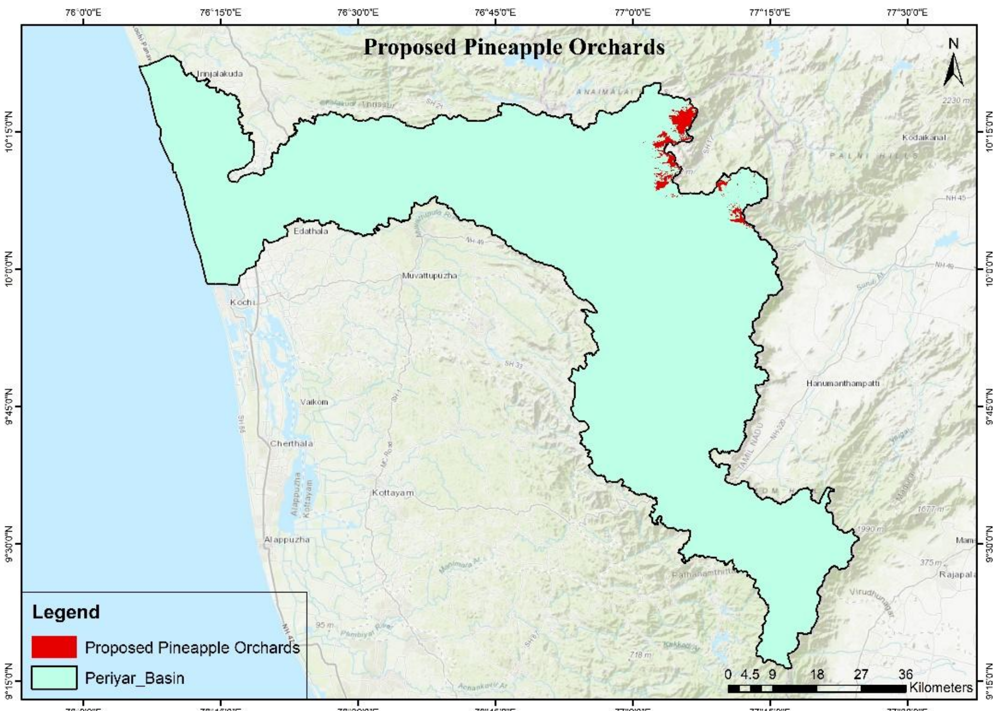


Figure 8. Suitable locations for Pineapple orchards in the Periyar River Basin

4.3 Suitable locations for Banana

Banana suitability zones (Figure 9) covered 42.46 km² of the Periyar River Basin. The selected suitable locations were mostly concentrated in the northern parts of Devikulam Block Panchayat, followed by areas in the eastern parts of Adimali, the western parts of Nedumkandam, and the northern parts of Kattappana. The distribution of these suitability zones reflects the crop's affinity for fertile soils, sufficient soil moisture, and good rainfall conditions. The humid upland and midland portions of the basin are ideal for banana agriculture due to their nutrient-rich soils and continuous water availability. Banana suitability is significantly wider than that of other orchard crops, implying more prospects for extension and integration within existing agricultural landscapes across the basin's upper and middle regions.

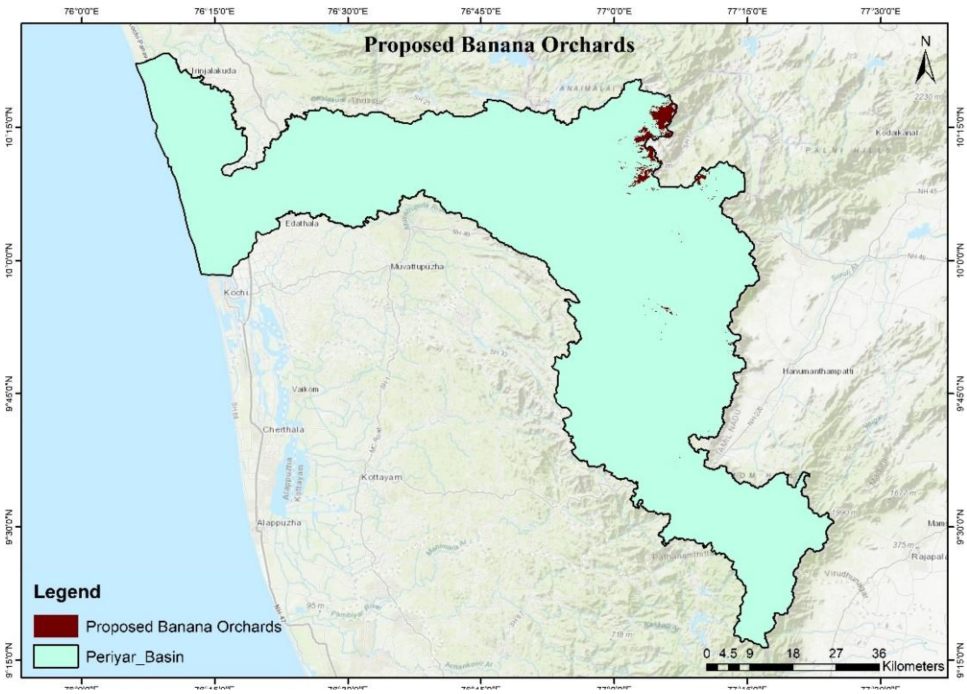


Figure 9. Suitable locations for Banana orchards in the Periyar River Basin

4.4 Suitable locations for Cashew

The cashew suitability zones (Figure 10) covered a small area of 1.96 km² and were spread as isolated patches within the basin. The indicated eligible locations were mostly located in the eastern portions of Adimali Block Panchayat, the western portions of Nedumkandam Block Panchayat, and the eastern portions of Kattappana Block Panchayat. The scattered distribution pattern reflects the unique environmental requirements needed for cashew agriculture, such as moderate rainfall and marginal upland landscapes. The suggested locations have less intensive agricultural use and good environmental conditions for cashew establishment. This spatial pattern is consistent with cashew's adaptability to marginal and low-fertility sites, where traditional agricultural production may be limited (Saroj & Rupa, 2014). Despite the scarcity of suitable locations, the selected zones offer opportunities for targeted orchard development and the diversification of agricultural land use in the upper reaches of the Periyar River Basin.

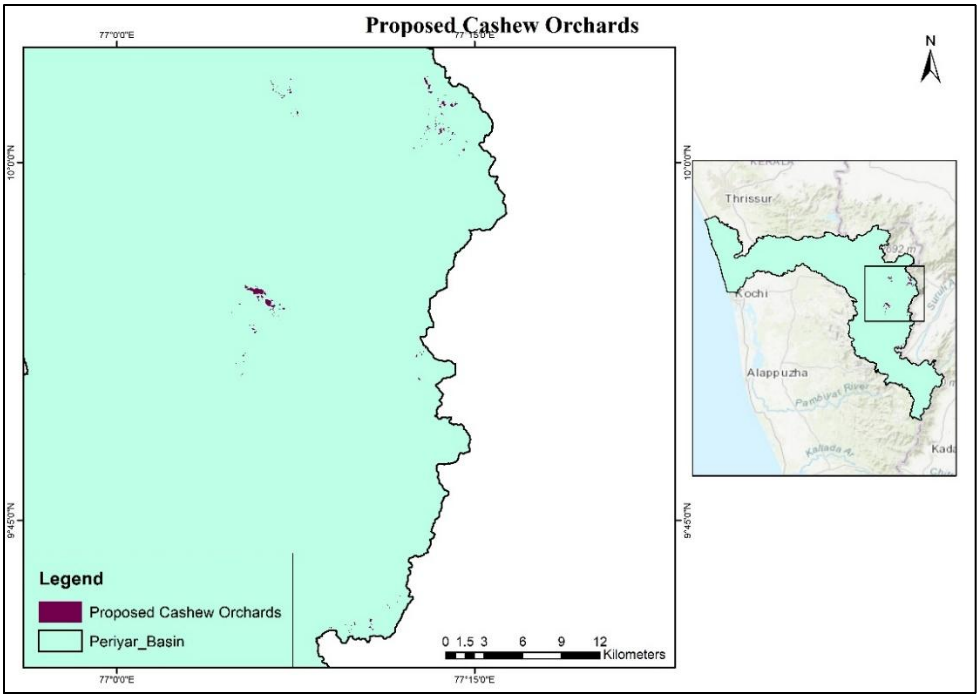


Figure 10. Suitable locations for Cashew orchards in the Periyar River Basin

4.5 Suitable locations for Arecanut

Arecanut suitability zones (Figure 11) were found to be geographically restricted and extremely localised, occurring exclusively in the basin's humid eastern uplands and midlands. Arecanut cultivation requires shady tropical conditions, consistent soil moisture, and high atmospheric humidity, limiting its suitability to specific ecological niches in the Periyar River Basin (Nampoothiri & Sairam, 2001). The suitability analysis identified approximately 3.62 km² suitable for arecanut cultivation, with 3.36 km² in the Devikulam Block Panchayat and 0.26 km² in the Angamaly Block Panchayat. The concentration of suitable places in these locations indicates the ideal meteorological and environmental conditions for arecanut farming, including high rainfall, moderate temperatures, and sufficient soil moisture.

The significant impact of topography and climatic gradients on perennial horticultural suitability is underscored by the observed concentration of orchard suitability zones in the upstream and elevated eastern regions of the basin. The western downstream and coastal regions near the river mouth were comparatively unsuitable due to the reduced availability of marginal lands, higher urbanisation, land-use constraints, and varying hydrological conditions.

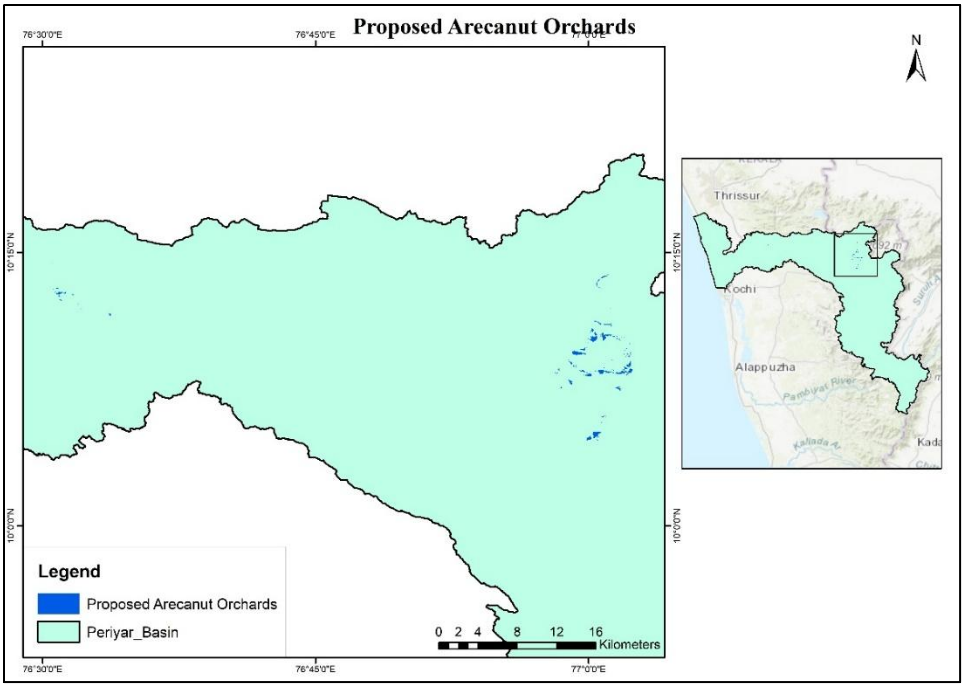


Figure 11. Suitable locations for Arecanut orchards in the Periyar River Basin

It is anticipated that the orchard development zones proposed will make a substantial contribution to the sustainable utilisation of underutilised lands, the improvement of agricultural productivity, and the diversification of livelihoods in the basin. Furthermore, perennial orchard systems offer a continuous vegetative cover that can improve soil organic matter, reduce soil erosion, and improve ecological stability in fragile environments (Lal, 2005). The empirical foundation for the planning of sustainable horticultural expansion within the Periyar River Basin is established by the crop-specific thematic maps that are generated through the analysis. Table 3 shows the total suitable area identified for each crop and its proportion compared to the overall orchard suitability area. Pineapple had the greatest amount of acceptable land, followed by banana and coconut, collectively accounting for more than 95% of the total indicated orchard development area. In contrast, the arecanut and cashew suitability zones were relatively small and confined to specific ecological niches within the basin. These variances reflect crop-specific climate, soil, and land-suitability needs across the Periyar River Basin.

Table 3. Potential Suitable Areas Identified for Orchard Development in the Periyar River Basin

Crop	Suitable Area (km²)	Percentage of Total Suitable Orchard Area (%)
Pineapple (*Ananas comosus*)	44.49	33.3%
Banana (*Musa spp.*)	42.46	31.8%
Coconut (*Cocos nucifera*)	41.00	30.7%
Arecanut (*Areca catechu*)	3.62	2.7%
Cashew (*Anacardium occidentale*)	1.96	1.5%
Total	**133.53**	**100%**

(*Note:* Percentages are calculated relative to the total area identified as suitable for the selected orchard crops. Individual suitability zones may overlap spatially; therefore, the cumulative area should be interpreted as the sum of crop-wise suitability areas rather than a unique land area.)

The cumulative area obtained from the crop-specific suitability maps (133.53 km²) exceeds the total orchard development area identified within the basin (101 km²). This difference arises because certain locations satisfy the suitability criteria for more than one orchard crop, resulting in overlapping suitability zones. The reported total orchard area therefore represents the unique geographical area suitable for at least one of the selected orchard crops, whereas the crop-wise areas include overlapping locations that may be suitable for multiple crops simultaneously. The overlap indicates the presence of agro-climatically favourable zones where farmers may have the flexibility to select among multiple orchard crops based on market demand, management preferences, and local conditions.

Although a substantial proportion of the identified orchard suitability zones (especially for coconut and pineapple) occur within the Devikulam Block Panchayat, the results should not be interpreted as indicating suitability across the entire high-altitude Munnar landscape. Devikulam Block Panchayat encompasses a diverse range of physiographic settings, including both the high-elevation plantation regions around Munnar and comparatively lower-elevation valleys and foothill areas. The suitability assessment identified only those locations that satisfied the crop-specific soil and climatic criteria considered in the analysis. Consequently, the mapped suitability zones are restricted to localised areas within the block and do not represent the entire high-range region. Furthermore, the present assessment was undertaken as a basin-scale climate-envelope analysis based on soil texture, rainfall, and temperature conditions. Additional factors such as elevation, slope, drainage characteristics, existing plantation land use, and local management constraints should be incorporated during detailed site-level planning and field verification prior to implementation.

5. Potential Organic Farming Zones

Spatial suitability analysis of the Periyar River Basin for organic farming identified a total area of 91.44 km^2 as suitable for promoting the utilisation of organic agricultural practices. The analysis incorporated land-use characteristics, proximity to human settlements, access to composting facilities/units, and availability of marginal and underutilised lands to identify environmentally and economically viable zones for the development of organic farming.

The organic farming suitability analysis was conducted using a GIS-based spatial screening approach, with the location of existing composting units serving as the major criterion. The latest NRSC Land Use/Land Cover (LULC) data were used to identify barren, marginal, and underutilised lands in the Periyar River Basin. A 5-kilometre buffer zone was then created around the indicated composting units (source: LSGD Kerala) to define areas with easy access to organic manure and other compost-derived inputs. The identified barren, marginal, and underutilised lands within this buffer zone were selected as acceptable locations for organic farming (Figure 12). The selection of a 5 km buffer around existing composting units was based on practical considerations related to the cost and logistics of transporting bulky organic amendments. Transport and handling account for the largest share of energy use and costs in compost and manure use, with compost purchase and transport representing up to 80% of total application costs and transport is identified as the most energy-demanding operation (Souček et al., 2017; De Rosa et al., 2022). Measured diesel consumption for manure and compost transport is about 0.28–0.30 L per tonne-kilometre, so increases in distance translate directly into higher operating costs. Field measurements and normative values indicate that practical transport distances for manure and compost typically range from 5-10 km, and energy analyses of spreading operations often standardise calculations to a 5 km distance as a representative short haul (Souček et al., 2017). Optimisation and regional logistics studies similarly indicate that economically efficient manure redistribution tends to occur over relatively short distances (typically a few to a few tens of kilometres), emphasising the importance of spatial proximity between organic waste sources and recipient fields (Kamilaris & Prenafeta-Boldú, 2021; Deng et al., 2022). In this context, a 5 km radius is adopted as a conservative, planning-level threshold representing very short, low-cost hauling distances that favour regular application of compost, farmyard manure, and other biomass-derived amendments. It is intended to prioritise land with good access to organic nutrient sources rather than to define a fixed agronomic or economic limit; longer transport distances may be feasible where crop value, infrastructure or policy incentives justify higher logistics costs.

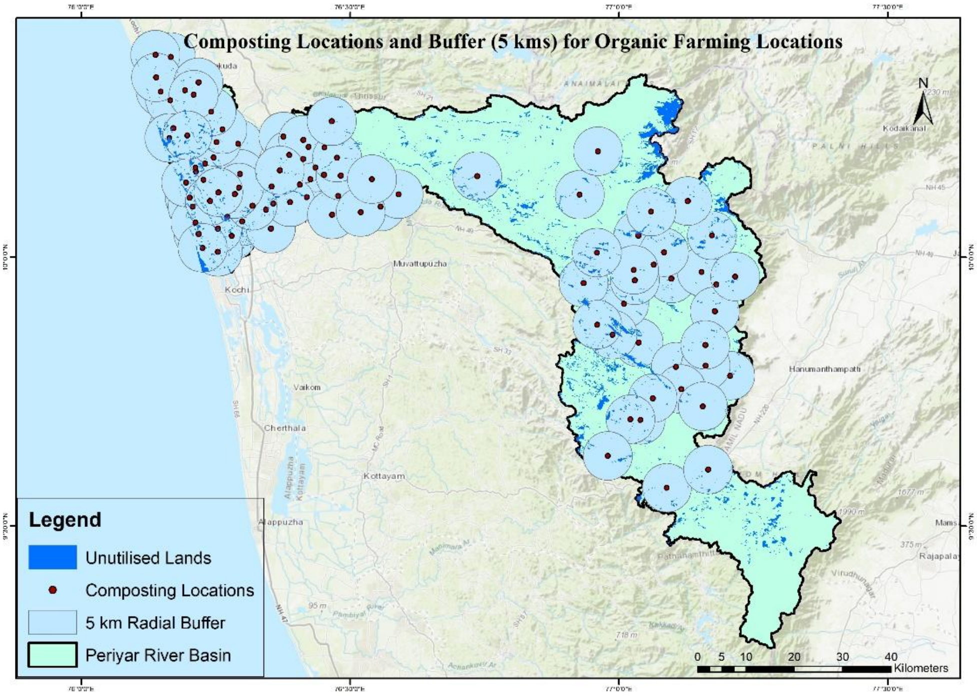


Figure 12. Location of composting units and the 5 km buffer zones considered for the organic farming suitability assessment.

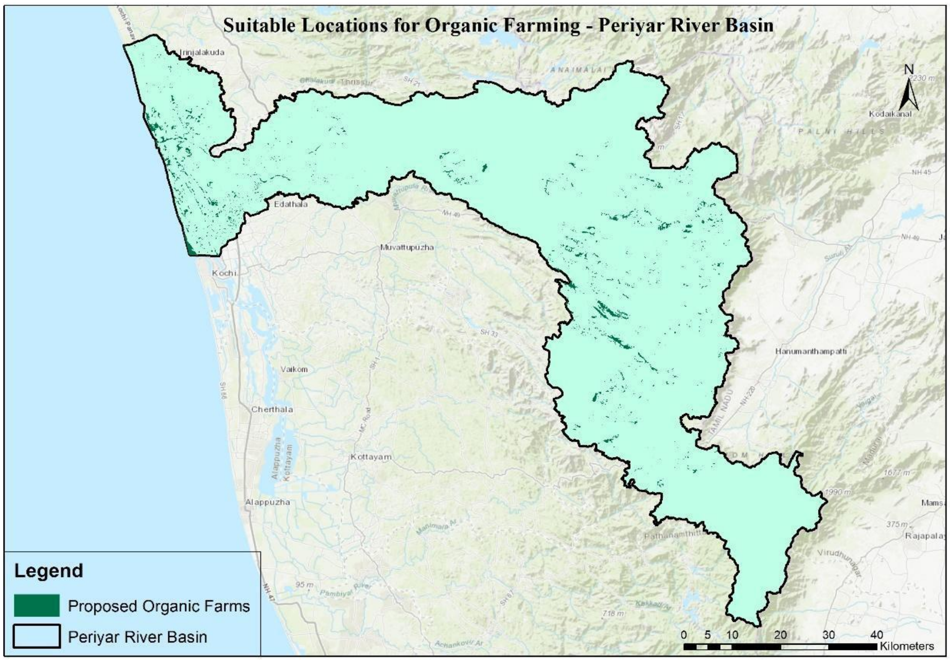


Figure 13. Suitable locations for organic farming in the Periyar River Basin

The spatial distribution of the identified organic farming zones (Figure 13) indicates that appropriate sites exist in both the upstream and downstream portions of the basin. A significant concentration is found in the western downstream portions near the river mouth, as well as scattered patches in the middle and eastern upstream sectors. The density of appropriate zones was higher in the western sections of the basin, which corresponded to the coastal lowlands and downstream areas. The location of composting facilities can explain this distribution pattern, as well as the availability of organic waste resources suitable for compost production, proximity to human settlements, and improved transit accessibility. Organic agriculture systems are heavily influenced by the availability of organic inputs and local nutrient recycling; hence, proximity to composting infrastructure is a significant factor in assessing compatibility (Reganold & Wachter, 2016).

The combined influence of accessibility, market proximity, and availability of organic resource streams resulted in concentrated suitability zones in the downstream western portions of the basin near the river mouth. Shorter supply chains and enhanced market connectivity are generally advantageous for organic agricultural systems, particularly for certified organic produce and perishable agricultural products (Pimentel et al., 2005). Consequently, the proximity of these regions to urban centers can facilitate the development of economically viable organic agricultural practices while simultaneously mitigating the environmental consequences of transportation.

It is anticipated that the organic agricultural zones that have been identified will yield numerous socio-economic and ecological advantages in the Periyar River Basin. Organic farming systems are recognised for their ability to increase soil organic carbon, improve microbial activity, increase water retention capacity, and decrease reliance on synthetic fertilisers and pesticides (Gomiero et al., 2011). The implementation of organic farming in tropical river basins can also contribute to the enhancement of water quality by minimising the entry of nutrient discharge and chemical contamination into river systems (Tuomisto et al., 2012). Additionally, the promotion of organic agriculture in marginal lands promotes sustainable land management and improves the livelihood opportunities of local agricultural communities.

The significance of decentralised and location-specific implementation strategies is underscored by the scattered yet widespread distribution of suitable organic agricultural zones throughout the basin. The scientific basis for prioritising areas for sustainable agricultural interventions, organic farming initiatives, and integrated watershed management programs within the Periyar River Basin is provided by the thematic suitability map (Figure 13) generated through the analysis.

6. Implementation Roadmap

The suitability assessment identified potential areas for forestation, orchard development, and organic farming within the Periyar River Basin. However, effective implementation requires a systematic, stepwise approach that includes scientific planning, field verification, institutional coordination, and long-term monitoring. The proposed implementation roadmap outlines a framework for translating the identified suitability zones into real on-the-ground initiatives.

Phase 1: Planning & Verification

The initial step should centre on rigorous field verification of the selected suitability zones. While spatial analysis provides a scientific foundation for prioritisation, field-level investigations are required to analyse land ownership patterns, current land use, accessibility, hydrological conditions, slope stability, and local environmental restrictions.

The fragmented landholding pattern and diverse land-use systems of Kerala should be given special consideration, as they may affect implementation feasibility. During this stage, prioritised intervention sites may be chosen based on environmental suitability, implementation feasibility, and stakeholder willingness.

Phase 2: Capacity Building & Pilot Projects

Pilot-scale interventions in high-priority areas can be initiated after the field verification. Pilot projects allow for the evaluation of technical feasibility, operational requirements, economic viability, and stakeholder acceptance before large-scale implementation.

Small-scale forestation initiatives, orchard demonstration plots, and organic farming clusters are all examples of pilot activities. Capacity-building programs should also be implemented during this phase to raise technical awareness among farmers, local communities, and implementing agencies. Plantation management, orchard establishment, organic nutrient management, compost preparation, and sustainable agricultural methods are all possible training topics.

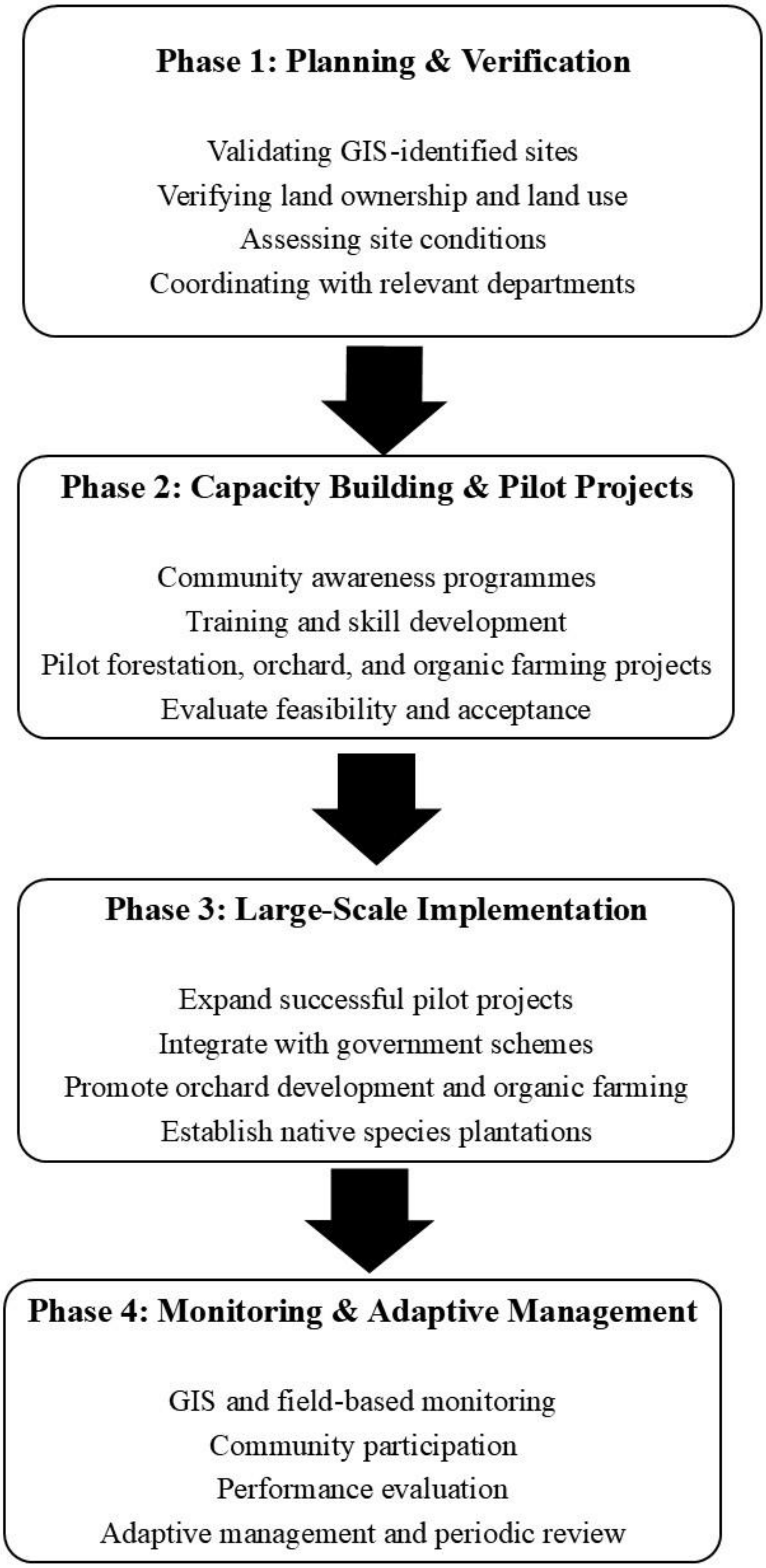


Figure 14. Proposed Phased Implementation Roadmap for Forestation, Orchard Development, and Organic Farming Interventions in the Periyar River Basin

Phase 3: Large – scale Implementation

Successful pilot initiatives may then be expanded to the basin's identified suitable locations. Implementation in this phase should be carried out in convergence with existing government initiatives and development programmes, whenever possible.

The expansion process should prioritise ecologically friendly and socially acceptable places identified during the field verification phase. Site-specific implementation plans can be created to account for local environmental circumstances, land-use patterns, infrastructure availability, and community needs.

Phase 4: Monitoring & Adaptive Management

Long-term monitoring is required to assess the effectiveness and sustainability of suggested solutions. Monitoring operations should evaluate plantation establishment, orchard implementation, the adoption of organic farming practices, and overall land-use changes in the intervention regions.

Remote sensing and GIS-based monitoring can be used with regular field visits to track development and assess results. Monitoring outcomes should be utilised to detect implementation issues, improve management tactics, and facilitate adaptive decision-making.

Long-Term Sustainability

The long-term success of the proposed interventions will be dependent on continued institutional support, stakeholder participation, and periodic evaluation. Regular review protocols should be established to monitor implementation success and incorporate lessons learned into future planning efforts. Such adaptive management approaches guarantee that interventions stay responsive to changing environmental conditions, socioeconomic realities, and emerging management objectives in the Periyar River Basin.

6.1. Phases of Community Engagement

Community participation will be vital to the effective implementation and long-term viability of the proposed forestation, orchard development, and organic farming initiatives in the Periyar River basin. The region already has a robust network of community-based agricultural projects, including Kudumbashree collective farming organisations, farmer cooperatives, self-help groups (SHGs), farmer producer organisations (FPOs), and local self-government institutions.

Building on these existing institutional networks can boost local acceptance, improve implementation efficiency, and enhance long-term management of the proposed solutions.

Community engagement should begin during the planning stage by identifying stakeholders, raising awareness, and holding public discussions. Farmers, tribal communities, local government institutions, youth groups, and community-based organisations should all be actively involved in talks about intervention priorities, implementation strategies, and expected outcomes. Such participatory approaches can increase transparency, reduce possible land-use conflicts, and build confidence among stakeholders.

During the implementation phase, residents should be encouraged to get involved in plantation activities, orchard establishment, organic input preparation, soil and water conservation, and maintenance operations. To boost local technical knowledge and increase adoption rates, capacity-building programs concentrating on sustainable farming techniques, compost preparation, orchard maintenance, biodiversity conservation, and watershed management should be implemented.

Community participation should also include monitoring and evaluation activities. Community-based monitoring systems can aid in the timely identification of implementation issues while also increasing responsibility and local ownership. Periodic review meetings with community members, local institutions, and implementing agencies can support adaptive management and help ensure that interventions remain socially acceptable and environmentally effective over time.

The long-term viability of the suggested initiatives will ultimately depend on ongoing collaboration among government agencies, scientific institutions, and local communities, supported by participatory decision-making and shared responsibility for natural resource management.

6.2. Strategy for Transitioning Land Use

The transition in land use in the Periyar River Basin necessitates a well-planned, region-specific approach that accounts for the basin's natural diversity and existing agricultural landscape. The basin includes dense forests, plantation-dominated areas, cultivated lands, water bodies, wastelands, and fallow lands, all with varying levels of productivity and environmental sensitivity. While deciduous and evergreen woods make up the majority of the basin area, plantations account for roughly 22.28%, showing a landscape already marked by significant perennial vegetation. At the same time, the presence of wastelands, degraded scrub forests, and underutilised lands creates an opportunity to implement sustainable land-use interventions such as forestation, orchard development, and organic farming.

Forestation can be encouraged in environmentally sensitive and degraded areas, particularly upper catchments, to increase vegetation continuity and support watershed management goals. Areas currently classified as degraded or scrub forests may be gradually restored by introducing native and regionally adapted species such as Neermaruthu (*Terminalia arjuna*), Njaval (*Syzygium cumini*), Athi (*Ficus racemosa*), Anjili (*Artocarpus hirsutus*), Thampakam (*Hopea parviflora*), Thanni (*Terminalia bellirica*), and Venga (*Pterocarpus marsupium*). These plants are well adapted to the Western Ghats' climatic and ecological circumstances, and they can help with soil conservation, groundwater recharge, carbon sequestration, biodiversity enhancement, and long-term ecosystem sustainability. Restoration efforts should focus on native species assemblages that reflect the region's natural vegetative characteristics. Such interventions may be supported by national and state-level afforestation, watershed development, and ecosystem restoration programs.

The basin's extensive plantation landscape and diversified farming practices make it ideal for orchard growth. Existing perennial cropping systems can be modified by incorporating fruit-bearing tree crops and multi-tier growing techniques tailored to local environmental conditions. Mixed cropping and intercropping systems are already common in Kerala, particularly in farming systems centred on coconut and arecanut. Some popular pairings include *coconut-banana-pineapple*, *coconut-pepper-banana*, *arecanut-pepper-banana*, *coconut-cocoa-pineapple*, and *coconut-nutmeg*-based systems. Fruit crops, including mango, jackfruit, pineapple, banana, and cashew, can also be grown in appropriate plantation environments. Such methods increase land-use efficiency, diversify farm revenue, preserve vegetation cover, and improve resource utilisation. Schemes such as the Mission for Integrated Development of Horticulture (MIDH) and the State Horticulture Mission Kerala can help with orchard expansion by providing aid for new orchards, revitalising old plants, developing nurseries, and establishing horticultural infrastructure.

The basin's land-use structure also allows for the promotion of low-input, sustainable farming methods. Current fallow lands and underutilised areas are potential sites for organic farming interventions, and the relatively limited extent of intensive seasonal cropping suggests that a phased transition to organic production can be implemented without causing significant disruption to existing agricultural systems. Organic agricultural strategies such as composting, green manuring, biofertilisers, crop residue recycling, and integrated nutrient management can improve soil fertility and minimise reliance on synthetic inputs. The suitability assessment emphasises the importance of conducting scientific assessments of environmental and socioeconomic conditions before implementing large-scale land-use changes. Such methods aid in prioritising places where improvements are both environmentally acceptable and operationally practical.

Government programmes can help to facilitate these changes. The Paramparagat Krishi Vikas Yojana (PKVY) encourages cluster-based organic farming by providing farmer training, certification assistance, and input support. At the same time, horticultural development initiatives can help with orchard installation and management. Integrating scientific suitability assessments into existing government programs helps guarantee that improvements are executed in areas that are both environmentally friendly and economically viable. Forestation, orchard expansion, and organic farming can all contribute to sustainable land management in the Periyar River Basin through a progressive, coordinated approach.

7. Recommendations and Role of Stakeholders

The suitability assessment identified possibilities for orchard development, afforestation, and organic cultivation across various regions of the Periyar River Basin. Section 6 provides a comprehensive implementation roadmap. The following recommendations and stakeholder responsibilities are proposed to facilitate the effective implementation of the identified interventions, as per the findings of the present study.

7.1. Prioritise Forestation in Degraded and Environmentally Sensitive Areas

Forestation activities should be emphasised in the identified degraded and underutilised lands around Mullakanam, Kannampady, Padikappu, Valara, Neendapara, Elamplassery, Mamalakandam, Inchathotty, and the surrounding areas. Although the basin has limited forestation potential (approximately 34.20 km^2, representing 0.66% of the area), these areas offer significant opportunities to improve watershed management and ensure vegetation continuity in environmentally sensitive landscapes.

Forestation initiatives should target native and regionally adapted plants suited to the Western Ghats' ecological conditions. Site-specific conditions and departmental recommendations may lead to the consideration of species such as Neermaruthu (*Terminalia arjuna*), Njaval (*Syzygium cumini*), Athi (*Ficus racemosa*), Anjili (*Artocarpus hirsutus*), Thampakam (*Hopea parviflora*), Thanni (*Terminalia bellirica*), and Venga (*Pterocarpus marsupium*). Wherever possible, forestation activities can be combined with existing afforestation, watershed development, and ecosystem restoration programs at the national and state levels.

7.2. Promote Location-Specific Orchard Development

The suitability analysis identified 101 km^2 of land suitable for orchard growth in the basin. Suitable orchard crops, including coconut, banana, pineapple, cashew, and arecanut, can be promoted in agro-climatically favourable areas, particularly in Devikulam, Adimali, Nedumkandam, Kattappana, and Angamaly Block Panchayat. These are locations where the selected soil and climatic conditions meet crop-specific compatibility requirements, presenting opportunities to expand perennial horticultural systems.

Existing plantation and mixed farming systems can be diversified by incorporating fruit-bearing tree crops and multi-tier cultivation methods. Common combinations used in Kerala, such as coconut-banana-pineapple, coconut-pepper-banana, arecanut-pepper-banana, coconut-cocoa-pineapple, and coconut-nutmeg-based systems, can be used anywhere appropriate. Support from initiatives such as the Mission for Integrated Development of Horticulture (MIDH) and the Kerala State Horticulture Mission can help with orchard establishment, plantation rejuvenation, nursery development, and horticultural infrastructure development.

7.3. Strengthen Organic Farming and Nutrient Recycling Systems

Organic farming initiatives may be encouraged in both upstream and downstream regions, as indicated by the research, particularly in areas with convenient access to existing composting facilities. Strengthening decentralised compost production, organic waste management, and nutrient recycling systems will boost organic farming's long-term profitability while lowering reliance on synthetic fertilisers.

Cluster-based approaches can be used to build suitable areas, with programs like the Paramparagat Krishi Vikas Yojana (PKVY) providing aid for organic farming, certification, farmer training, and input support. Community-based compost production centres and local nutrient recycling programs could increase the availability of organic inputs and improve the sustainability of organic farming systems in the basin.

7.4. Role of Stakeholders

The proposed forestation, orchard development, and organic farming initiatives will require coordinated efforts from government departments, local institutions, scientific organisations, and community stakeholders.

- **The Forest Department**: Lead forestation and restoration activities, including species selection, forestation establishment, site protection, and long-term monitoring of restoration sites.
- **Soil Conservation Department**: Support soil and water conservation measures such as contour bunding, vegetative barriers, slope stabilisation, watershed protection initiatives, and erosion-control interventions.
- **Department of Agriculture Development and Farmers' Welfare**: Provide technical guidance on orchard establishment, crop selection, organic farming practices, agricultural extension, and convergence with relevant agricultural development schemes.
- **Revenue Department**: Facilitate land ownership verification, land classification, and identification of suitable government-owned lands while minimising potential land-use conflicts.
- **Local Self-Government Institutions (LSGIs)**: Support field-level coordination, community mobilisation, beneficiary identification, and integration of interventions within local development plans.
- **Farmer Producer Organisations (FPOs), Kudumbashree Units, Self-Help Groups (SHGs), and Community-Based Organisations**: Assist in awareness generation, organic input production, orchard management, plantation activities, capacity building, and community-based monitoring.
- **Scientific and Academic Institutions**: Provide technical support for field verification, GIS-based assessments, monitoring, impact evaluation, and adaptive management.

Basin-Specific Recommendations for Different Zones

The spatial variability observed within the Periyar River Basin indicates the need for location-specific land management interventions based on physiographic characteristics, land-use patterns, and ecological sensitivity of different basin regions. In the upstream and highland regions of the basin, priority may be given to forestation and ecological restoration activities, particularly in degraded and erosion-prone landscapes. Protection of existing forest cover, slope stabilisation measures, and restoration using native species may support watershed conservation and reduce land degradation in environmentally sensitive areas. Suitable orchard crops such as coconut, banana, pineapple, cashew, and arecanut may be promoted in agro-climatically favourable regions identified through the suitability assessment. Coconut and pineapple cultivation may be prioritised in the northern and central parts of Devikulam Block Panchayat. In contrast, banana cultivation may be encouraged in the northern parts of Devikulam and selected areas of Adimali, Nedumkandam, and Kattappana Block Panchayats. Arecanut cultivation may be promoted in suitable locations within Devikulam and Angamaly Block Panchayats. In contrast, cashew cultivation may be considered in the eastern parts of Adimali, the western part of Nedumkandam, and the eastern part of Kattappana Block Panchayat. These areas possess favourable climatic, soil, and land-suitability characteristics and offer opportunities for sustainable orchard expansion and diversification of agricultural land use within the basin.

The midstream regions may focus on sustainable orchard development and integrated agricultural practices. Expansion of perennial horticulture in marginal and underutilised lands may improve vegetative cover, support livelihood diversification, and reduce soil erosion. Sustainable land management practices and soil conservation measures may be incorporated within existing agricultural landscapes. Organic farming interventions may be prioritised in suitable areas identified across the basin, including the western downstream regions near the river mouth and scattered patches in the central and eastern upstream sectors. The identified locations benefit from proximity to existing composting facilities and organic input sources, making them suitable for promoting decentralised nutrient management, local nutrient recycling, and sustainable agricultural practices. The higher concentration of settlements, accessibility, and availability of organic resource streams in these regions may support the development of organic farming clusters, composting systems, and market-linked sustainable agriculture initiatives. Across all basin zones, participatory planning, institutional coordination, long-term monitoring, and community engagement should be incorporated to support sustainable land-use management and ecological resilience within the Periyar River Basin.

References

1. AbdelRahman, M. A. E., Saleh, A. M., & Arafat, S. M. (2022). Assessment of land suitability using a soil-indicator-based approach in a geomatics environment. *Scientific Reports*, 12(1), 18113. https://doi.org/10.1038/s41598-022-22727-7
2. Akhtar, M., Zhao, Y., Gao, G., Gulzar, Q., & Hussain, A. (2022). Assessment of spatiotemporal variations of ecosystem service values and hotspots in a dryland: A case-study in Pakistan. *Land Degradation & Development*, 33(9), 1383–1397. https://doi.org/10.1002/ldr.4245
3. Alagulakshmi, K., Arulraj, G. P., Gautam, S., & Joshi, S. K. (2025). Spatio-temporal patterns of land use and land cover, and their impact on groundwater quality in the industrialized Muvattupuzha basin. *Scientific Reports*, 15(1). https://doi.org/10.1038/S41598-025-24567-7
4. Bartholomew, D. P., Paull, R. E., & Rohrbach, K. G. (Eds.). (2003). The pineapple: Botany, production, and uses. *CAB International*. https://doi.org/10.1079/9780851995038.0000.
5. Biru, M. K., Gadisa, C. W., Dirbaba, N. B., & Nunes, M. R. (2025). Land Use Changes and Their Impacts on Soil Erosion in a Fragile Ecosystem of the Ethiopian Highlands. *Land*, 14(7), 1473. https://doi.org/10.3390/LAND14071473/S1
6. Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science*, 320(5882), 1444–1449. https://doi.org/10.1126/SCIENCE.1155121;WEBSITE:WEBSITE:AAAS-SITE;JOURNAL:JOURNAL:SCIENCE;WGROUP:STRING:PUBLICATION
7. Bruijnzeel, L. A. (2004). Hydrological functions of tropical forests: Not seeing the soil for the trees? *Agriculture, Ecosystems & Environment*, 104(1), 185–228. https://doi.org/10.1016/j.agee.2004.01.015
8. Burrough, P. A., MacMillan, R. A., & van Deursen, W. (1992). Fuzzy classification methods for determining land suitability from soil profile observations and topography. *Journal of Soil Science*, 43(2), 193–210. https://doi.org/10.1111/j.1365-2389.1992.tb00129.x
9. Centre for Earth Science Studies. (2010). Annual report 2009-10. Government of India. https://www.ncess.gov.in/images/annual-report/NCESS_Annual_Report_2009-10_Eng.pdf

10. Chacko, S., Kurian, J., Ravichandran, C., Vairavel, S., & Kumar, K. (2019). An assessment of water yield ecosystem services in Periyar Tiger Reserve, Southern Western Ghats of India. *Geology, Ecology, and Landscapes*, 3(1), 32–39. https://doi.org/10.1080/24749508.2019.1699988
11. Chazdon, R. L. (2008). Beyond deforestation: Restoring forests and ecosystem services on degraded lands. *Science*, 320(5882), 1458–1460. https://doi.org/10.1126/SCIENCE.1155365;JOURNAL:JOURNAL:SCIENCE;WGROUP:STRING:PUBLICATION
12. De Rosa, D., Biala, J., Nguyen, T., Mitchell, E., Friedl, J., Scheer, C., Grace, P., & Rowlings, D. (2022). Environmental and economic trade-offs of using composted or stockpiled manure as partial substitute for synthetic fertilizer. *Journal of Environmental Quality*, 51(4), 589–601. https://doi.org/10.1002/jeq2.20255
13. Debesa, G., Gebre, S. L., Melese, A., Regassa, A., & Teka, S. (2020). GIS and remote sensing-based physical land suitability analysis for major cereal crops in Dabo Hana district, South-West Ethiopia. *Cogent Food & Agriculture*, 6(1). https://doi.org/10.1080/23311932.2020.1780100
14. Deng, B., Chen, T., Pu, Z., Peng, X., Qin, X., Zhan, X., & Wen, J. (2022). A Transportation Network Optimization Model for Livestock Manure under Different Terrains Considering Economic and Environmental Benefits. *Sustainability*, 14(13), 7721. https://doi.org/10.3390/su14137721
15. Faraslis, I., Dalezios, N. R., Spiliotopoulos, M., Tziatzios, G. A., Sakellariou, S., Dercas, N., Giannousa, K., Belaud, G., Daudin, K., Cameira, M. d. R., Paredes, P., & Rolim, J. (2025). Satellite-Based Innovative Agroclimatic Classification Under Reduced Water Availability: Identification of Optimal Productivity Zones. *Land*, 14(11), 2147. https://doi.org/10.3390/land14112147
16. Food and Agriculture Organization. (2018). Globally Important Agricultural Heritage Systems (GIAHS). Combining agricultural biodiversity, resilient ecosystems, traditional farming practices and cultural identity. FAO, Rome, Italy. https://openknowledge.fao.org/server/api/core/bitstreams/0ef0c947-d959-4be0-9a4a-1c2633262b2e/content
17. Fox, T. A., Rhemtulla, J. M., Ramankutty, N., Lesk, C., Coyle, T., & Kunhamu, T. K. (2017). Agricultural land-use change in Kerala, India: Perspectives from above and below the canopy. *Agriculture, Ecosystems & Environment*, 245, 1–10. https://doi.org/10.1016/J.AGEE.2017.05.002

18. Gayathri, S., Dev, V. v., Shiny Raj, R., Krishnakumar, A., Vishnu Maya, T. M., & Anoop Krishnan, K. (2021). Spatiotemporal evaluation of hydrochemical facies and pesticide residues in the cardamom plantations of Southern Western Ghats, India. *Environmental Nanotechnology, Monitoring & Management*, 16, 100599. https://doi.org/10.1016/J.ENMM.2021.100599
19. George, A., Joseph, S., Mohan, M., & Kunhamu, T. K. (2025). Carbon pools in the agroforestry landscapes of the Western Ghats biodiversity hotspot of Kerala, India. *CATENA*, 250, 108807. https://doi.org/10.1016/J.CATENA.2025.108807
20. George, A., Joseph, S., Sreejith, P. N., Mohan, M., & Kunhamu, T. K. (2024). Phytosociological attributes of high-elevation agroforestry systems in the Western Ghat regions of Kerala, India. *Agroforestry Systems*, 99(1), 13-. https://doi.org/10.1007/S10457-024-01105-4
21. Giriraj, A., Irfan-Ullah, M., Ramesh, B. R., Karunakaran, P. v, Jentsch, A., & Murthy, M. S. R. (2008). Mapping the potential distribution of Rhododendron arboreum Sm. ssp. nilagiricum (Zenker) Tagg (Ericaceae), an endemic plant using ecological niche modelling. CURRENT SCIENCE, 94(12). http://www.lifemapper.org/desktopgarp/
22. Gomiero, T., Pimentel, D., & Paoletti, M. G. (2011). Environmental impact of different agricultural management practices: Conventional vs. organic agriculture. *Critical Reviews in Plant Sciences*, 30(1-2), 95–124. https://doi.org/10.1080/07352689.2011.554355
23. Government of Sikkim. (2016). Sikkim Organic Mission: Policy and Strategy Document. Department of Agriculture, Government of Sikkim, Gangtok, India. https://www.sikkim.gov.in/Mission/Mission-info/1?Mission=Sikkim%20Organic%20Mission
24. Grüter, R., Trachsel, T., Laube, P., & Jaisli, I. (2022). Expected global suitability of coffee, cashew and avocado due to climate change. *PLoS ONE*, 17(1), Article e0261976. https://doi.org/10.1371/journal.pone.0261976
25. Halder, S., Banerjee, S., Youssef, Y. M., Chandel, A., Alarifi, N., Bhandari, G., & Abd-Elmaboud, M. E. (2025). Ground–Surface Water Assessment for Agricultural Land Prioritization in the Upper Kansai Basin, India: An Integrated SWAT-VIKOR Framework Approach. *Water*. https://doi.org/10.3390/w17060880
26. Hashim, H.Q., Sayl, K.N. Detection of suitable sites for rainwater harvesting planning in an arid region using geographic information system. *Appl Geomat,* 13, 235–248 (2021). https://doi.org/10.1007/s12518-020-00342-3

27. Hebbar, K. B., Abhin, P. S., Jose, V. S., Neethu, P., Santhosh, A., Shil, S., & Prasad, P. (2022). Predicting the Potential Suitable Climate for Coconut (Cocos nucifera L.) Cultivation in India under Climate Change Scenarios Using the MaxEnt Model. *Plants*, 11(6), Article 731. https://doi.org/10.3390/plants11060731
28. Intergovernmental Panel on Climate Change. (2006). 2006 IPCC guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies. https://iges.or.jp
29. Jacob, P., & Dwarakish, G. (2015). Temporal Analysis of Spatial Distribution of Built-Up Area in Peri-Urban Areas of Cochin, Kerala: Case-Study of Sub-Watershed in Periyar River. *Aquatic Procedia, 4*, 1445-1451. https://doi.org/10.1016/j.aqpro.2015.02.187
30. Jose, M., & Padmanabhan, M. (2016). Dynamics of agricultural land use change in Kerala: A policy and social-ecological perspective. *International Journal of Agricultural Sustainability*, 14(3), 307–324. https://doi.org/10.1080/14735903.2015.1107338
31. Kamilaris, A., & Prenafeta-Boldú, F. X. (2021). Examining the perspectives of using manure from livestock farms as fertilizer to crop fields based on a realistic simulation. *Computers and Electronics in Agriculture*, 191, 106486. https://doi.org/10.1016/J.COMPAG.2021.106486
32. Kerala Agricultural University. (2016). Package of practices recommendations: Crops (15th ed.). Thrissur, Kerala, India. https://kau.in/sites/default/files/documents/pop2016.pdf
33. Kumar, B. M., & Nair, P. K. R. (Eds.). (2006). Tropical homegardens: A time-tested example of sustainable agroforestry. *Springer*. https://doi.org/10.1007/978-1-4020-4948-4
34. Lal, R. (2005). Soil erosion and carbon dynamics. *Soil and Tillage Research*, 81(2), 137–142. https://doi.org/10.1016/J.STILL.2004.09.002
35. Mantino, A., Burbi, S., Re, M., Finocchi, M., Ripamonti, A., Pulido Fernández, M., Schnabel, S., Joaquín, ·, Lavado-Contador, F., Jäger, M., Baumann, M., Clémence, ·, Ulrich, B. ·, Victor, S. ·, & Gabourel-Landaverde, A. (2026). Enhancing ecosystem services to mitigate agro-environmental pressures: integrating participatory mapping and land suitability analysis for crop-livestock mixed farming and agroforestry systems. *Agroforestry Systems*, 3(100). https://doi.org/10.1007/S10457-026-01461-3

36. Ministry of Jal Shakti (2024). *River at a Glance Periyar,* National River Conservation Directorate (NRCD), Government of India. https://cperiyar.org/wp-content/uploads/2025/12/Periyar-River-at-a-Glance_20251218.pdf
37. Ministry of Jal Shakti (2025). *Periyar Agriculture Profiling Report*, National River Conservation Directorate (NRCD), Government of India. https://cperiyar.org/wp-content/uploads/2025/12/Agricultural-Profile-Periyar-Final.pdf
38. Ministry of Jal Shakti (2025). *Periyar River Atlas,* National River Conservation Directorate (NRCD), Government of India. https://cperiyar.org/wp-content/uploads/2025/10/Periyar-River-Atlas-Report-Draft-3.pdf
39. Mohan, M., Jaya, D. S., & Sheeja, R. V. (2022). Mapping of Land Use/Land Cover Changes in the Selected Midland Paddy Fields of Kollam District, Kerala, India. *Current Journal of Applied Science and Technology*, 41(22), 7–17. https://doi.org/10.9734/cjast/2022/v41i2231755
40. Nabati, J., Nezami, A., Neamatollahi, E., & Akbari, M. (2020). GIS-based agro-ecological zoning for crop suitability using fuzzy inference system in semi-arid regions. *Ecological Indicators*, 117, Article 106646. https://doi.org/10.1016/j.ecolind.2020.106646
41. Nampoothiri, K. U. K., & Sairam, C. V. (2001). Economics of arecanut and coffee mixed cropping system. *Plant Horti Tech*, 2(5), 30–33. http://14.139.158.120:8080/server/api/core/bitstreams/60ff2745-c36a-41da-a048-3b39c0c545eb/content
42. National Horticulture Board. (2021). Soil and Climate Requirements for Commercial Banana Cultivation in India. NHB, Ministry of Agriculture & Farmers Welfare, Government of India. https://nhb.gov.in/pdf/fruits/banana/ban012.pdf
43. Pimentel, D., Hepperly, P., Hanson, J., Douds, D., & Seidel, R. (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience*, 55(7), 573–582. https://doi.org/10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2
44. Prasad, A., & Kuruvila, A. (2024). Vanishing Paddies: Tracing the Transformation of Rice Cultivation in Kerala, India. *Asian Journal of Agricultural Extension, Economics & Sociology*, 42(11), 284–296. https://doi.org/10.9734/ajaees/2024/v42i112613
45. Reganold, J., Wachter, J. Organic agriculture in the twenty-first century. *Nature Plants* 2, 15221 (2016). https://doi.org/10.1038/nplants.2015.221

46. Saddique, N., Mahmood, T., & Bernhofer, C. (2020). Quantifying the impacts of land use/land cover change on the water balance in the afforested River Basin, Pakistan. *Environmental Earth Sciences, 79*. https://doi.org/10.1007/s12665-020-09206-w
47. Sadhwani, K., Eldho, T., Jha, M., & Karmakar, S. (2022). Effects of Dynamic Land Use/Land Cover Change on Flow and Sediment Yield in a Monsoon-Dominated Tropical Watershed. *Water*. https://doi.org/10.3390/w14223666
48. Saroj, P. L., & Rupa, T. R. (2014). Cashew research in India: achievements and strategies. *Progressive Horticulture*, 46(1), 1–17. https://www.cabidigitallibrary.org/doi/full/10.5555/20153009056
49. Sawant, N., Das, B., Mahajan, G., Desai, S., Raizada, A., Kumar, P., & Singh, P. (2025). Crop suitability analysis for the coastal region of India through fusion of remote sensing, geospatial analysis and multi-criteria decision making. *Scientific Reports*, 15, Article 8727. https://doi.org/10.1038/s41598-025-90754-1
50. Souček, J., Pražan, R., Roy, A., Plíva, P., Jelínek, A., & Vegricht, J. (2017). Comparison of logistic, energy and exploitative parameters of compost and manure application by spreaders. *Research in Agricultural Engineering, 63*. https://doi.org/10.17221/37/2017-rae
51. Thekkeyil, A., George, A., Abdurazak, F., Kuriakose, G., Nameer, P. O., Abhilash, P. C., & Joseph, S. (2023). Land use change in rapidly developing economies-a case study on land use intensification and land fallowing in Kochi, Kerala, India. *Environmental Monitoring and Assessment*, 195(9), Article 1089. https://doi.org/10.1007/s10661-023-11731-7
52. Tuomisto, H. L., Hodge, I. D., Riordan, P., & Macdonald, D. W. (2012). Does organic farming reduce environmental impacts? A meta-analysis of European research. *Journal of Environmental Management*, 112, 309–320. https://doi.org/10.1016/j.jenvman.2012.08.018
53. Zainulabdeen, Yomna & Nagaraj, H. (2023). Geospatial analysis of impact of changing land use pattern on Paddy wetlands: a case study of Thrissur District, Kerala, India. *Sustainability, Agri, Food and Environmental Research*. 11. https://doi.org/10.7770/safer-V11N1-art619.
54. Zeshan, M., Mustafa, M. R., & Baig, M. F. (2021). Monitoring Land Use Changes and Their Future Prospects Using GIS and ANN-CA for Perak River Basin, Malaysia. *Water*. https://doi.org/10.3390/w13162286