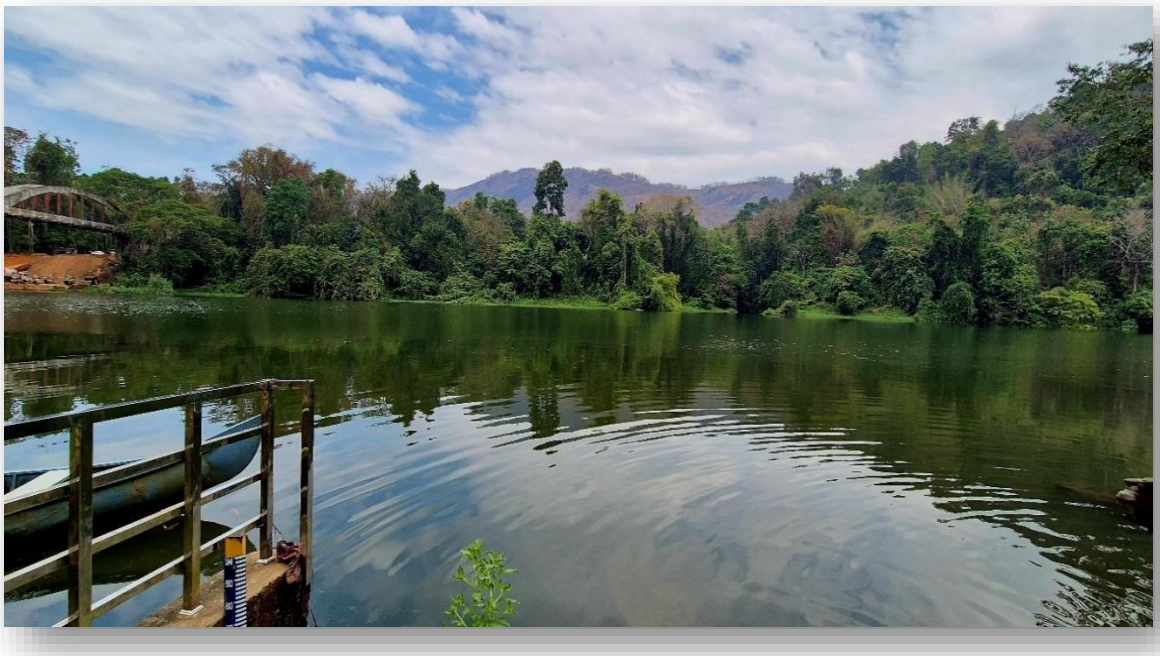
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Geological Profile of
Periyar River Basin



January 2025

Geological Profile of
Periyar River Basin

National River Conservation Directorate (NRCD)

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

www.nrcd.nic.in

Centres for Periyar River Basin Management Studies (cPeriyar)

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

www.cPeriyar.org

Centre for Ganga River Basin Management and Studies (cGanga)

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

www.cganga.org

Acknowledgment

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 2024. We gratefully acknowledge the individuals who provided information and photographs for this report.

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Preface

In an era of rapid environmental and geological transformation, understanding the dynamic nature of our river basins and the landscapes they shape has never been more critical. This report provides a comprehensive geological overview of the Periyar river basin**,** with a particular focus on the natural and anthropogenic factors that influences its terrain, resources, and stability.

Spanning diverse ecosystems and complex geological formations, the Periyar river serves as a critical lifeline for both biodiversity and human livelihoods in Kerala. Through this report, we aim to highlight key aspects such as the impacts of excavations, mining activities, granite quarrying, and hillslope changes, alongside detailed investigations into mineral exploration, deforestation trends, and riverbed mining. We also delve into the growing risks posed by natural geological disasters, including earthquakes, landslides, and tsunamis.

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

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

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

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

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List of Abbreviations

PRB	Periyar River Basin
PTR	Periyar Tiger Reserve
KOMPAS	Kerala Online Mining Permit Awarding Services
DMF	District Mineral Foundations
FSI	Forest Survey of India (FSI)
ISFR	India State of Forest Report
DEM	Digital elevation model
GSI	Geological Survey of India
MoEFCC	Ministry of Environment, Forest and Climate Change
NGT	National Green Tribunal
NASADEM	NASA Digital Elevation Model
Copernicus GLO-DEM	Copernicus Global Digital Elevation Model
BIS	Bureau of Indian Standards
KSDMA	Kerala State Disaster Management Authority

1. Introduction of the Periyar River Basin (PRB)

Periyar is the longest river in Kerala with a large discharge potential. It has a total length of approximately 244km and is also the state's second-largest river basin, covering an area of 5,245 km². The river originates from the remote forest of the Periyar Tiger Reserve (PTR), known as the Sivagiri hills of the Western Ghats. It flows through the Idukki, Ernakulam, and Thrissur districts of Kerala. It joins the Arabian Sea at Cochin. The PRB also acts as a region of sensitive ecological balance by supporting a rich and unique biodiversity. It is also an important source of irrigation and hydroelectric power generation.

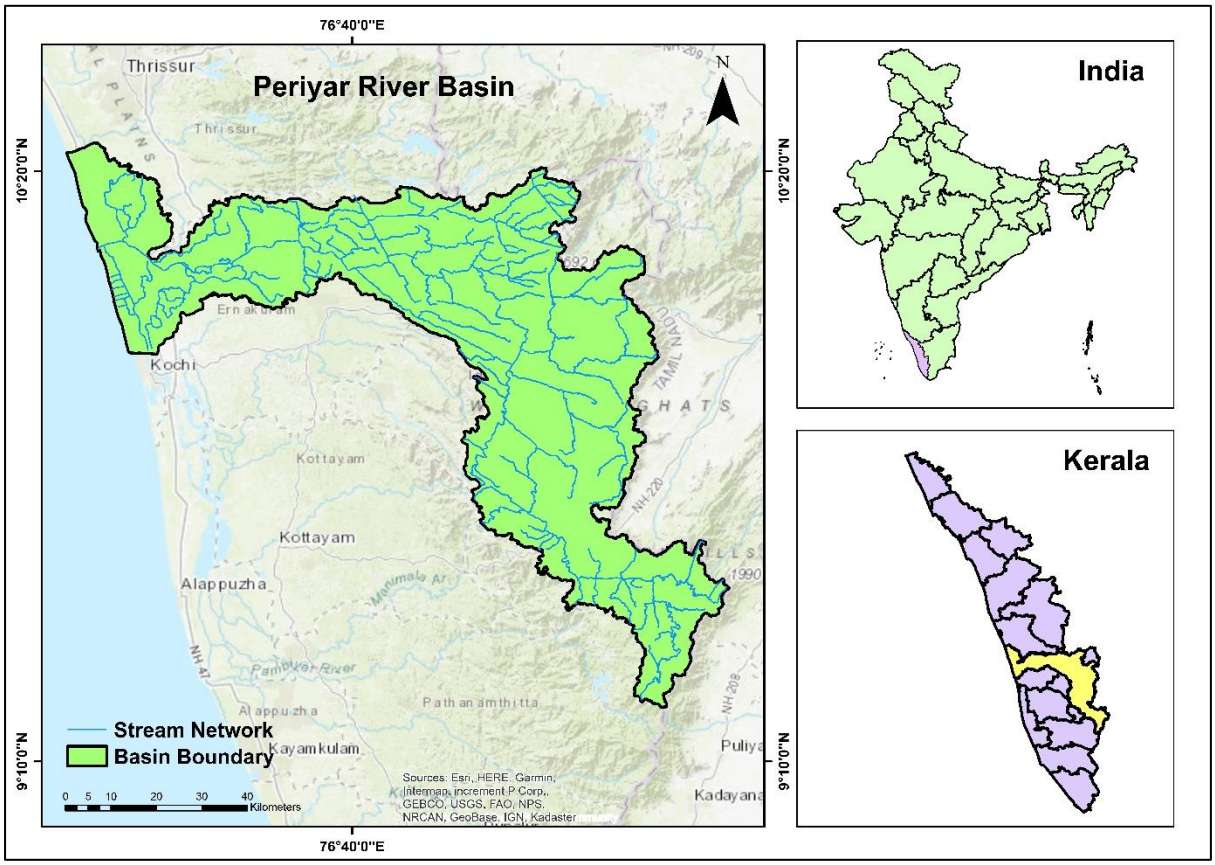

Figure 1. Boundary of the PRB

2. Excavations, explosions, and mining activities

The PRB, situated in the southern Western Ghats of Kerala, India, is a region of immense geological and ecological significance. The basin is underlain by Precambrian crystalline rocks, including charnockite, gneisses, and schists, which form the core of the Western Ghats. These ancient rocks are overlain by younger sedimentary formations and lateritic soils, shaped by prolonged weathering and erosion processes. The PRB topography is characterized by steep hillslopes, deep valleys, and a dense network of tributaries, contributing to its dynamic geomorphology. The region lies in a tectonically active zone, with evidence of past seismic activity

and faulting, which has influenced the basin's structural framework. This complex geological setting, combined with the region's high rainfall and tropical climate, has resulted in a landscape that is both diverse and fragile, making it highly susceptible to natural and anthropogenic disturbances.

The basin has been subject to significant human interventions, including excavations, mining activities, and deforestation, which may have influenced its natural geological profile. Riverbed mining, particularly for construction materials, has the potential to alter the river's physical structure, affecting its flow dynamics and sediment transport. Deforestation, driven by agricultural expansion and urbanization, could contribute to soil erosion and hillslope instability, potentially increasing the risk of landslides and flash floods. While these anthropogenic activities, along with the region's inherent geological vulnerabilities, are often associated with an increased frequency and intensity of natural disasters, such as landslides and floods, further detailed investigations are required to establish definitive causal relationships. This study aims to collect relevant data to better understand these interactions and assess their potential implications for the sustainability of the PRB.

2.1 Mineral exploration scenario in Kerala

Mining activities in Kerala are regulated by both central and state legislation, ensuring scientific mining practices, environmental conservation, and prevention of illegal mining. The legal foundation for worker safety, mining leases, and mineral exploration is provided by the Mines Act of 1952 and the Mines and Minerals Development and Regulation Act (MMDR Act of 1957), along with related regulations.

2.2 Mineral concession rules in Kerala

To regulate minor mineral administration, the Government of Kerala has enacted specific rules, including:

1. Kerala Minor Mineral Concession Rules, 2015 – Lays down procedures for granting quarrying permits, leases, and renewal terms for minor minerals under state jurisdiction.
2. Kerala Minerals (Prevention of Illegal Mining, Storage, and Transportation) Rules, 2015 – Focuses on curbing illegal mining, ensuring compliance with legal requirements for storage and transport.
3. Kerala District Mineral Foundation Rules, 2018 – Establishes District Mineral Foundations (DMF) to utilize a share of mining revenue for the welfare of affected communities.

4. Kerala Minor Mineral Concession (Amendment) Rules, 2023 – Introduces revisions to streamline mineral concession procedures and enhance transparency.
5. Kerala Minerals (Prevention of Illegal Mining, Storage, and Transportation) (Amendment) Rules, 2023 – Strengthens enforcement measures to prevent unauthorized extraction and trade of minerals.

While the Mineral Concession Rules - 1960 and the Mineral Conservation and Development Rules - 1988 regulate mineral leases and conservation at the national level, they do not apply to coal, atomic minerals, and minor minerals, which fall under state control. The state government plays a key role in granting and regulating quarrying leases for minor minerals, ensuring environmental sustainability and compliance with statutory provisions. There are two types of concessions given in terms of winning the minerals, and they are as follows:

1. Quarrying permit – A short-term permit issued for the quarrying of minor minerals in an area up to 1 hectare and for a maximum duration of one year.
2. Quarrying lease – A long-term permit issued for the quarrying of minor minerals, with a validity of up to 12 years.

2.3 Granite quarrying

The data collected from the Kerala Department of Mining and Geology shows that granite is the primary mineral being extracted in the PRB. Granite is a common construction material, and its extraction is widespread in the region due to its economic value and demand in the construction industry.

As per the Granite Conservation and Development Rules, 1999, the term "granite" includes dolerites, granite gneisses, migmatites, gabbros, anorthosites, rhyolites, syenites, leptynites, charnockites, and other igneous and ortho-metamorphic rock types that:

1. Are amenable to recovery as dimensional stone
2. Are capable of taking polish, and
3. Are commercially exploitable.

Since all quarries in the PRB consist of granite rock formations, these rules are relevant in ensuring scientific quarrying, environmental conservation, and sustainable utilization of resources. Quarrying activities in this region must comply with the prescribed guidelines to minimize ecological impacts and maintain commercial viability.

The distribution of quarries in the PRB and its vicinity is influenced by a combination of geological, ecological, and land-use factors. The central and western parts of the basin have the highest concentration of quarries due to the abundance of granite reserves, accessible terrain,

and proximity to urbanized areas with high demand for construction materials. In contrast, the eastern part of the basin, particularly beyond Kothamangalam, has very few quarries due to the presence of protected forest areas where quarrying is prohibited. Additionally, the stringent environmental regulations in the Idukki district, which encompasses vast ecologically sensitive zones, further contribute to the uneven distribution of quarrying activities across the PRB.

A 10 km buffer was created around the PRB to account for the fact that quarrying activities may not be restricted to a local area or immediate vicinity. Using this buffer polygon, all quarries within the PRB and its surrounding 10 km area were identified and extracted. The quarry data was sourced from Kerala Online Mining Permit Awarding Services (KOMPAS), the e-Governance initiative of the Department of Mining and Geology, which ensures transparency and efficiency in mineral administration. KOMPAS provides location-specific information on mining entities, quarries, crushers, and related details through a Google Maps-based service. This dataset offers a spatial distribution of quarries, which can be used for further geological and environmental studies.

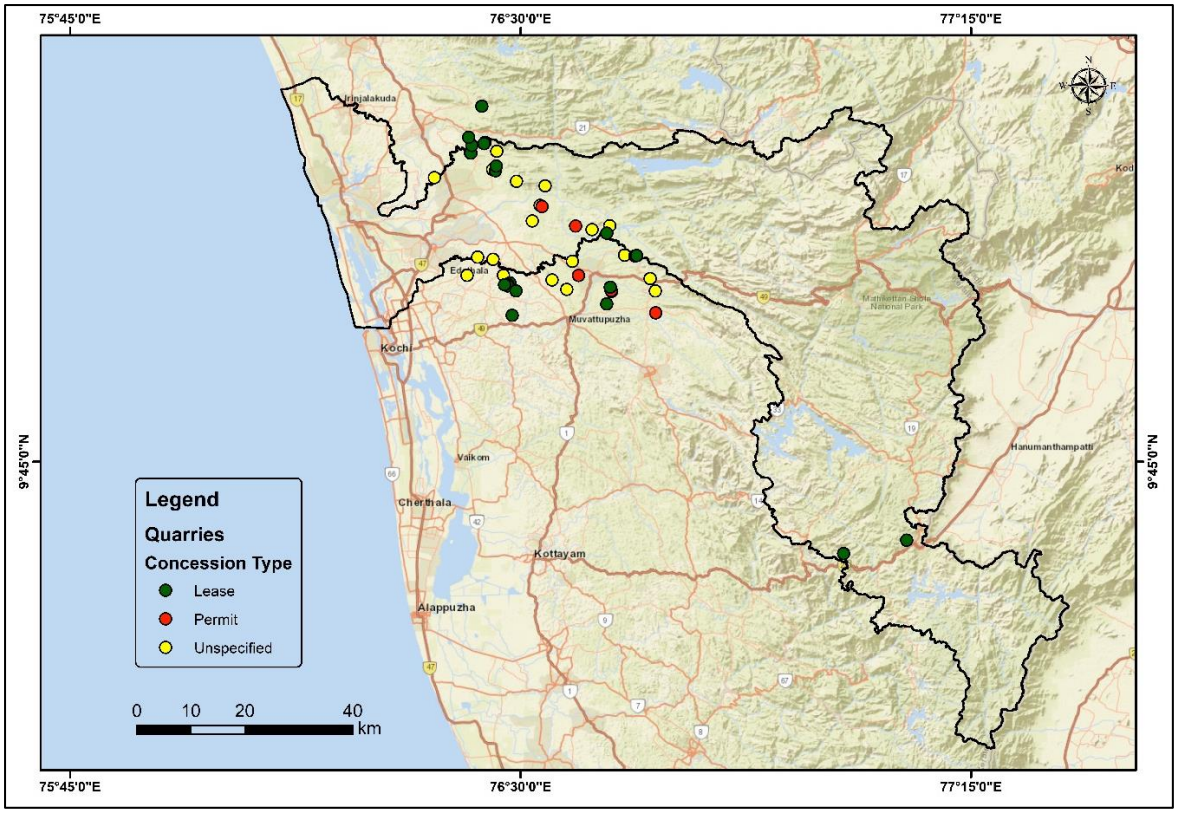

Figure 2. Concession type of active quarries in the PRB

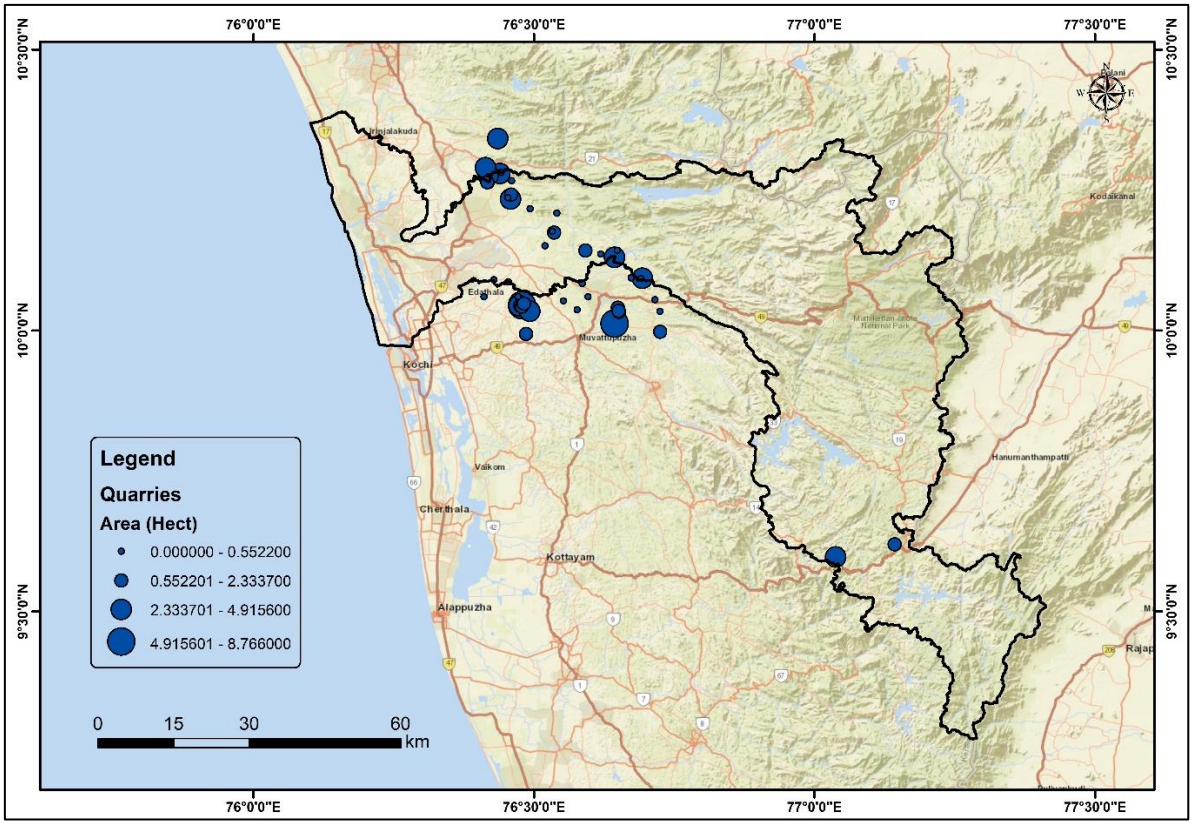

Figure 3. Quarrying activity areas in the PRB (not to scale)

Table 1. Details of quarries in and around PRB (Collected from district wise Permit/Lease/License details, KOMPAS Portal)

Sl. No.	Latitude	Longitude	DMG ID	Mineral	Name	Area (Ha)	Quantity (tonnes)	Valid from	Valid till	Concession type
1	10.14222222	76.59166667	ERN/Q/2023/428	Granite	Mary Alias	0.9843	36000	08.04.2024	07.04.2025	Permit
2	10.03333333	76.65166667	ERN/Q/2023/433	Granite	P P Varghese	0.9987	45468	27.05.2024	27.05.2024	Permit
3	10.03500000	76.65083333	ERN/Q/2023/434	Granite	P P Varghese	0.9981	56829	12.06.2024	11.06.2025	Permit
4	10.26361111	76.41666667	ERN/Q/2024/465	Granite	Amal P Wilson	0.7494	42153	28.06.2024	27.06.2025	Permit
5	10.17444444	76.53583333	ERN/Q/2024/466	Granite	Vysali Resorts Pvt Ltd	0.754	125000	01.07.2024	30.06.2025	Permit
6	9.99777778	76.72500000	ERN/Q/2022/425	Granite	Cherian K Jose	0.9845	78260	23.07.2024	22.07.2025	Permit
7	10.06000000	76.59652778	ERN/Q/2023/442	Granite	P M Moitheen	0.5522	59975	19.08.2024	18.08.2025	Permit
8	10.23416667	76.45833333	ERN/Q/2018/340	Granite	G M Granites	4.82	241002	04.05.2018	03.05.2029	Lease
9	10.04750000	76.48222222	ERN/Q/2019/373	Granite	St Marys Super Granites	1.4905	51656	15.02.2019	14.02.2031	Lease
10	10.01250000	76.64361111	ERN/Q/2019/375	Granite	P K Prasad	7.6606	320000	15.02.2019	14.02.2029	Lease
11	10.26361111	76.41750000	ERN/Q/2019/385	Granite	Gigi Mathew	1.4176	46314	29.07.2019	28.07.2027	Lease
12	10.27638889	76.41888889	ERN/Q/2020/390	Granite	Saji Vadakkekara	4.18	100000	25.11.2031	24.11.2031	Lease
13	10.24194444	76.45944444	ERN/Q/2020/392	Granite	Star Granites	1.2064	1925	03.06.2020	02.06.2025	Lease
14	10.04027778	76.64944444	ERN/Q/2023/440	Granite	Four Star Granites	1.642	107000	06.05.2023	05.05.2030	Lease
15	10.04500000	76.47888889	ERN/Q/2023/443	Granite	Cochin Granites Pulickal Associates	8.766	231000	20.06.2023	19.06.2033	Lease
16	10.04416667	76.47555556	ERN/Q/2024/463	Granite	Eldho Kuruvila	2.3337	150000	08.04.2024	07.04.2031	Lease
17	9.99361111	76.48611111	ERN/Q/2024/474	Granite	Kadakanad Aggregates Pvt Ltd	1.5281	55000	27.09.2024	26.09.2029	Lease
18	10.04250000	76.47861111	ERN/Q/2024/473	Granite	P K Prasad	2.123	124094	23.09.2024	22.09.2034	Lease
19	10.03416667	76.49250000	ERN/Q/2017/276	Granite	P K Prasad	3.6238	90000	05.10.2017	04.10.2029	Lease
20	10.27944444	76.43944444	ERN/Q/2018/298	Granite	P K P Granites	4.4497	8344	18.08.2017	17.08.2029	Lease
21	10.13027778	76.64361111	ERN/Q/2018/301	Granite	Annamma Antony	3.936	148900	17.02.2018	16.02.2030	Lease
22	10.04444444	76.47333333	ERN/Q/2018/307	Granite	P V Santhosh	3.947	75000	17.02.2018	16.02.2029	Lease
23	9.59694444	77.03777778	IDU/Q/2023/72	Granite	Raji Mathew	4.606	110000	08.03.2023	07.03.2035	Lease
24	9.61916667	77.14277778	IDU/Q/2015/47	Granite	Kizhakkethalackal Rocks	1.2344	40000	27.05.2015	26.05.2027	Lease
25	9.61916667	77.14277778	IDU/Q/2015/48	Granite	Kizhakkethalackal Rocks	0.9309	25000	27.05.2015	26.05.2027	Lease
26	10.34166667	76.43555556	THR/Q/2017/85	Granite	Pynadath Granites Ltd	4.7981	25882.5	16.01.2017	15.01.2028	Lease
27	10.28972222	76.41361111	THR/Q/2018/89	Granite	Ashokan M V	3.7415	50173	27.12.2017	26.12.2029	Lease
28	10.09305556	76.69333333	THR/Q/2018/92	Granite	Three Star Granites Pvt. Ltd.	4.9156	240000	27.12.2017	26.12.2027	Lease

Table 2. Details of quarries in PRB (Collected from quarry distribution map in KOMPAS Portal)

Sl. No.	Latitude	Longitude	DMG ID	Mineral	Name
1	10.21662900	76.49334300	ERN/Q/2015/243	Granite	T P Sabu
2	10.22265800	76.35667900	ERN/Q/2015/250	Granite	T M Joy
3	10.26660700	76.46036200	ERN/Q/2018/337	Granite	Star Rock Products pvt ltd
4	10.28148400	76.44101500	ERN/Q/2018/298	Granite	P K P Granites
5	10.23629000	76.45356400	ERN/Q/2015/56	Granite	Crystal Granite Ltd
6	10.20901000	76.54103200	ERN/Q/2022/406	Granite	Anugraha Metals and Sands Pvt Ltd
7	10.13613600	76.61911800	ERN/Q/2024/461	Granite	N A Thomas
8	10.14250600	76.64849800	ERN/Q/2018/327	Granite	Vettampara Nobel Granites Pvt ltd
9	10.09417000	76.67344200	ERN/Q/2018/313	Granite	Kumary Joy
10	10.09350300	76.67333000	ERN/Q/2018/314	Granite	Rema Rajeev
11	10.09241300	76.69058100	ERN/Q/2015/214	Granite	Reji Kuriakose
12	10.08351800	76.58631500	ERN/Q/2018/291	Granite	Kothamangalam Aggre-gates
13	10.05464900	76.71576600	ERN/Q/2018/309	Granite	Denson K S
14	10.03398900	76.72454800	ERN/Q/2018/288	Granite	Ever One Properties India Pvt Ltd
15	10.09031600	76.42855300	ERN/Q/2020/389	Granite	Anu J Kadavan
16	10.08671600	76.45427900	ERN/Q/2018/328	Granite	Cochin Granites
17	10.15062400	76.51960300	ERN/Q/2024/457	Granite	Saju GeorgeE
18	10.17650200	76.53263600	ERN/Q/2015/137	Granite	P C Baby
19	10.06006100	76.41109700	ERN/Q/2015/189	Granite	K T Paul
20	10.06030300	76.47161300	ERN/Q/2018/329	Granite	N V Kuriakose
21	10.05247000	76.55249400	ERN/Q/2015/212	Granite	M K Salim
22	10.03668600	76.57699000	ERN/Q/2015/119	Granite	A H Sheriff

While the number of active quarries within the PRB has been compiled using data available from the Department of Mining and Geology through the KOMPAS platform, it is important to acknowledge that numerous instances of illegal quarrying have been reported across Kerala by various media outlets. Despite the existence of stringent rules and monitoring mechanisms to prevent unauthorized operations, certain quarries continue to function outside the purview of regulation. These unregistered operations often go undocumented, making it difficult to assess their exact extent and environmental impact. However, considering their potential contribution to landscape alteration, habitat disruption, and pollution, the existence of such illegal activities must be acknowledged. Even though precise data is unavailable, such quarries still add to the overall pressure on the environment in the region.

3. Deforestation in PRB

The PRB, located in the ecologically sensitive Western Ghats of Kerala, is home to some of the richest and most diverse forest ecosystems in India. The PRB, which spans the districts of Idukki and Ernakulam as well as small areas of Thrissur district in Kerala and Coimbatore district in Tamil Nadu, is essential for controlling the hydrology, climate, and biodiversity of the area. The largest portion of the PRB includes vegetation comprising evergreen forest, deciduous forest, degraded forest, and shrubs. The PRB forests are classified as wet-evergreen, semi-evergreen, moist-deciduous, dry-deciduous, and pure reed areas (Periyar at a Glance Report 2024).

3.1 Data used for deforestation mapping

Table 3. Data used for deforestation mapping

Sl no.	Data type	Source	Format
1	Secondary data	Forest Survey of India	Reports i. Kerala Forest Statistics Report ii. India State Forest Report
2	Forest cover data	Forest Survey of India	Shapefile

To assess the forest cover changes within the PRB, a combination of secondary data and remote sensing data sources was utilized. The India State Forest Report (ISFR) by the Forest Survey of India (FSI) provided essential information on forest area distribution from 1991-2023. Forest cover shapefiles for 2022 and 2023, obtained from the FSI, were used to map the current distribution of forest within the basin.

3.2 Protected areas and forest cover

The Idukki district, which is well-known for its thick forests, rich biodiversity, and protected wildlife areas, which contain a major portion of PRB. The forests here are part of the Western Ghats. The district is home to several wildlife sanctuaries, national parks, and reserve forests, making it a crucial ecological hotspot. National parks are protected habitats for wildlife and ecosystems; Kerala is home to five national parks, of which 2 are in PRB. Eravikulam National Park is the largest in Kerala, covering around 79 square kilometers in PRB. This reflects the exceptional ecological value and its central role in wildlife conservation. Wildlife sanctuaries are protected areas for diverse species and ecosystems. They play a key role in conserving endangered species, preserving biodiversity, and maintaining ecological balance.

In Ernakulam, forest cover spans approximately 3063 sq. km (ISFR - 2023), primarily comprising moderately dense and open forests in regions like Kothamangalam, Iringole Kavu orest, Reserve Forest Chathamattam and Muvattupuzha, with Mangalavanam bird sanctuary a unique mangrove forest bird sanctuary. Thrissur district has a forest cover of 3027 sq. km (ISFR 2023).

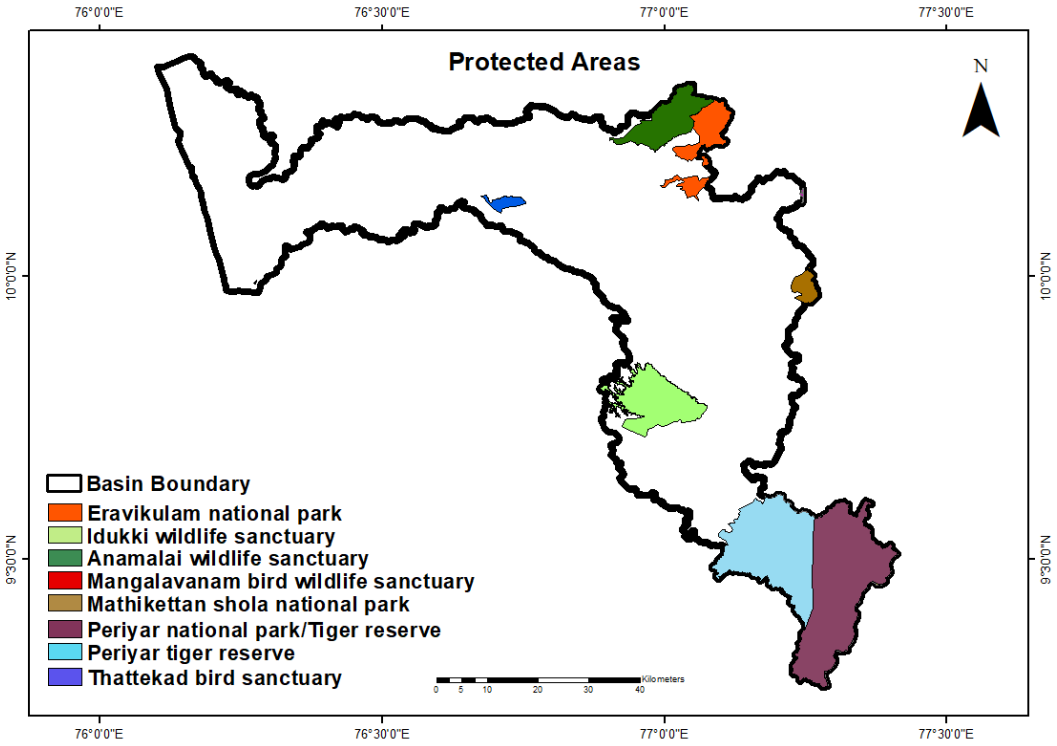

Fig 4. Protected areas in PRB

Table 4. List of protected areas in PRB

Sl No.	Name of wildlife sanctuaries/ National parks	Year of formation	Area within the PRB (Sq. km)
	National parks		
1	Eravikulam National Park	1978	78.85
2	Mathikettan Shola National Park	2003	22.075
	Wildlife Sanctuaries		
1	Periyar Wildlife Sanctuary/Tiger Reserve	1950	280.09
2	Idukki Wildlife Sanctuary	1976	142.78
3	Anamalai Wildlife Sanctuary	1976	98.57
4	Thattekkad Bird Sanctuary	1983	13.73
5	Mangalavanam Bird Sanctuary	2004	0.139
6	Periyar National Park/Tiger Reserve	1982	356.67

3.3 Forest statistics from 1991 – 2023

The India State of Forest Report (ISFR), released by the Forest Survey of India (FSI), offers a detailed evaluation of the nation's forest resources. Tables 5, 6, and 7 show the forest area details for the Idukki, Ernakulam, and Thrissur districts, respectively, from 1991 to 2023, which were collected from ISFR reports. It is important to note that earlier reports show relatively low forest area coverage, primarily due to limitations in mapping technology at the time. As remote sensing and geospatial technologies have advanced over the years, the accuracy and extent of forest mapping have significantly improved.

Table 5. Idukki district forest cover (ISFR)

Sl No	Year	Dense forest (km^2)	Open forest (km^2)	Total forest area (km^2)	Percentage of forest cover to geographical area
1	1991	2226	310	2536	50.10
2	1993	2226	310	2536	50.11
3	1995	2239	297	2536	50.11
4	1997	2239	297	2536	50.11
5	1999	2242	294	2536	50.11
6	2001	2671	1055	3726	74.24
7	2003	2476	1240	3179	74.10
8	2005	2497	1222	3719	74.10
9	2009	2510	1422	3932	78.34
10	2011	2509	1421	3930	78.30
11	2013	2458	1394	3852	76.75
12	2015	2430	1340	3770	75.11
13	2017	1955	1184	3139	72.07
14	2019	2143.99	1006.66	3150.65	72.33
15	2021	2139.05	1016.27	3155.32	72.44
16	2023	2207.69	1003.23	3210.92	73.71

The forest cover data for Idukki district (Table 5) shows both periods of growth and decline in forest area over time. From 1991-1999, the dense forest area remained constant within a range of 2226–2242 km², covering approximately 50% of the district's geographical area. However,

the open forest decreased slightly from 310 – 294km². This shows minimal forest change during this period. A notable increase occurred in 2001, with the total forest area rising sharply to 3726 km² (74.24%). This upward trend continued until 2011, peaking at around 78% of the district's area under forest cover. However, a decline followed, with the total forest area dropping to 3139 km² in 2017, and a significant reduction in dense forest. This period indicates a phase of deforestation, which may be due to increased human activities, urbanization, and land use changes. The period of 2019 – 2023 shows a slight recovery in forest cover. Overall, deforestation did occur during certain periods, especially post-2011.

Table 6. Ernakulam district forest cover (ISFR)

Sl No	Year	Dense forest (km^2)	Open forest (km^2)	Total forest area (km^2)	Percentage of forest cover to geographical area
1	1991	251	21	272	11.29
2	1993	251	21	272	11.29
3	1995	251	21	272	11.29
4	1997	251	21	272	11.29
5	1999	251	21	272	11.29
6	2001	433	128	561	23.31
7	2003	233	232	465	19.32
8	2005	244	293	469	19.48
9	2009	311	385	696	28.92
10	2011	310	385	695	28.87
11	2013	299	399	698	29
12	2015	294	412	706	29.33
13	2017	739	534	1273	41.56
14	2019	782.04	583.67	1365.71	44.59
15	2021	779.92	604.56	1384.48	45.20
16	2023	821.99	647.02	1469.01	47.96

The forest cover data for Ernakulam district (Table 6) shows significant changes to forested land over the years. From 1991 to 1999, the district had a stable forest cover of 272 km², for just 11.29% of its geographical area. In 2001, the total forest area increased to 561 km² (23.31%). After a short decline of about 92 km², the forest area from 2009 to 2023 showed

overall an upward trend, reaching 1290 km², approximately 42% of the district's geographical area. Peak forest cover was mapped in 2021 (1384km²). Recent forest cover shows a slight decline (1290 km²).

Table 7. Thrissur district forest cover (ISFR)

Sl No	Year	Dense forest (km^2)	Open forest (km^2)	Total forest area (km^2)	Percentage of forest cover to geographical area
1	1991	807	42	849	28
2	1993	807	73	880	29.03
3	1995	807	73	880	29.03
4	1997	807	73	880	29.03
5	1999	807	73	880	29.03
6	2001	549	344	893	29.45
7	2003	524	394	918	30.28
8	2005	524	394	918	30.28
9	2009	570	363	933	30.77
10	2011	569	362	931	30.71
11	2013	628	440	1068	35.22
12	2015	635	490	1125	37.09
13	2017	645	507	1152	38.06
14	2019	694.67	464.55	1159.22	38.30
15	2021	696.65	469.6	1166.25	38.53
16	2023	714.55	575.48	1290.03	42.62

The forest cover data for Thrissur district (Table 7) from 1991 to 2023 indicates a consistent increase in forest area over the years, with no evidence of deforestation. In 1991, the total forest area was 849 km², comprising 807 km² of dense forest and 42 km² of open forest, accounting for 28% of the geographical area. This positive trend in the area continued, peaking in 2023 with 1290.03 km² of forest cover, which is 42.62% of the district's geographical area

3.4 Forest area mapping

The FSI assesses the forest cover mapping of the country on a two-year cycle using satellite data. The forest cover is broadly classified into 4 classes, namely very dense forest, moderately dense forest, open forest, and mangrove. FSI classification criteria for forest mapping are provided in Table 8.

Table 8: Classification scheme of the forest as per FSI

Very dense Forest	All lands with tree cover, including mangrove cover, with a canopy density of 70% and above.
Moderately dense forest	All lands with tree cover, including mangrove cover, of canopy density between 40% and 70% above.
Open forest	All lands with tree cover, including mangrove cover, of canopy density between 10% and 40%.
Scrub	All forest lands with poor tree growth, mainly of small or stunted trees, having canopy density of less than 10 percent.
Non forest	Any area not included in the above classes

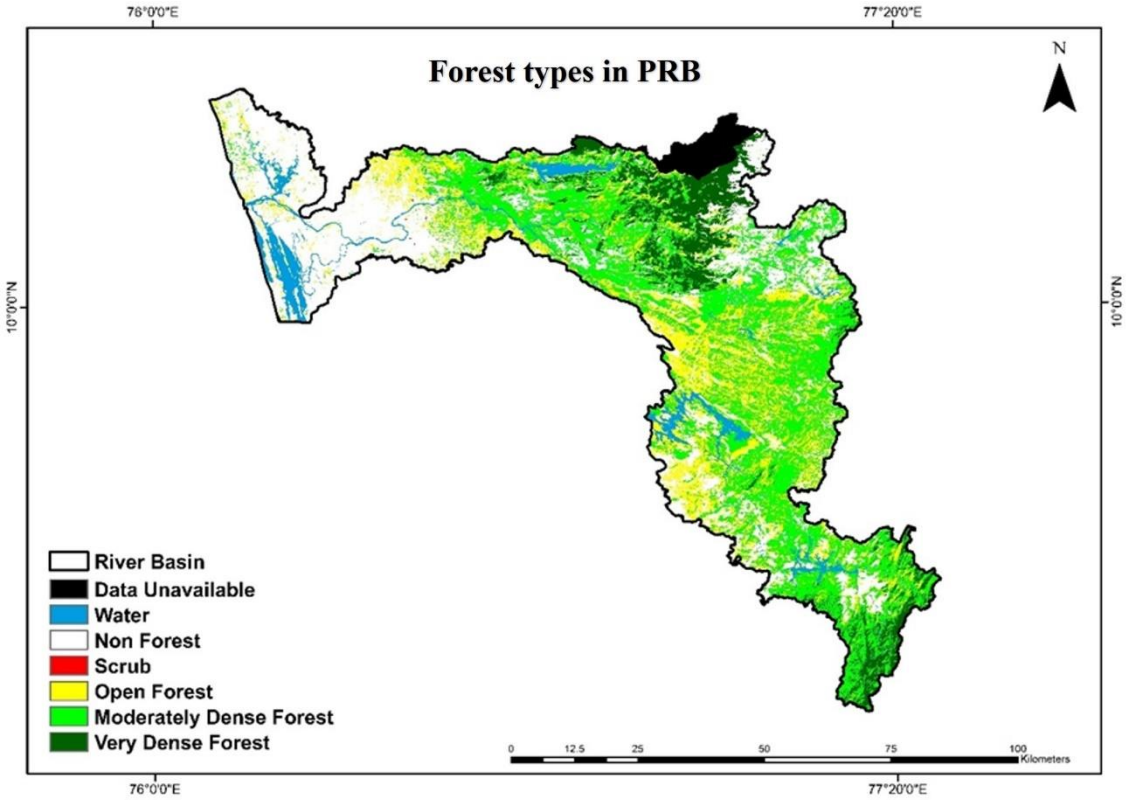

Figure 5. Distribution of forest types in PRB

Figure 5 represents the distribution of various forest types within the PRB for the year 2023. The Coimbatore district in Tamil Nadu is where the data that is unavailable falls. The area is included in the Anamalai Wildlife Sanctuary's protected zones (Figure 4). The eastern and southeastern regions of the basin exhibit a significant concentration of very dense forest, about 502km^2, particularly in higher elevation zones, indicating areas with rich biodiversity. Mostly the dense forest type is concentrated near the origin of the river and the north-eastern region. Moderately dense forests dominate a substantial portion of the central and southern parts. Table 9 shows the areal extent of different forest cover types within the river basin, as derived from the mapping analysis.

Table 9. Areal extent of different types of forest cover

Sl No.	Type	Area in 2023 (km^2)
1	Very dense forest	502.16832
2	Moderately dense forest	1756.183104
3	Open forest	982.668672
4	Scrub	0.491904
	Non forest	1634.070528

4. Riverbed mining

River sand mining in Kerala is controlled by the state government. River sand mining is regulated through the provisions of the Kerala Protection of Riverbanks and Regulation of Removal of Sand Act, 2001 (amended in 2013) and the associated Rules, 2002, along with the binding guidelines issued by the Ministry of Environment, Forest and Climate Change (MoEFCC), and the directives of the Hon'ble National Green Tribunal (NGT) and the Hon'ble Supreme Court. Since 2016, the state of Kerala has prohibited riverbed sand mining due to a lack of environmental clearance (Government of Kerala, 2022).

1) Periyar is included in the list of sand mining potential stretches.
2) A total number of 22 cases are registered against illegal sand mining from 01/04/2021 to 31/03/2022 for Idukki district and 12 cases for Thrissur district.

The major reasons for the sand mining are increased demand due to urban development. In-stream sand mining, which involves removing sand from an active river channel, and floodplain sand mining, which involves removing sand from overbank areas that flood during the monsoon, are the two forms of sand mining that are seen in the PRB. Both manual and mechanical techniques are used for this. The sand extraction in the midlands of the Periyar is 8 times higher

than in the lowlands and is most intense in urban centers. Severe and unregulated mining near city areas poses threats to riverine ecosystems and geomorphology (Sreebha & Padmalal, 2011). A total of five sand mining sites have been identified along the stretches of the Periyar river. From an area-wise perspective, all these sites are relatively small, each covering less than 5 hectares (CSIR-NIIST, 2023). Additionally, potential sand mining sites were identified along the Periyar, where future extraction may be considered based on observed suitability and impact assessments. (CSIR-NIIST, 2023).

Table 10. List of potential sand mining sites identified along the Periyar river during the 2022 field survey (CSIR–NIIST, 2023).

Sl no	Location	Total sediment available (m^3)	Mineable sand (m^3)	Latitude	Longitude
1	i.Towards Inchathotty Neriamangalam Road ii. Oonnukal-Acalichal-Neriamangalam Road	23180	13120	10.06	76.76
2	Towards Krariyely Kochupurakkankdavu Road	22930	4430	10.18	76.57
3	i.Towards Nedumbassery – Kodaikanal Road ii. Towards Vallom Panamkuzhi Road	2660	750	10.19	76.54
4	Towards Kannampuzha Road	17440	6220	10.19	76.51
5	i. Perumattom Road ii. Towards Kanjoor-Parappuram Road	5650	560	10.14	76.44

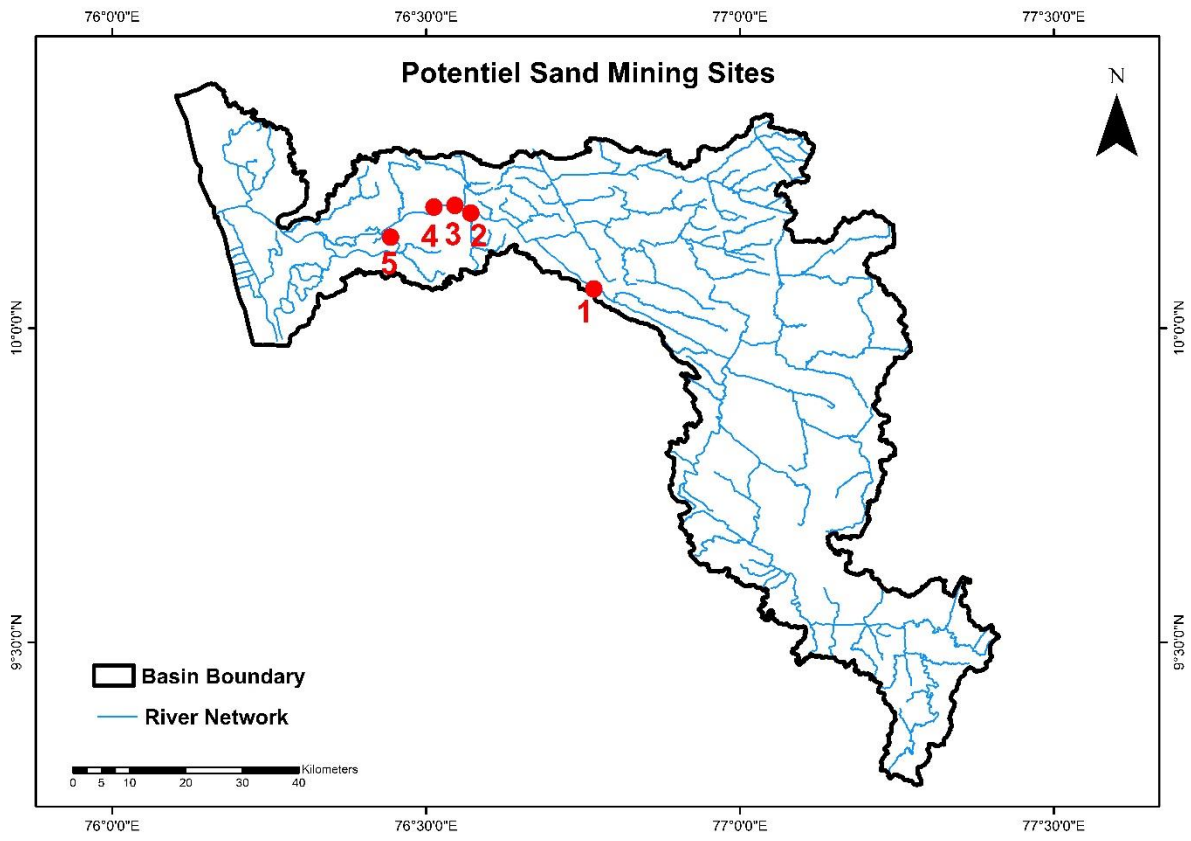

Figure 6. Location of potential sand mining sites identified along the Periyar river during the 2022 field survey (CSIR–NIIST, 2023).

5. Hillslope change

The slope change analysis for the PRB was carried out using elevation data from two sources: NASA Digital Elevation Model (NASADEM) and the Copernicus Global Digital Elevation Model (Copernicus GLO-30 DEM). NASADEM represents terrain conditions around the year 2000, derived from the Shuttle Radar Topography Mission (SRTM). In contrast, the Copernicus GLO-DEM (30m resolution) integrates elevation data primarily captured between 2011 and 2015 via the TanDEM-X mission. Both datasets were processed to generate slope maps using a standard slope calculation algorithm, and the slope values from the Copernicus DEM were subtracted from those of NASADEM to derive a slope change map, with values ranging from –67 to +66 degrees. This change map was then reclassified into four categories based on the magnitude of change: gentle, moderate, steep, and very steep.

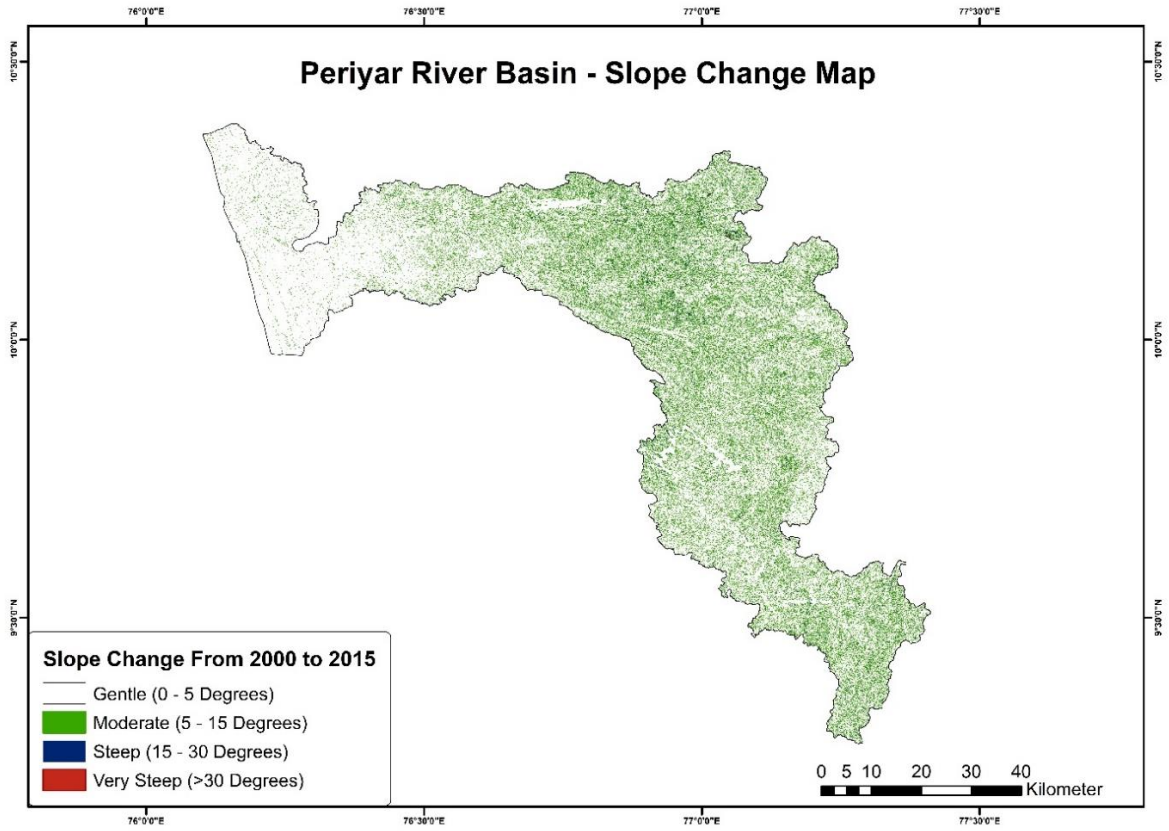

Figure 7. Slope change of PRB

The results of the slope change classification show that a significant portion of the PRB experienced only gentle slope changes, covering approximately 79.2% of the total area (around 4155 km²). Moderate slope changes account for 19.8% (1039.6 km²), while steep slope changes represent only 0.94% (49.05 km²) of the basin. Very steep slope changes are extremely limited, occupying less than 0.1 % of the area, or about 1.29 km². However, it is important to note that these very steep slope change regions may not solely reflect real geomorphic transformations. Some of these extreme values could arise due to data processing anomalies, particularly in areas where NASADEM (or the original SRTM) had voids or non-data values, which can lead to artificial spikes in slope calculations. Therefore, caution is advised while interpreting very steep and steep slope change zones, as they may partly result from such limitations in the input datasets rather than actual terrain modifications.

6. Natural geological disasters

Natural geological disasters are sudden, naturally occurring events that result from geological processes of the Earth, often causing damage to the environment, human life, and property. These disasters are closely related to the Earth's internal and surface dynamics, such as plate tectonics, erosion, weathering, and sedimentation. Studying natural geological disasters as part of river basin management is crucial for ensuring the safety, sustainability, and resilience of both human and ecological systems within the basin. The PRB is highly prone to natural geological disasters due to its complex geological structures, steep terrain, and heavy monsoonal rainfall.

Major types of natural geological disasters across PRB are,

a. Earthquake: Shaking of the ground caused by the sudden release of energy along fault lines.
b. Landslides: Sudden downward movement of rock, earth, or debris on slopes, usually triggered by heavy rainfall, earthquakes, or human activities like deforestation and construction.
c. Tsunamis: A tsunami is a series of large, powerful ocean waves caused primarily by undersea earthquakes.

The PRB spans across the districts of Idukki, Ernakulam, and Thrissur, each exhibiting distinct geographical and geological features. Idukki, located in the high-range Western Ghats, is highly susceptible to landslides due to its steep terrain, making most landslide-prone district in the basin. Ernakulam experiences landslides and earthquakes very rarely due to its lowland topography. The estuarine zones of the Periyar river near Kochi in Ernakulam could experience minor backwater effects during severe oceanic disturbances.

6.1. Earthquakes

The Bureau of Indian Standards (BIS) has classified the PRB's Idukki, Ernakulam, and Thrissur districts as being in Seismic Zone III. This zone indicates a moderate risk of earthquakes. While no significant earthquake has been reported in Ernakulam (Kerala State Disaster Management Authority [KSDMA], 2016). The Idukki district, sharing a significant portion of the PRB, has experienced notable low to moderate seismic activity, particularly in the vicinity of the Idukki reservoir.

According to John et al. (2016), the Periyar lineament is a prominent fault line along which the Periyar river flows. The mild earthquakes near Idukki are likely caused by increased water pressure within the fault zone. Historical records indicate that central Kerala has witnessed

repeated occurrences of earthquake doublets in the Idukki–Pala–Kottayam region, where major fault lines intersect.

Table 11 Details of historic earthquakes in Idukki district (Kerala State Disaster Management Authority [KSDMA], 2016)

Date	Location	Remarks
07 June 1988	Kallar-Idukki area, Kerala	Three events recorded, largest magnitude ML 4.5
12 Dec 2000	Idukki-Kottayam area, Kerala	Local magnitude (ML) of 5.0, felt strongly in Kochi, Idukki, Ernakulam
07 Jan 2001	Idukki-Kottayam area, Kerala	Felt throughout southern Kerala and adjoining parts of Tamil Nadu, local magnitude (ML) of 4.8

Historical earthquakes of Kerala show the occurrence of considerable seismic activity in the Kottayam-Idukki region of central Kerala because of the presence of several lineaments and bedrock fissures that transect these districts. An earthquake that occurred in 1988 was near the southeastern end of the Periyar fault, also 20 km east of the Idukki reservoir (Rastogi, Chadha, & Sarma, 1995). Reservoir-induced earthquakes are triggered by tectonic earthquakes. Several smaller aftershocks followed it. The tremor was felt within a 50 km radius and caused damage to buildings near the epicentre, with a maximum intensity of VI on the intensity scale. Based on gravity studies, Mishra et al. (1989) identified a shallow underground structure linked to the Periyar fault in that region. Further analysis confirmed that the earthquake was connected to this fault.

An earthquake occurred in the bordering regions of Idukki in 2000, followed by another event in 2001 in the same region. The second quake was accompanied by a short sequence of aftershocks, indicating an active seismic phase during that period (Bhattacharya & Dattatrayam, 2002).

Table 12 Earthquake classification details as per BIS

Earthquake classification	Earthquake (Magnitude-M)
Microearthquake	<3.0
Slight	3.2-4.9
Moderate	5.0-6.9
Great	7.0-8.0
Very Great	>8.0

Table 13: Earthquake-vulnerable areas of Idukki district (Kerala State Disaster Management Authority [KSDMA], 2016)

Taluk	Village	Earthquake (Magnitude)
Thodupuzha	Muttom	>3
	Alackode	>3
Devikulam	Kottakamboor	5
	Vattavada	5
Udumbachaola	Bisonvalley	5.7
	Chinnakanal	5.7
	Upputhodu	4.1
	Thankkamony	3.4 –4.5
	Vathikudy	3.4 –4.5
Peermade	Elappara	>3
	Mlappara	>3

Earthquake magnitudes in Idukki district range between 3 and 5.7, with Bison Valley and Chinnakanal recording the highest values, indicating the presence of moderate-intensity seismic activity in these areas.

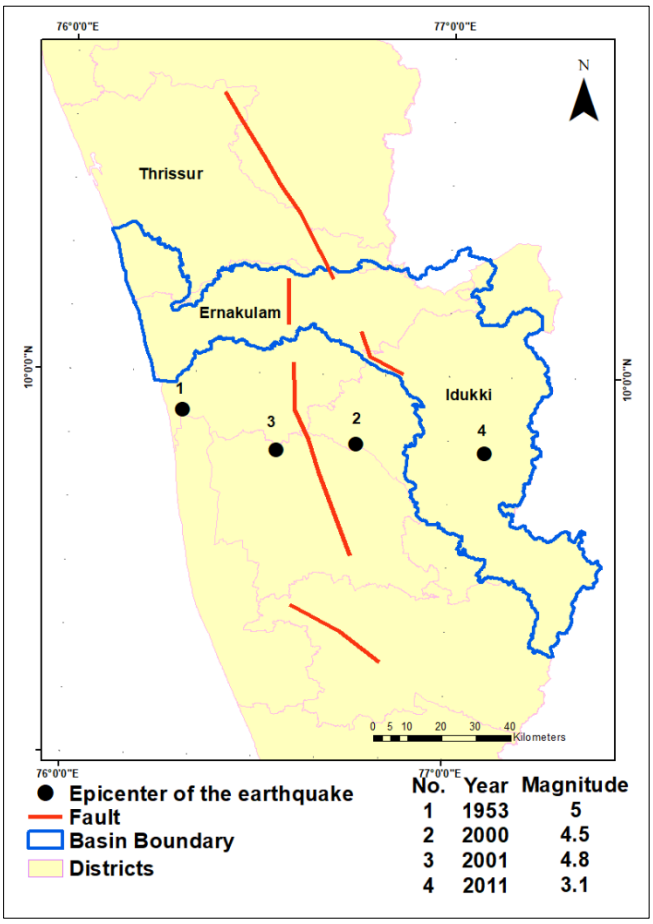

Figure 8. Earthquake epicenters and faults in PRB

Two earthquake events were reported in the Idukki district, which lies within the PRB, on 18 November 2011, with magnitudes of 2.8 ML and 3.1 ML. According to IMD data, the epicenter of the 3.1 ML earthquake was located at latitude 9.8° N and longitude 77.1° E. This falls near the Kalkoothal area of Idukki district, close to Upputhode and Nedumkandam near the Erattayar Dam in Idukki district. Kattapana, Erattupetta, Teekoy, Vazhikkadavu, Vagamon, Poonjar Thekkekkara areas felt the impact of tremors (Department of Disaster Management, Government of Kerala, 2011).

6.2 Landslides

Landslides are a serious geological hazard common in hilly regions. The PRB in Kerala is prone to landslides, particularly during the monsoon season. The region is experiencing a significant increase in the frequency and intensity of landslides due to extreme rainfall. Figure 9 shows the locations of landslide events that happened in PRB. The landslide data, represented by red dots, is sourced from the Geological Survey of India (GSI).

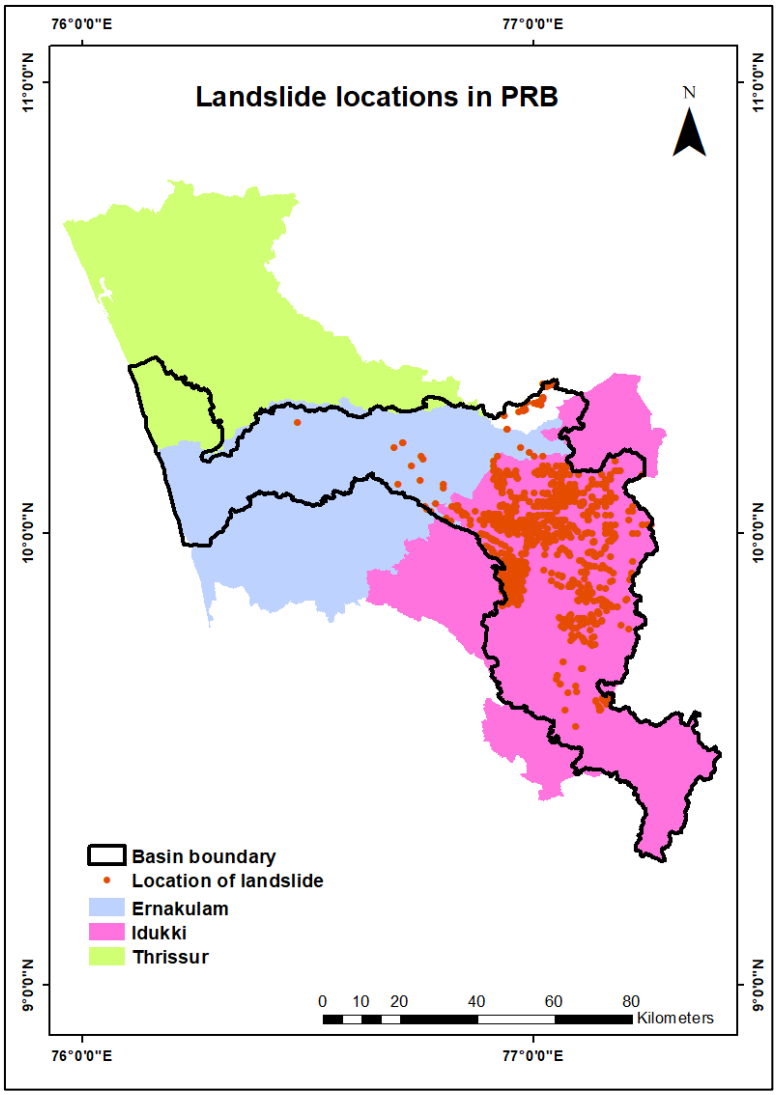

Figure 9. Landslide locations in the PRB

The Idukki district is extremely prone to landslides, while Ernakulam and Thrissur districts show less landslide activity within their respective portions of the basin. The eastern parts of Idukki are part of the Western Ghats, characterized by steep slopes, rugged terrain, and high relief factors that naturally increase slope instability. This region receives intense monsoonal rainfall. Specific areas in Idukki, like Munnar, Rajamala, Pettimudi, and Devikulam, are particularly vulnerable, especially during the monsoon season, especially southwest. Landslides in Idukki has caused extensive damage to roads, bridges, human dwellings, agricultural lands, orchards, forests, etc., resulting in loss of property and life as well. The District Emergency Operations Centre (DEOC), Idukki (2019) published a report identifying the possible causes of the landslides that occurred during the 2018 monsoon season. According to the report, soil saturation due to heavy rainfall increased the weight and pressure on slope materials, which was one of the major factors triggering landslides. Additionally, the presence of lateritic soil, known for its high-water retention and poor drainage capacity, led to the development of excessive water pressure within the slope. The absence of adequate protective measures, such as retaining walls along road cut slopes, further contributed to slope failure. The report also noted that some landslides blocked river channels, resulting in changes to the natural course of rivers. Past studies reveal that the Ernakulam district is susceptible to landslides, especially in areas under Kothamangalam and Aluva taluks. Studies show that most of the events of landslides are triggered by heavy rainfall (Kerala State Disaster Management Authority, 2015).

According to Kerala State Disaster Management Authority (2015), the factors contributing to landslide events are as follows:

1) Steep slopes cut for road or building construction can lead to earth or debris falling, especially during heavy rains (average annual rainfall is about 3300 mm), due to increased water pressure in the soil.
2) Dense trees near the edge of cut slopes add extra weight to already weak slopes, making them more likely to slide.
3) Poor land use practices like terracing, building culverts, and contour bunding can disturb natural slope stability.
4) Blocking natural drainage paths for housing and settlements prevents proper water flow and increases the risk of landslides.
5) Human activities such as cutting trees, waterlogging, farming on steep slopes, blocking small streams, and unplanned quarrying disturb the land and contribute to landslides.

As per the 2015 report of the Kerala State Disaster Management Authority, the landslide-prone locations in Idukki and Ernakulam districts have been identified. The major vulnerable sites within each village are detailed in Table 15.

Table 14. Landslide-prone location within each village in Idukki district (Kerala State Disaster Management Authority, 2015)

District	Taluk/Village	Landslide-prone area
Idukki	**Thodupuzha taluk**	
	Kumaramangalam	
	Kodikulam	
	Vannappuram	High (Vannapuram, Forest) Low (Amailakandam, Thommankuthu,Vannapuram, Forest)
	Kanjikuzhy	High (Thottakani, Kirithod, Chelachvada, Kanjikuzhi, Forest)
		Low (Varikkamuttom, Pazhayerikandam, Mailapuzha, Churuli, Forest)
	Udumbannoor	High (Chirikuzhi, Venniyanimudi, Mannukadu, Peringaserri, Forest)
		Low (Tattakkuzha, Vellamthanam, Kuzhimattom, Cheppukulam, Forest)
	Neyyassery	
	Karimannoor	
	Todupuzha	
	Manakkad	
	Purappuzha	Low (Kurinji, Toyipara)
	Karimkunnam	Low (NellaparaOttallur,Ilayarimala)
	Muttom	High (Kollankunnu, Kuzhiyanai,Tudonganad) Low (Kanayamala,Kollankunnu)
	Alacode	High (Ilamdesam,Kondilapalli) Low (Vettimattom,Onnaramala)
	Velliamattom	High (ParambukaduMala,Pumala,Velliyamattom,Forest) Low (Mudiyamala,Kuvakandam,)
	Arakulam	High (Mulamattom,Nadukanimala,Tumbikkalmala)
	Kudayathoor	High (Kudayattoormala, anakunnumudimala)
	Elappally	High (Edad,Chellikkal) Low (Kannikal,Manapad)
	Idukki taluk	
	Idukki	High (Painavu,Karara,Forest)

		Low (Kulamavu,Tadiyampadu,Forest)
	Kanjikuzhy	High (Thottakani, Kirithod, Chelachvada, Kanjikuzhi, Forest) Low (Varikkamuttom, Pazhayerikandam, Mailapuzha, Churuli Forest)
	Konnathady	High (Kambilikandam, Chinnar, Panikkankudi,) Low (Mullirikudi, Parathodu, Mukkudam, Injapatal, Ponmudi)
	Upputhode	High (KarikkumMedu) Low (RajamudiUpputod)
	Mannamkadam	High (Ayiram Acre,Chattupara,Machiplavukudi Forest) Low (Machiplavu, Deviarcolny, Forest)
	Devikulam taluk	
	Mankulam	High (Mankulam, Forest) Low (Anakulam,Perumbamkuthu, Forest)
	Anaviratty	High (Kallavattayar,KallarEstate, KainakarEstate) Low (TaliyamEstate, PlamalaEstate)
	Vellathooval	High (Kallarkutti,Elakunnu, Forest) Low (Vellathuval,Mankadav,Forest)
	Kunnjithanny	High (Elakallu,KunjithaniTukupara) Low (AnachalChengalam)
	Pallivasal	High (PallivasEstate,Mincutcolony) Low (PallivasalEstate,Chithirapuram)
	Kannan Devan Hills	High (Munnar, Devikulam Estate, Kallar Estate, Mattupetti Estate, Valkadavu Estate, Kadalar Estate, Forest)
	Marayoor	High (Kudakkad, Forest) Low (Marayur,Pattikadu,Karumutti, Forest)
	Keezhanthoor	High (Vananthurai,Kolattamala,Chundakattumala, Forest) Low (KIlandur,Punganpalli, Forest)
	Kanthalloor	High (Kolachivayal,Puthur,kanthallur, Forest)
	Kottakamboor	High (Thattumpera,Kadavari, Kattamboor,Forest)
	Vattavada	High (Kovilur,Vattavada,Pattithalaichelimala, Forest)
	Bisonvally	High (PallivasalEstate,PeriyakanalEstate,Korangupara) Low (MunnurekkarEstateMuduvakodu,Bisonvalley)
	Udumbanchola taluk	
	Chinnakanal	High (Nadupara,PeriyakanalEstate,NagamalaEstate,)
	Poopara	High (Mullantandu, Panniyar Estate, Forest) Low (Pupara, Koranpara, Panniyar Estate)

	Rajakumari	High (Manjakuzhi, Mullantand, Periyakanal Estate) Low (Kumbapara Estate, Periyakanal Estate)
	Rajakadu	Low (Rajakkad,Ennarsiti,Kanakkapulla,Panni-yarkutti)
	Udumbanchola	Low (Tinkalkadu Estate, Attupara Estate, Elappara Estate, Vallarakkan Estate, Leshmi vilasom Estate)
	Kanthipara	Low (Gandhipara Estate, Kuttankal)
	Santhanpara	High (NadupaniEstate) Low (Ilayakod Estate, Apparpullu Estate, Kallip-araEstate)
	Chadhuramga para	High (Talayankavu Estate)
	Parathodu	High (IsvarimedEstate,Nainarmudi) Low (Nedumkandam,AsokavanamEstate,Valpar-aEstate)
	Kalkoonthal	Low (Ponnamala,Ittithoppu,Kumbanmala)
	Thankamany	
	Kattappana	High (TankamanyChattikuli,Idukki,Nayarupara) Low (Ampalamedu,Valiyakamakshi,Veliyaka-tumali)
	Pampadumpara	Low (Pampadumpara Estate, Chakkakanam, Kallar, Mundiyeruma)
	Karunapuram	Low (Kurivikkonam,Kulitholuvmala,Prakkadavu)
	Vandanmedu	Low (Anniyartolu, Puliyamala)
	Anakkara	Low (Pampumpara)
	Chakkupallam	Low (SitamparaEstate,ChakkupalamEstate)
	Ayyappancoil	High (TahsilparaEstate, Forest) Low (Karinku-lamEstate,Kaltotti, Forest)
	Anavilasom	Low (TahsildarparaEstate,MadhavankanmEstate,)
	Vagamon	High (Vedikuzhi,AlampallyEstate) Low (Pulikanam Estate, Kotamala Estate, Chintala, Pasupara Estate, VagamonEstate)
	Peermade taluk	
	Elappara	High (AnnantambiMala, Theppakulam Estate, Glanmary Estate) Low (KoduvakaranamEstate, ThyfordEstate,)
	Kokkayar	High (UrumbikkaraEstate,MukkulamEstate,) Low (Puvali,BoyceEstate)
	Peruvanthanam	High (ChuzhuppilEstate, MeloramEstate, cheru-vallikulam, Kanayang avayal,AmalagiriEstate) Low (OrkadanEstate,ManikalluEstate)
	Peermade	High (RanimudiEstate,PampanarMala,Forest) Low (Peermed,Forest)

	Manjumala	High (Kirikara, Forest) Low (Varayattumotta,PasuMalaEstate,Manjumala
	Periyar	Low (ThankamalaEstate,Vandiperyar,Nel-likayEstate, Forest)
	Kumily	High (Forest) Low (Attapaam, MurukkadiEstate, Dymock, Chen-kara, Vellaramkunnu, Forest)
	Mlappara	High (Periyar RF)
Ernakulam	Kothamangalam taluk	NeryaMangalam, Kuttampuzha, Kadavoor
	Aluva taluk	Ayyamppuzha, Malayyattur

In 2020, a severe landslide occurred in the Rajamala and Pettimudi areas of Devikulam Taluk, Idukki district. One of the most significant events was the Pettimudi landslide on August 6, 2020, which was primarily triggered by intense and continuous rainfall in the region. The affected residential structures, known as layams, were situated at the foot slope near the confluence of a second-order streamlet with the Anaimudi Ar, a major stream that flows southwest and ultimately joins the Periyar river. The geomorphological setting, combined with hydrometeorological factors, played a key role in the slope failure (Achu et al., 2021).

Figure 10. An aerial view of the Pettimudi debris flow

6.3 Tsunamis

The low-lying coastal area located in the Ernakulam and Thrissur districts, where the Periyar river joins with Arabian sea, is prone to tsunamis. In 2004, the Indian Ocean tsunami caused damage across three southern districts of Kerala, with Ernakulam being one of the affected areas. The tsunami caused more severe damage in areas where the seawall was absent or interrupted. A total of three tsunami waves were observed, each with a height exceeding 4 meters. The waves travelled approximately 1000 meters inland, resulting in an inundation depth of about 2.4 meters. (Sheth et al., 2006).

Table 15. Eroding sectors along the coast in each district of the PRB (Kerala State Disaster Management Authority [KSDMA], 2016).

District	**Taluk**	**Length**		**Length**		**Length**	
		Km	%	Km	%	Km	%
		High		High		Low	
		Without sea wall		With sea wall			
Ernakulam				33.39	69.02		
	Kochi			33.39	69.02		
Thrissur		2.58	3.43	17.37	23.16	0.98	1.3
	Chavakkad	2.58	6.3	8.04	19.66	0.98	2.38
	Kodungallor			9.32	45.86		

The regions like Kochi, Paravur, and Kanayannur were the most exposed to the tsunami in the Ernakulam district (Kerala State Disaster Management Authority [KSDMA], 2016).

Table 16. Area exposed to the tsunami in Ernakulam district (Kerala State Disaster Management Authority [KSDMA], 2016).

Districts	**Taluk**	**Area Km^2**	**Area %**
Ernakulam		58.02	1.9
	Kochi	45.06	31.11
	Paravur	4.05	2.11
	Kanayannur	8.91	2.8

7. Conclusion

The underlying Precambrian crystalline rocks, steep terrain, and tectonic setting make the region inherently vulnerable to geomorphic disturbances, which are further intensified by anthropogenic activities such as quarrying, deforestation, and excavation. The ongoing extraction of granite primarily through regulated quarrying under the Kerala Minor Mineral Concession Rules has been identified as a prominent land use in parts of the basin, particularly where geological and infrastructural conditions permit. However, unregulated and illegal quarrying continues to pose significant environmental risks, undermining sustainability efforts and potentially worsening hillslope instability and sediment imbalance in river systems.

Analysis of the forest cover data reveals the ecological significance of the PRB due to its rich and diverse forest ecosystems. Idukki district contains the largest area of forested land. In the Ernakulam district, forest cover increased after 2001, though recent data show a slight decline from its peak in 2021. Thrissur district showed a consistent increase in forest area. The PRB is mostly covered by moderately dense forest, followed by open forest and very dense forest, with the presence of protected areas such as national parks and wildlife sanctuaries playing a crucial role in biodiversity conservation. Continuous monitoring, sustainable land management, and proactive forest protection policies help preserve the ecological integrity of the PRB.

Regarding sand mining studies and official reports revealed that the Periyar is under pressure due to both instream and floodplain sand mining, especially in urbanized midland zones, where extraction is up to eight times higher than in the lowlands. The increasing demand for sand, driven by rapid urban development, is a major contributing factor. Although sand mining in Kerala has largely ceased since 2016 due to the lack of environmental clearances, reports show ongoing and potential future mining activities along the Periyar were under 5 hectares. Unregulated and excessive sand mining, particularly near urban areas, threatens the ecological balance, river geomorphology, and aquatic ecosystems. These findings highlight the urgent need for sustainable sand mining practices, and continuous impact assessments to mitigate further degradation of the Periyar and its surrounding habitats.

The slope change analysis using multi-temporal elevation datasets indicates that while most of the basin has experienced gentle changes, localized areas of moderate to steep slope variation do exist, which need further investigation. Although some variations may be artifacts of DEM

resolution and data gaps, others could correspond to real alterations driven by excavation and land use changes over the past two decades.

The PRB, due to its varying terrain and geologic features, is highly prone to natural geological disasters, mainly earthquakes, landslides, and tsunamis. Historical data indicate that several earthquakes, most notably in 1988, 2000, and 2001, were associated with the Periyar fault line, suggesting the region's tectonic sensitivity. These events pose potential risks, especially around major infrastructure like the Idukki Dam.

Landslides are the most frequent and damaging geological hazard in the basin, especially in the eastern and central regions of Idukki. These are primarily triggered by intense rainfall, steep slopes, unscientific land use, deforestation, and human interventions along riverbanks and hill slopes. Though rare, tsunami threats affect the coastal areas of Ernakulam and Thrissur districts.

The Periyar River Basin, with its intricate geological framework and ecological significance, represents a dynamic landscape shaped by both natural processes and human interventions. Along with these natural factors, human activities further intensified the pressures on the basin's geological stability. Together, these challenges highlight the importance of proper planning, efficient land use, and effective environmental protection measures for the long-term safety and resilience of the PRB. Preserving the geological and ecological integrity of the PRB requires a balanced approach that considers both developmental needs and long-term environmental sustainability.

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