ASSESSING THE INFLUENCE OF LAND COVER CHANGES ON THE BASEFLOW REGIME:

A CASE OF BHARATHAPUZHA RIVER

BACHELOR OF PLANNING

Samudra D

2021BPLN022

Under the guidance of

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School Of Planning and Architecture, Bhopal

Neelbad Road, Bhauri, Bhopal, M.P.

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A PLANNING THESIS

Submitted in partial fulfilment of the requirement for the award of the degree of

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Declaration

I Samudra D, Scholar No.2021BPLN022 hereby declare that the thesis entitled Assessing the Influence of Land Cover Changes on the Baseflow regime: A case of Bharathapuzha River, submitted by me in partial fulfilment for the award of Degree of Bachelor of Planning, at School of Planning and Architecture, Bhopal, India, is a record of bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

Signature of the Student

Date:

Certificate

This is to certify that the declaration of my thesis titled ‘Assessing the Influence of Land Cover Changes on the Baseflow regime: A case of Bharathapuzha River is true to the best of my knowledge and that the student has worked under my guidance for one semester in preparing this thesis.

RECOMMENDED

Signature of the Guide
Name and Designation

ACCEPTED

Signature of the HOD

Name and Designation

Date:

Place:

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Samudra D

ABSTRACT

The Bharathapuzha River, Kerala's second-longest river, has experienced significant hydrological shifts over recent decades, notably in its baseflow regime. As baseflow represents the groundwater-fed component of streamflow critical for sustaining river health during dry periods, understanding its variability is essential. This study investigates how land cover changes—particularly deforestation, urban expansion, and agricultural intensification—have influenced baseflow patterns over a 30-year period.

The research adopts a multidisciplinary approach, integrating remote sensing and GIS-based land cover classification (using Landsat imagery from 1993–2023) with hydrological modelling. The Base Flow Index (BFI) was calculated using the HYSEP digital filter method within the USGS framework, and temporal trends in baseflow, streamflow, precipitation, and groundwater levels were analysed. The Mankara gauging station served as the primary data point for sub-watershed-level analysis. Results show a consistent decline in BFI in areas where natural vegetation was converted into built-up or intensively farmed land, indicating reduced infiltration and aquifer recharge.

The study identifies critical intervention zones and proposes watershed-scale strategies including riparian restoration, managed aquifer recharge, afforestation, and urban land-use regulation. By integrating qualitative stakeholder inputs with quantitative analysis, it emphasizes the need for incorporating baseflow sustainability metrics into river basin planning and water governance. The findings contribute to the broader discourse on climate-adaptive river management and underline the importance of land system stewardship in preserving groundwater-supported river flows.

Keywords: Base Flow Regime, Land Cover, Base Flow Index (BFI), Streamflow Analysis, Watershed Management, Remote Sensing and GIS

सारांश

भरतपुझा नदी, केरल की दूसरी सबसे लंबी नदी, ने हाल के दशकों में महत्वपूर्ण जलविज्ञान संबंधी परिवर्तनों का अनुभव किया है, विशेष रूप से इसके बेस फ्लो प्रणाली में। बेस फ्लो वह प्रवाह होता है जो मुख्यतः भूजल द्वारा पोषित होता है और सूखे मौसम के दौरान नदी के स्वास्थ्य को बनाए रखने में अहम भूमिका निभाता है, इसलिए इसकी परिवर्तनशीलता को समझना अत्यावश्यक है। यह अध्ययन यह जांच करता है कि भूमि उपयोग और भूमि आवरण में आए बदलाव—विशेषकर वनों की कटाई, शहरी विस्तार और कृषि तीव्रीकरण—पिछले 30 वर्षों में बेस फ्लो के पैटर्न को किस प्रकार प्रभावित कर रहे हैं।

शोध एक बहु-विषयक दृष्टिकोण को अपनाता है, जिसमें लैंडसैट उपग्रह चित्रों (1993–2023) का उपयोग करते हुए रिमोट सेंसिंग और जीआईएस आधारित भूमि आवरण वर्गीकरण को हाइड्रोलॉजिकल मॉडलिंग के साथ एकीकृत किया गया है। बेस फ्लो इंडेक्स (BFI) की गणना USGS ढांचे के अंतर्गत HYSEP डिजिटल फ़िल्टर विधि द्वारा की गई, और बेस फ्लो, स्ट्रीमफ्लो, वर्षा और भूजल स्तरों में समयानुसार रुझानों का विश्लेषण किया गया। सब-वाटरशेड स्तर पर विश्लेषण के लिए माणकरा गेजिंग स्टेशन को प्रमुख डेटा स्रोत के रूप में लिया गया। परिणामों से पता चलता है कि उन क्षेत्रों में BFI में निरंतर गिरावट आई है जहाँ प्राकृतिक वनस्पति को शहरी या तीव्र कृषि उपयोग में परिवर्तित किया गया, जिससे जल का अंतःस्रवण और जलभृत पुनर्भरण घटा है।

अध्ययन कुछ महत्वपूर्ण हस्तक्षेप क्षेत्रों की पहचान करता है और वाटरशेड स्तर की रणनीतियाँ सुझाता है जिनमें नदी तटीय बहाली, प्रबंधित जलभृत पुनर्भरण, वनीकरण तथा शहरी भूमि उपयोग नियमन शामिल हैं। यह अध्ययन मात्रात्मक विश्लेषण के साथ-साथ हितधारकों से प्राप्त गुणात्मक इनपुट को एकीकृत करता है और नदी बेसिन योजना तथा जल शासन में बेस फ्लो की स्थिरता को एक प्रमुख मीट्रिक के रूप में शामिल करने की आवश्यकता पर बल देता है। ये निष्कर्ष जलवायु-उन्मुख नदी प्रबंधन पर व्यापक विमर्श में योगदान करते हैं और भूजल-आधारित नदी प्रवाह को बनाए रखने के लिए भूमि प्रणालियों के सतत प्रबंधन की महत्ता को रेखांकित करते हैं।

कीवर्ड्स: बेस फ्लो रेजीम, भूमि आवरण, बेस फ्लो इंडेक्स (BFI), स्ट्रीमफ्लो विश्लेषण, जलग्रहण प्रबंधन, रिमोट सेंसिंग और जीआईएस

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1. INTRODUCTION

"The river is the longest story of all; It is the mother of all knowledge. It teaches patience, persistence, and the ability to flow with the rhythm of life".

1.1 Study Background

Rivers have been fundamental to the development of human civilizations, serving as vital sources of sustenance, transportation routes, and cultural anchors (Homer-Dixon, 1999). In urban contexts, these waterways often form the very heart of the city, shaping its landscape and influencing its growth (Elvin, 1998). However, rapid urbanization and industrialization have taken a significant toll on many urban rivers, leading to pollution, habitat destruction, and increased flood risks (World Bank, 2012). This degradation not only impacts the environment but also diminishes the quality of life for city dwellers (Grimm et al., 2008). Recognizing the critical role of rivers in urban ecosystems, a strong emphasis on river rejuvenation has emerged as a cornerstone of sustainable urban planning (Beatley, 2000). Rivers provide a multitude of invaluable services to urban areas. Ecologically, they support a rich tapestry of life, serving as vital habitats for a diverse array of aquatic and terrestrial species (Dudgeon, 2000). They act as natural filters, purifying water and replenishing groundwater reserves (Vörösmarty et al., 2000). Furthermore, rivers play a crucial role in climate regulation by influencing local temperatures and precipitation patterns (IPCC, 2013). From a social perspective, rivers offer invaluable recreational opportunities, fostering community bonding through activities like boating, fishing, and swimming (Kaplan & Kaplan, 1989). They also hold immense cultural and historical significance, connecting communities to their past and providing a strong sense of place (Cosgrove, 1998). Economically, healthy rivers contribute significantly to urban prosperity. They attract tourists, generating revenue for local businesses (OECD, 2001), and can serve as efficient transportation corridors, reducing traffic congestion and air pollution (Bates et al., 2008). Despite their undeniable importance, many urban rivers are facing severe challenges. Industrial and domestic waste, agricultural runoff, and untreated sewage contaminate waterways, degrading water quality and harming aquatic life (USEPA, 2023). Uncontrolled development along riverbanks, deforestation, and the alteration of natural river channels have led to the destruction of vital habitats, resulting in a significant loss of biodiversity (Zedler & Kercher, 2005). Moreover, the impact of climate change is exacerbating these issues, leading to increased water temperatures, altered precipitation patterns, and more frequent extreme weather events, further increasing the risk of flooding (IPCC, 2021). In response to these challenges, river rejuvenation has become a critical component of sustainable urban planning. This multifaceted approach aims to restore the ecological integrity and social value of degraded rivers. Key strategies include implementing advanced wastewater treatment plants to reduce pollution loads, promoting sustainable agricultural practices to minimize nutrient and pesticide runoff, and controlling industrial emissions through stricter environmental regulations. Habitat restoration initiatives are crucial, involving the re-establishment of natural river channels and floodplains, the protection and restoration of riparian vegetation to stabilize banks and improve water quality, and the creation of fish passages to enhance connectivity for aquatic species. Flood risk management is another crucial aspect of river rejuvenation. By incorporating nature-based solutions such as floodplain restoration and wetland creation, cities can mitigate flood risks more effectively (Ehler & Klein, 2008). Furthermore, developing early warning systems and robust evacuation plans can significantly enhance community safety during flood events. Public access and recreation along rejuvenated rivers are vital for enhancing the quality of life for urban residents. Creating public parks and greenways along riverfronts provides opportunities for leisure and recreation, while also improving air quality and creating more aesthetically pleasing urban spaces (Beatley, 2000). Ultimately, the success of river rejuvenation hinges on active community engagement. Involving local communities in the planning and implementation of restoration projects fosters a sense of ownership and ensures that the needs and priorities of local residents are addressed. Raising public awareness about the importance of river health and promoting responsible river use are also crucial for long-term success. In conclusion, rivers are not merely geographical features; they are the lifeblood of urban ecosystems. By prioritizing river rejuvenation as a core component of urban planning, cities can create more sustainable, liveable, and resilient environments for future generations. This involves a holistic approach that addresses water quality, habitat restoration, flood risk management, and public access, all while fostering strong community engagement and environmental stewardship.

1.2 Site Context

Bharathapuzha, also known as Nila, is the second-largest river in Kerala and holds significant cultural, ecological, and economic importance for the region. Originating from Anamudi in Tamil Nadu, it flows through Kerala before merging with the Arabian Sea at Ponnani. This river serves as a critical source of drinking water for the communities residing along its banks and plays an essential role in sustaining their livelihoods. Bharathapuzha is not only important for its environmental significance but also deeply woven into the heritage of the region, with numerous myths, traditions, and festivals linked to it. Its ecological health is crucial for maintaining the balance of the local ecosystem and the well-being of the people dependent on it.

The Bharathapuzha River drains a catchment area of approximately 6,000 square kilometres, flowing through the districts of Palakkad, Thrissur, and Malappuram in Kerala. It is fed by several tributaries, including Gayathripuzha, Kunthipuzha, Thoothapuzha, Kannadi Puzha, and Kalpathy Puzha which contribute to its flow and support the ecosystems along its course. These tributaries are vital for sustaining the river’s flow and supporting the communities that rely on it for agriculture, drinking water, and fishing. The river's extensive catchment area and its tributary network make it a vital water resource for the region.

The Bharathapuzha River, stretching 209 kilometers in length, is the second longest river in Kerala. Its flow is seasonal, heavily dependent on the monsoon rains and groundwater, with water levels varying throughout the year. The river's average width ranges from 100 to 200 meters, though this can fluctuate along its course due to changes in topography and seasonal variations. The river’s flow and width play a significant role in the region's agricultural and ecological systems, supporting the diverse plant and animal life that rely on it.

The Bharathapuzha River's course is punctuated by a series of dams, primarily constructed for irrigation purposes, which have significantly altered its natural flow regime. Among these, the Malampuzha Dam stands as the largest, a prominent landmark in Palakkad. Other notable dams within the Bharathapuzha basin include the Walayar, Mangalam, Pothundi, Meenkara, Chulliyar, and Kanjirapuzha dams. While these structures have played a vital role in providing water for agriculture and other needs, they have also contributed to the river's ecological challenges by fragmenting the river's flow, altering sediment transport, and impacting aquatic ecosystems. The management of these dams and their impact on the river's health is a crucial aspect of any rejuvenation effort.

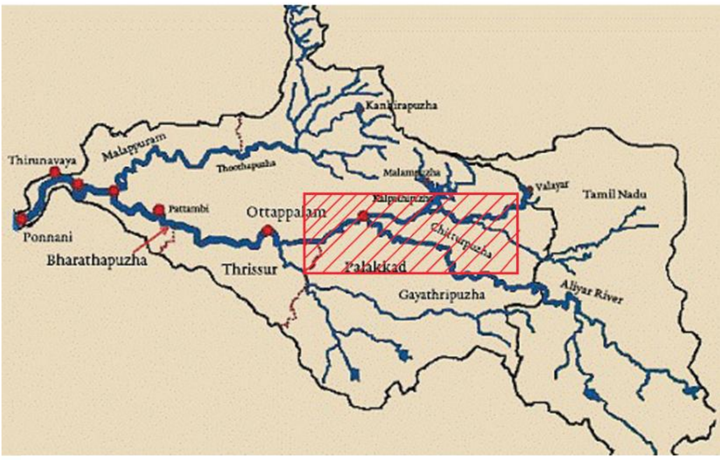

Figure 1 Tributaries of Bharathapuzha

Source: PSC Arivukal.com, modified by Author

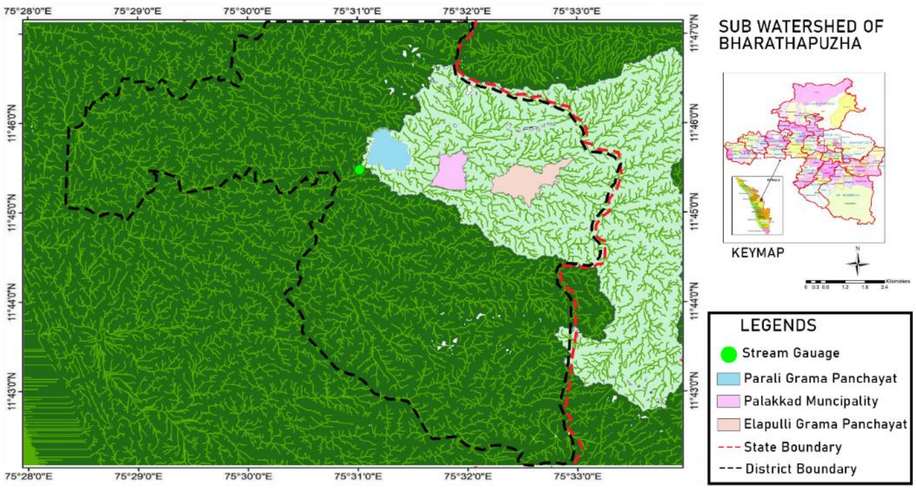

Figure 2 Study Area with State Boundaries and Watershed

Source: Author

1.3 Need For the Study

Addressing River Degradation: The Bharathapuzha River faces significant degradation stemming from pollution and unsustainable sand extraction practices. Pollution arises from various sources, including untreated or inadequately treated domestic sewage, industrial effluents, and agricultural runoff containing fertilizers and pesticides. These pollutants degrade water quality, impacting aquatic life, and rendering the water less suitable for irrigation and other uses. Furthermore, rampant and often illegal sand mining from the riverbed disrupts the river's natural flow, lowers the water table, increases erosion of riverbanks, and damages critical habitats for aquatic species. Addressing these issues requires a multi-pronged approach involving stricter enforcement of environmental regulations, investment in wastewater treatment infrastructure, promotion of sustainable agricultural practices, and stringent control over sand mining activities, including exploring alternative sources of construction materials.

Ensuring Sustainable Water Supply: Ensuring a sustainable water supply for both agriculture and local communities is paramount for the Bharathapuzha's future. The river's non-perennial nature, Alongside the effects of climate change and upstream water diversions, necessitates careful water resource management. This includes regulating water releases from existing dams to equitably meet the demands of various sectors, encouraging the use of efficient irrigation methods like drip and sprinkler systems to reduce water wastage, and introducing rainwater harvesting and groundwater recharge initiatives to enhance water availability during dry seasons. Effective water governance mechanisms, involving local communities and stakeholders, are also crucial for equitable water allocation and conflict resolution.

Preserving Cultural and Socio-Economic Significance: The Bharathapuzha River holds profound cultural and socio-economic significance for the region. It is deeply intertwined with local traditions, rituals, and festivals, and has historically sustained agricultural livelihoods and supported local economies. Preserving this heritage requires recognizing the river not just as a water resource, but as an integral part of the community's identity and well-being. This involves engaging local communities in river conservation and management efforts, promoting eco-tourism initiatives that respect the river's ecological integrity, and documenting and preserving the rich cultural heritage associated with the river. By recognizing and valuing the river's multifaceted significance, we can ensure that its rejuvenation contributes not only to environmental sustainability but also to the preservation of cultural heritage and the enhancement of local livelihood

2

Two years on, Bharathapuzha revival project yet to fructify

₹76.77 Cr Was Allotted For Its First Phase

Figure 3 View of Bharathapuzha from Various Sites

Source: Author, The Times of India

1.4 Aim

To explore the possibility for the sustainable management of Bharathapuzha River.

1.5 Objectives

1. To understand core Hydrological concepts and principles of sustainable river management
2. To analyze the 30-year trend (1993–2023) of the Baseflow Index (BFI) and groundwater levels in a sub-watershed of the Bharathapuzha River, and water quality improvement.

3. To propose Watershed level interventions for the sustainable management of Bharathapuzha River.

1.6 Scope

This study focuses on the Bharathapuzha River basin, the second-longest river system in Kerala, India. The basin spans diverse landscapes, from the Western Ghats to coastal plains, playing a crucial role in the region's agricultural economy and ecological integrity. The river is particularly significant for Palakkad district, often referred to as the "granary of Kerala," where it provides essential irrigation water. Understanding hydrological processes within this basin is key to effective water resource management and sustainable development.

1. **BFI Trend analysis over 30 years :** The study employs a temporal analysis approach, examining hydrological data across four key periods: 1994-2004, 2004-2014, 2014-2024, and the overall 30-year trend from 1994 to 2024. This long-term analysis helps identify trends, cyclical patterns, and shifts in hydrological variables. By comparing data across these periods, the study seeks to evaluate how climate variability, land use transformations, and human activities have influenced the river's hydrological behaviour.
2. **Location of gauging station:** A critical aspect of the study is the analysis of data based on the location of Central Water Commission (CWC) stream gauging stations, ensuring accuracy in hydrological assessments. Special attention will be given to the most drought-prone regions and areas facing severe groundwater exploitation, providing insights into water availability, recharge potential, and the broader implications for local communities. Accessibility challenges in data collection and communication will be addressed, ensuring that findings are effectively conveyed to relevant stakeholders. Language preferences of local communities will also be considered to facilitate meaningful engagement and the implementation of restoration strategies.

3. **Inclusion Criteria: Hydrological Dynamics:** This study incorporates a comprehensive suite of hydrological parameters to characterize the Bharathapuzha River basin's water resources. These parameters include:

- **Streamflow:** This parameter represents the amount of water discharged by the river channel at specific points and is a fundamental indicator of river health and water availability. Analysis of streamflow data will reveal seasonal variations, long-term trends, and the influence of upstream activities on downstream flow.
- **Baseflow:** Baseflow represents the portion of streamflow sustained by groundwater discharge and is crucial for maintaining aquatic ecosystems during dry periods. Analysis of baseflow data will provide insights into groundwater-surface water interactions and the river's resilience to drought.
- **Precipitation:** Precipitation, including rainfall and other forms of atmospheric moisture, is the primary input to the hydrological cycle. Analysis of precipitation data will reveal spatial and temporal patterns in rainfall distribution and their influence on river flow and groundwater recharge.
- **Runoff:** Runoff represents the portion of precipitation that flows over the land surface and contributes to streamflow. Analysis of runoff data will provide insights into the land surface processes that influence water movement and the potential for soil erosion and flooding.
- **Water Quality:** Water quality indicators—such as pH, dissolved oxygen, nutrient content, and pollutant levels—are critical for determining the water's suitability for uses like irrigation and domestic purposes. Evaluating this data helps pinpoint sources of pollution and measure their effects on the river's ecological integrity.
- **Groundwater:** Groundwater, stored in aquifers beneath the Earth's surface, serves as a vital water source for numerous communities. Examining groundwater levels and quality offers valuable information on its availability, recharge dynamics, and the connections between groundwater and surface water systems.

4. The study focuses on a sub-watershed of the Bharathapuzha River, encompassing regions located in both Kerala and Tamil Nadu. This geographical spread allows for a comprehensive assessment of the hydrological characteristics across state boundaries.

5. A macro-level hydrological analysis is conducted, covering both Kerala and Tamil Nadu. This broader scope facilitates an understanding of the watershed's overall behavior and regional hydrological dynamics.

6. The analysis spans a 30-year period from 1993 to 2023, enabling the evaluation of long-term trends in hydrology. This extended timeframe helps in identifying patterns and shifts that may be influenced by climatic or anthropogenic factors.

7. The parameters analyzed in this study include streamflow, baseflow (Base Flow Index or BFI), precipitation, runoff, and water quality. These components collectively offer insights into the hydrological regime and sustainability of the watershed.

8. Data for the analysis is primarily sourced from the Mankara gauging station. This station provides critical information essential for assessing the flow and water quality parameters within the study area.

By integrating these hydrological parameters, the study aims to develop a holistic understanding of the Bharathapuzha River basin's water resources and inform sustainable management strategies.

1.7 Limitation

1. Primary data collection and field surveys conducted for this study are limited exclusively to the Kerala portion of the sub-watershed. This restriction is due to jurisdictional and logistical challenges that prevent comprehensive field investigations across the state boundary into Tamil Nadu. As a result, empirical assessments and ground-level observations are confined to the areas within Kerala, potentially influencing the comprehensiveness of localized interpretations.

2. The Tamil Nadu segment of the watershed is excluded from direct field investigations and specific development proposals. This decision is based on the administrative separation between the two states, which presents challenges in terms of accessibility, coordination, and authority for conducting on-site research or implementing field-based initiatives in Tamil Nadu.

3. The analysis does not incorporate the impact of dam operations on river flow dynamics or associated hydrological alterations. While dam activities can significantly influence flow regimes, sediment transport, and seasonal variability, evaluating these effects requires access to detailed operational data and modeling frameworks, which were not within the scope of this study.
4. Temporal and spatial accuracy of the analysis may be limited by the resolution and availability of historical data. Many long-term datasets, particularly those related to streamflow and precipitation, may contain gaps, inconsistencies, or insufficient spatial coverage. These limitations may constrain the precision of trend analysis and the representation of hydrological patterns across the watershed.

1.8 Expected Outcome

1. The thesis analyzes three decades of baseflow variations in relation to urbanization and land use changes. By studying long-term trends from 1993 to 2023, it seeks to understand how alterations in land cover—such as increased built-up areas, deforestation, and agricultural expansion—have influenced the baseflow regime within the sub-watershed of the Bharathapuzha River. This approach helps in identifying correlations between human-induced landscape transformations and the declining or fluctuating baseflow patterns.

2. The study also examines the impact of pollution and the resulting reduction in the river’s natural self-cleansing ability on water quality. It considers how domestic waste discharge, agricultural runoff, and industrial effluents have compromised water quality parameters, leading to ecological stress. The diminished self-purification capacity of the river is evaluated as both a cause and consequence of hydrological degradation.

3. In response to the findings, the thesis proposes sustainable restoration measures aimed at enhancing baseflow and improving the ecological health of the river. These include nature-based solutions such as riparian buffer zones, wetland rehabilitation, and community-based water management practices. The objective is to develop integrated strategies that balance ecological preservation with human development needs.

2. METHODOLOGY

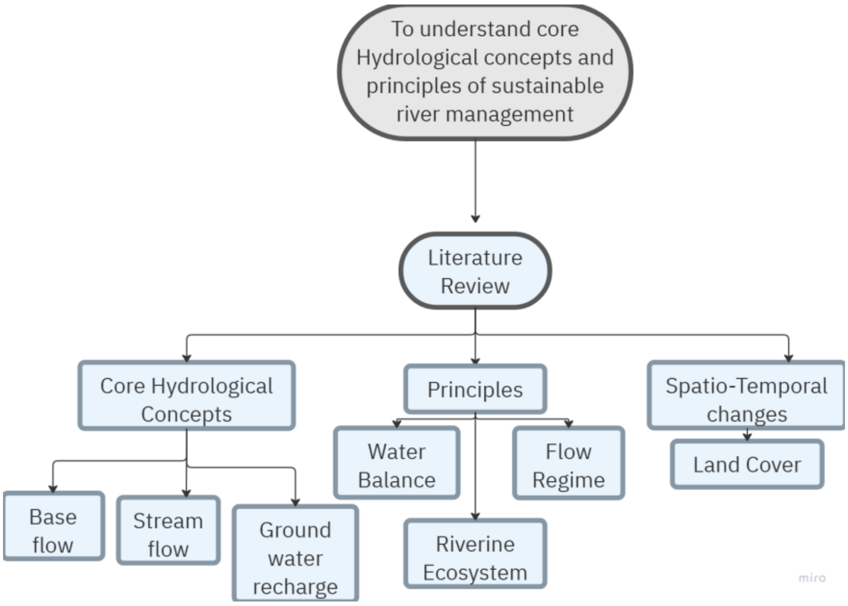

Figure 4 Flow Chart of First Objective

Source: Author

The methodology of this thesis is structured around a comprehensive literature review aimed at understanding the fundamental hydrological concepts and the principles that govern sustainable river management, particularly within the context of the Bharathapuzha River basin. This review forms the theoretical backbone of the study, enabling a critical evaluation of existing knowledge and approaches related to base flow and its interaction with land cover dynamics. The literature review is segmented into three principal thematic areas: Core Hydrological Concepts, Sustainability Principles, and Spatio-Temporal Changes in land cover, each contributing uniquely to the assessment of base flow variability.

The Core Hydrological Concepts component of the review focuses on the essential elements of the hydrological cycle that directly influence base flow. These include base flow itself—defined as the portion of streamflow sustained between rainfall events primarily by groundwater discharge—streamflow, and groundwater recharge processes. Understanding these hydrological interactions is critical for evaluating the extent to which Land Cover alterations impact the natural flow regime of the river. These concepts offer the foundation for analyzing how different land cover types affect infiltration, runoff, and subsurface water contributions to the river system.

In parallel, the thesis incorporates Principles of Sustainable River Management, centering on water balance, flow regimes, and riverine ecosystem health. These principles provide a framework for assessing not only the quantity but also the ecological quality of base flow within a changing landscape. Additionally, the Spatio-Temporal Changes segment examines patterns and transformations in Land Cover over time using remote sensing and GIS tools. This allows for a spatially and temporally explicit understanding of how human-induced changes—such as deforestation, urbanization, and agricultural expansion—have influenced hydrological responses. Altogether, this methodology provides a robust analytical pathway to assess the influence of Land Cover on the base flow regime in the Bharathapuzha River basin.

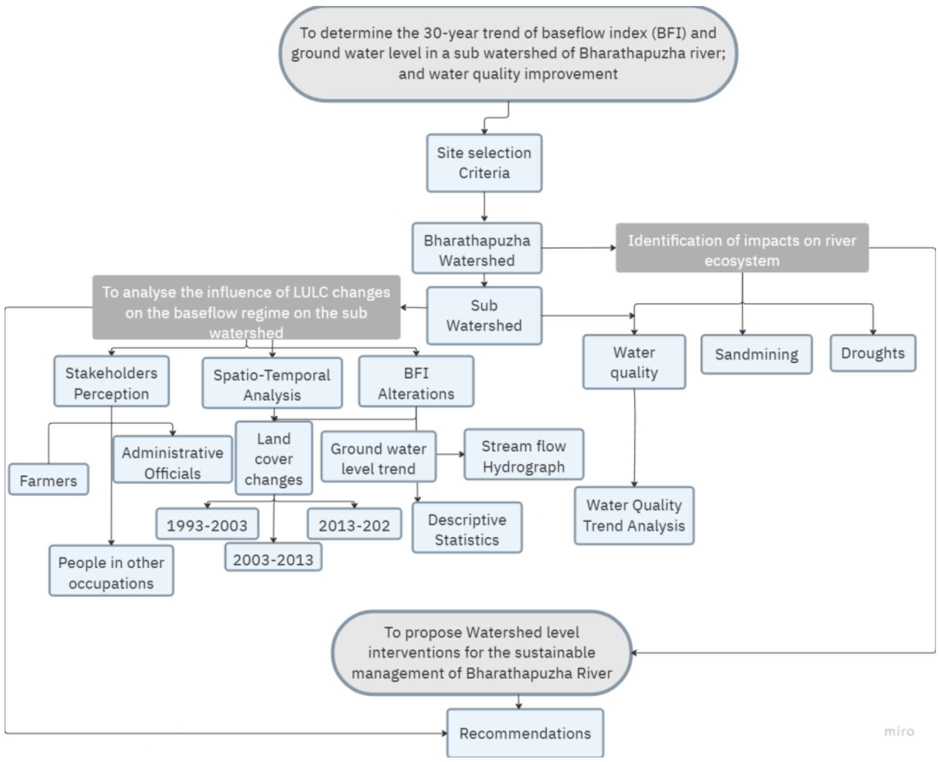

Figure 5 Other Objectives Structure of Research

Source: Author

The methodology for this thesis is designed to comprehensively evaluate the influence of land cover changes on the base flow regime in a sub-watershed of the Bharathapuzha River. At its core, the study aims to determine the 30-year trend of the Base Flow Index (BFI) and groundwater levels, thereby assessing the implications of land cover transformations on groundwater recharge and water quality. The process begins with the selection of a suitable sub-watershed within the Bharathapuzha River basin, based on specific criteria. From this foundation, the study proceeds to analyze multiple interrelated components: hydrological alterations, ecological impacts, and socio-environmental perceptions.

To assess the impact of land cover on the base flow, the methodology incorporates both spatial and temporal analyses, particularly over three distinct time periods—1993–2000, 2003–2013, and 2013–2023. This enables the detection of long-term land cover trends and their correlation with changes in groundwater levels and streamflow behaviour. Streamflow hydrographs and descriptive statistics are employed to evaluate BFI alterations. Meanwhile, stakeholder perceptions—gathered from farmers, administrative officials, and other local occupational groups—are integrated to contextualize quantitative data with experiential insights. This participatory element provides a human dimension to the understanding of hydrological shifts and land use practices.

Furthermore, the methodology extends to investigate the broader ecological consequences of base flow changes on river health. Water quality is analyzed through trend studies, while issues such as sand mining and droughts are also considered for their ecological and hydrological implications. Ultimately, the goal is to synthesize all findings to propose actionable watershed-level interventions. These recommendations are intended to guide sustainable river basin management strategies for the Bharathapuzha River, emphasizing the importance of maintaining base flow integrity in the face of evolving land use patterns.

2.1 Software Used

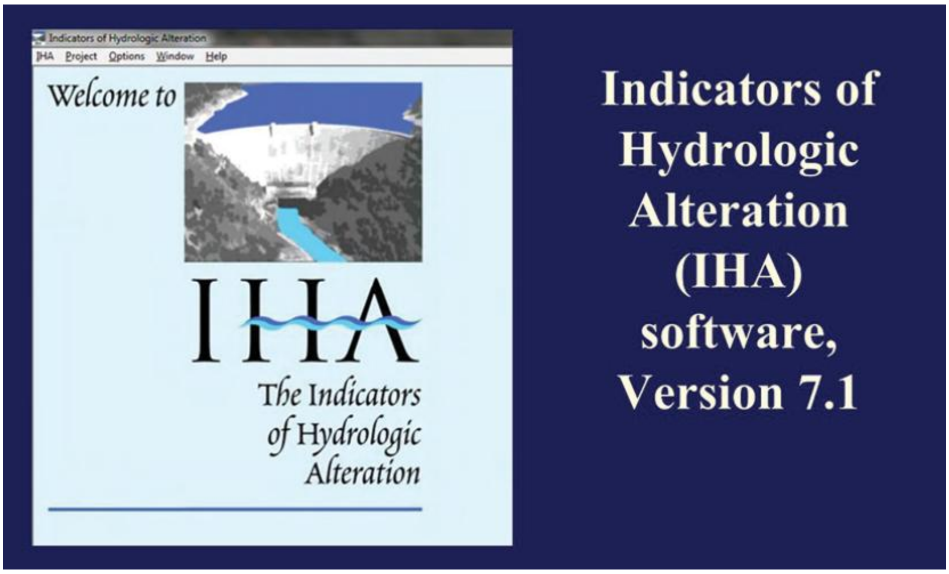

Figure 6 IHA software

Source: IHA Software

The Indicators of Hydrologic Alteration (IHA) software is a tool developed by The Nature Conservancy to assess hydrologic changes in river systems. It is widely used for calculating the Base Flow Index (BFI), which quantifies the contribution of baseflow to total streamflow. The software analyzes daily flow data to generate a range of ecologically relevant hydrologic statistics. IHA helps identify long-term trends and alterations in flow regimes, often due to land use changes or infrastructure development. Its BFI calculation is essential for understanding groundwater-surface water interactions and informing river restoration efforts.

3. LITERATURE REVIEW

3.1 River Systems and Water Security

Global river ecosystems face unprecedented degradation, impacting water security, biodiversity, and ecosystem services. This decline stems from the complex interplay of anthropogenic pressures and natural processes, necessitating robust assessment frameworks and effective management strategies. River health indices have emerged as crucial tools for evaluating the condition of these vital systems, providing quantifiable metrics for monitoring changes over time and assessing the efficacy of restoration interventions. Global trends in river degradation reveal a consistent pattern of decline attributed to several key stressors. Pollution, originating from point and non-point sources such as untreated sewage, industrial effluents, and agricultural runoff, leads to eutrophication, oxygen depletion, and toxicity, severely impacting aquatic life and human health. Hydrological changes resulting from dam construction, water diversions, and land use modifications disrupt natural flow patterns, fragment habitats, and interfere with sediment transport, leading to widespread impacts on downstream ecosystems. Physical habitat degradation, including channelization, riparian deforestation, and unsustainable sand mining, further exacerbates ecological damage. The introduction of invasive species disrupts native communities and alters ecosystem functioning, while climate change amplifies existing stressors through altered precipitation patterns, increased temperatures, and more frequent extreme events. In response to these challenges, various river health indices have been developed, encompassing biological, physio-chemical, and habitat indicators. Biological indices, including the Index of Biotic Integrity (IBI) and the Macroinvertebrate Biotic Index (MBI), evaluate the health of aquatic communities and indicate the cumulative impact of various environmental stressors. Physio-chemical indices measure key water quality parameters, providing direct insights into pollution levels and other environmental conditions. Habitat indices evaluate the physical structure and complexity of riverine habitats, crucial for supporting biodiversity. Multi-metric indices integrate these diverse indicators to provide a more holistic assessment of river health. The application of river health indices offers several key advantages, including standardized monitoring and assessment protocols, effective communication of river condition to stakeholders and policymakers, evidence-based support for policy development and decision-making, and the facilitation of comparative analyses across different river systems and time periods. However, challenges remain in index development, calibration, data availability, and the integration of multiple stressors and climate change projections. Need of research should prioritize developing more robust and adaptable indices, improving monitoring networks, and incorporating climate change scenarios into river health assessments to ensure effective and adaptive management of these critical ecosystems.

3.2 Hydrology and Hydraulics of River Systems

The hydrological cycle, a fundamental Earth system process, governs the continuous movement of water between the atmosphere, land surface, subsurface, and oceans. This cycle involves essential processes such as precipitation (rain, snow, etc.), interception, infiltration, surface runoff, evapotranspiration (evaporation from water bodies and transpiration from plants), subsurface flow, and groundwater recharge. A comprehensive understanding of these processes is vital for effective water resource management, especially in river systems. In riverine environments, streamflow reflects the cumulative response of a catchment to these hydrological processes, indicating the volume of water transported through the river channel over time. Baseflow, a key element of streamflow, represents the portion sustained by groundwater discharge and delayed subsurface flow. It is crucial for sustaining aquatic ecosystems during dry periods, ensuring a stable water supply and providing essential habitats for aquatic species. Baseflow separation techniques are employed to isolate the baseflow component from the total streamflow hydrograph.

Environmental flow

Environmental Flow (e-flow) pertains to the volume, timing, and quality of water flows necessary to maintain freshwater and estuarine ecosystems, along with the human livelihoods and well-being reliant on these ecosystems. Its goal is to strike a balance between preserving ecological health and meeting water demands for agriculture, industry, and domestic use.

Stream flow

Streamflow, or discharge, refers to the movement of water within a natural or artificial channel, such as a river, stream, or canal. It is usually measured as the volume of water passing a specific point in the channel over a given period of time.

Cubic meters per second (m^3/s), Cubic feet per second (cfs) = BASE FLOW+ RUNOFF+PRECIPITATION

Base flow

Baseflow is the portion of streamflow in a river or stream that originates from groundwater seeping into the streambed. It represents the sustained, steady flow of water in a stream, particularly during dry periods when there is little to no direct runoff from precipitation.

Base flow index

The Base Flow Index (BFI) is a hydrological measure that represents the proportion of streamflow that is sustained by groundwater, typically indicating the "base flow" of a river or stream. It is calculated by dividing the base flow (sustained flow) by the total streamflow over a specific period. BFI values range from 0 to 1, where a value closer to 1 indicates a stream highly influenced by groundwater, while a value near 0 suggests a more runoff-dominated stream. Typical BFI values vary by region and climate, but they often range from 0.2 to 0.8 in temperate climates.

$$\text{BFI} = \frac{\text{Base Flow}}{\text{Total Streamflow}}$$

Self-cleansing property

The self-cleansing property of a river refers to its natural ability to break down and remove pollutants through physical, chemical, and biological processes, such as sediment transport, aeration, microbial activity, and dilution, to maintain water quality and ecological balance.

Several methods exist, ranging from simple graphical techniques (e.g., straight-line separation, fixed-interval method) to more complex digital filtering and hydrograph analysis methods (e.g., Eckhardt filter, Lyne-Hollick filter). These techniques rely on different assumptions about the characteristics of baseflow and direct runoff, and their applicability varies depending on the hydrogeological setting and the nature of the streamflow hydrograph. Accurate baseflow separation is essential for understanding groundwater-surface water interactions, assessing groundwater recharge rates, and evaluating the impacts of land use change and climate variability on baseflow contributions.

Environmental Flow Assessment (EFA) has become a vital element of river management, aiming to reconcile human water usage with the ecological needs of river ecosystems. EFA focuses on determining the quantity, timing, and quality of water flows necessary to sustain essential ecological processes and biodiversity within a river system. A range of methodologies have been developed for EFA, from basic hydrological techniques (such as the Tennant method and flow duration curve analysis) to more sophisticated hydraulic and habitat modeling approaches (like the Instream Flow Incremental Methodology (IFIM) and River2D). These methods take into account various aspects of river ecosystems, including fish habitats, riparian vegetation, sediment transport, and water quality. The selection of an EFA methodology depends on the assessment’s objectives, the availability of data, and the complexity of the river system.

The construction of dams and other flow regulation structures profoundly disrupts the natural flow regime of rivers, with significant consequences for downstream ecosystems. Dams can alter the magnitude, frequency, duration, timing, and rate of flow changes, which in turn affects water temperature, sediment transport, nutrient cycling, and aquatic habitats. These modifications can create cascading effects on aquatic communities, impacting fish populations, riparian vegetation, and overall biodiversity. Downstream of dams, diminished flows can result in habitat drying, loss of spawning grounds, and shifts in species composition. On the other hand, altered flow releases may cause abnormal flooding patterns and disrupt natural ecological processes. Research has shown that dams can drastically reduce sediment transport downstream, leading to channel erosion, bank destabilization, and the loss of deltaic habitats. Additionally, changes in water temperature and nutrient concentrations can influence primary production and the overall health of aquatic ecosystems.

3.3 BFI, SDI & River Rejuvenation

Stream drought indices and baseflow indices are essential tools for understanding river hydrology and informing effective river rejuvenation strategies. Stream drought indices, such as the Standardized Streamflow Index (SSI), Streamflow Drought Index (SDI), and the Threshold Level Method, quantify deficits in streamflow, characterizing drought severity, duration, and spatial extent. The SSI standardizes streamflow data, enabling comparisons across time and locations, while the SDI uses a non-parametric approach, proving more suitable for skewed data. The Threshold Level Method identifies drought events based on streamflow falling below pre-defined thresholds. These indices are crucial for identifying drought-prone river reaches, evaluating the effectiveness of mitigation measures like water conservation or flow regulation, and developing drought management plans with specific triggers for action. Baseflow indices, in contrast, measure the contribution of groundwater to streamflow, which is essential for sustaining aquatic ecosystems during dry periods. The Baseflow Index (BFI), which represents the ratio of baseflow to total streamflow, and groundwater recession curve analysis, which estimates baseflow characteristics and groundwater discharge, are commonly employed methods. A higher BFI signifies a stronger influence of groundwater and greater resilience to drought. Baseflow indices are valuable for assessing groundwater dependency, evaluating the impact of groundwater extraction on streamflow, and guiding the design of groundwater recharge projects to enhance baseflow. By combining stream drought and baseflow indices, a comprehensive understanding of river hydrology and drought vulnerability is achieved. This integrated approach allows for targeted interventions, such as focused groundwater recharge in low baseflow areas and stricter water conservation during drought periods identified by stream drought indices, ultimately contributing to more effective and sustainable river rejuvenation.

3.4 Base flow and Land Cover

The intricate relationship between baseflow and land cover constitutes a critical area of investigation in hydrological science, with significant implications for water resource management and river health. Baseflow, the sustained component of streamflow derived from groundwater discharge and delayed subsurface flow, is a crucial ecological driver, particularly during periods of low precipitation. Land Cover changes exert a profound influence on baseflow dynamics by altering infiltration rates, subsurface flow paths, and groundwater recharge processes. Forested areas, characterized by extensive root systems and high soil permeability, generally promote enhanced infiltration and groundwater recharge, leading to sustained baseflow contributions, as evidenced by numerous studies correlating forest cover with increased baseflow (Bosch and Hewlett, 1982; Farley et al., 2005). Conversely, agricultural lands exhibit more variable impacts, with conventional intensive agriculture often reducing infiltration and increasing surface runoff, thereby diminishing groundwater recharge and baseflow. However, sustainable agricultural practices, such as conservation tillage and cover cropping, can mitigate these negative effects and potentially enhance baseflow (Blume et al., 2009). Urbanization, with its proliferation of impervious surfaces, represents a significant hydrological perturbation, drastically reducing infiltration, increasing surface runoff, and consequently diminishing groundwater recharge and baseflow, as documented in studies of urbanizing watersheds (Walsh et al., 2005). Beyond infiltration, subsurface flow paths and storage are also significantly influenced by land cover. Soil properties, including texture, structure, and hydraulic conductivity, govern water movement through the subsurface, while geological formations dictate groundwater flow paths and storage capacity. Topography further modulates surface and subsurface flow, with steep slopes favouring rapid runoff and gentle slopes promoting infiltration. Groundwater usage, particularly through extraction for irrigation, domestic supply, and industry, directly impacts baseflow by lowering groundwater levels and reducing groundwater discharge to streams, as exemplified by cases of streamflow depletion in intensively irrigated regions like the High Plains Aquifer (Sophocleous, 2010). The interplay between groundwater and surface water is crucial, with groundwater sustaining baseflow and surface water contributing to groundwater recharge. Specific factors further mediate the baseflow-land cover relationship. Riparian vegetation plays a vital role in regulating baseflow through its influence on infiltration, evapotranspiration, and bank stability, while artificial drainage networks can expedite water conveyance to streams, bypassing groundwater recharge. Climate variability interacts with land cover to influence baseflow, with droughts exacerbating the negative impacts of deforestation or urbanization. Case-specific studies, such as those conducted in the south eastern United States (Sun et al., 2006) and the Loess Plateau of China (Wang et al., 2011), underscore the importance of considering land cover in baseflow assessments and water management strategies. These studies demonstrate that integrated approaches, considering the complex interactions between land cover, groundwater, and surface water, are essential for effective river ecosystem management and sustainable water resource utilization.

3.5 Ground Water Recharge Factors

Groundwater recharge, baseflow, and overall river health are intimately interconnected components of the hydrological system, and their integrated understanding is essential for sustainable water resource management. Groundwater recharge, the process of water percolating into aquifers from precipitation, rivers, or artificial systems, serves as the foundational mechanism supporting baseflow—the sustained flow in rivers during non-rainfall periods. Numerous studies underscore that groundwater is not just a buffer during dry spells but a critical contributor to perennial river flows, with baseflow accounting for up to 90% of dry-season discharge in certain catchments (Smakhtin, 2001; Winter et al., 1998). The rate and quality of recharge are significantly influenced by land use changes, soil permeability, vegetation cover, and anthropogenic interventions such as urbanization and intensive agriculture. Urban development, in particular, has been shown to reduce infiltration capacity and disconnect recharge zones, leading to lowered water tables and diminished baseflow (Sophocleous, 2002; Lerner, 2002). Conversely, reforestation, green infrastructure, and managed aquifer recharge (MAR) techniques have proven effective in enhancing infiltration and stabilizing groundwater levels (Dillon et al., 2009). The decline in baseflow due to over-extraction of groundwater and reduced recharge compromises river health by altering ecological flow regimes, increasing stream temperature variability, and reducing aquatic biodiversity (Bunn and Arthington, 2002). Riverine ecosystems thrive on flow consistency, and baseflow serves as an ecological lifeline, especially in semi-arid and monsoon-dominated regions. The concept of environmental flows has thus emerged as a framework for maintaining river health, which includes preserving baseflow thresholds necessary to sustain aquatic habitats and ecological processes (Acreman and Dunbar, 2004). Empirical research from Indian river basins, such as the Ganga and Godavari, has illustrated that intensive groundwater extraction not only reduces baseflow but reverses hydraulic gradients, leading to river-aquifer disconnection (Shah et al., 2003). Additionally, the degradation of riparian zones and floodplains—natural recharge areas—further exacerbates this disconnection and impairs the river's self-purification capacity. Integrated water resource management approaches increasingly advocate for conjunctive use of surface and groundwater, emphasizing aquifer recharge zones protection, sustainable pumping regimes, and land use planning that supports infiltration. Innovations such as GIS-based recharge mapping, remote sensing for baseflow estimation, and hydro-ecological models have expanded our capability to assess and manage these interactions holistically (Scanlon et al., 2002; Richey et al., 2015). Ultimately, maintaining baseflow through sustained groundwater recharge is not only a hydrological necessity but a prerequisite for ensuring the ecological integrity, water quality, and socio-economic functions of rivers. As climate change alters rainfall patterns and intensifies hydrological extremes, preserving the recharge–baseflow continuum becomes even more critical to safeguarding river health in urbanizing and agriculturally stressed basins.

3.6 River Rejuvenation and Management Strategies

Effective river rejuvenation and management necessitate a multifaceted approach encompassing ecological restoration, morphological rehabilitation, water quality improvement, and sustainable water resource management. Principles of river restoration focus on reinstating natural processes and functions within degraded river ecosystems. Ecological restoration aims to recover biodiversity, enhance habitat complexity, and restore ecological connectivity. This may involve re-establishing native riparian vegetation, removing invasive species, and creating or restoring instream habitats such as riffles and pools. Morphological restoration focuses on restoring the river's physical form and processes, including channel reconfiguration, floodplain reconnection, and sediment management. This can involve removing artificial constraints, restoring natural channel sinuosity, and managing sediment inputs to maintain dynamic equilibrium. Water quality enhancement focuses on mitigating pollution sources through measures such as upgrading wastewater treatment, adopting best management practices in agriculture and urban areas to minimize non-point source pollution, and cleaning up contaminated sediments.

Integrated Water Resource Management (IWRM) offers a comprehensive approach to sustainable water management, recognizing the interdependence of hydrological, ecological, social, and economic systems. IWRM prioritizes stakeholder involvement at all stages of decision-making, ensuring that a wide range of perspectives are taken into account and that management strategies are both socially acceptable and fair. A key principle of IWRM is adaptive management, which acknowledges the uncertainties in complex systems and encourages ongoing learning and the adjustment of strategies based on regular monitoring and assessment. The IWRM framework promotes the integration of environmental, social, and economic factors into water resource planning and management, striving to balance competing water demands while safeguarding the long-term health of water resources and ecosystems.

Studying successful river management and restoration case studies from around the world offers valuable lessons and adaptable strategies. For example, the restoration of the Rhine River in Europe illustrates the power of international collaboration and coordinated efforts to reduce pollution and restore ecological connectivity. The Kissimmee River restoration in Florida demonstrates the advantages of re-establishing natural flow patterns and reconnecting floodplains to improve wetland functions and biodiversity. The Murray-Darling Basin Plan in Australia serves as a model of large-scale integrated water resource management, addressing complex water allocation challenges while balancing environmental and socio-economic priorities. These case studies emphasize the significance of setting clear goals, involving stakeholders, relying on solid scientific knowledge, and applying adaptive management approaches.

Sustainable irrigation practices are essential for reducing water consumption and enhancing agricultural water use efficiency, especially in areas where agriculture is a primary water consumer. Techniques such as drip irrigation and micro-sprinklers efficiently deliver water directly to plant roots, minimizing evaporation losses and significantly lowering water usage compared to traditional surface irrigation. Drip irrigation, for instance, can boost water use efficiency by up to 90%, while conventional flood irrigation typically operates at an efficiency of 40-60%. Improved irrigation scheduling, based on real-time weather data and soil moisture monitoring, can further optimize water usage and reduce water stress on crops. Encouraging the use of drought-resistant crop varieties and adopting water conservation practices at the farm level are also key elements of sustainable irrigation management. Integrating these practices into broader river basin management plans is vital for ensuring the long-term sustainability of both agriculture and river ecosystems.

3.7 Socio-economic and Political Dimensions

The socio-economic and policy dimensions of river management are crucial for achieving sustainable and equitable outcomes. River degradation has far-reaching socio-economic impacts, affecting livelihoods, economies, and human well-being. Understanding these impacts and integrating social and economic considerations into river management strategies is essential for effective and sustainable interventions. Community participation plays a pivotal role in successful river management, ensuring that local knowledge, values, and needs are incorporated into decision-making processes. Effective water governance frameworks are necessary to facilitate stakeholder engagement, ensure equitable water allocation, and enforce environmental regulations. Sound environmental policies provide the legal and institutional framework for river protection and restoration. Economic valuation of ecosystem services helps to quantify the economic benefits provided by healthy river ecosystems, highlighting the importance of investing in river conservation and restoration. Finally, a clear understanding of water rights and robust water policy analysis are essential for resolving water allocation conflicts and promoting sustainable water use.

River degradation exerts a wide range of negative socio-economic impacts. Declining water quality and quantity can negatively affect agricultural productivity, leading to reduced incomes for farmers and impacting regional food security. Degraded river ecosystems can also negatively impact fisheries, tourism, and other economic activities that rely on healthy rivers. Furthermore, river degradation can lead to increased health risks due to waterborne diseases and exposure to pollutants. The loss of ecosystem services, such as flood control and water purification, can also have significant economic costs. Studies have demonstrated strong links between river health and local economies, particularly in regions where communities depend directly on rivers for their livelihoods. For instance, research on the Mekong River has shown that dam construction and overfishing have negatively impacted fish stocks, leading to reduced incomes for fishing communities and increased food insecurity. Similarly, studies on degraded rivers in developing countries have documented significant health impacts associated with poor water quality.

Community participation is increasingly acknowledged as a vital component of effective river management. Involving local communities in the decision-making process helps ensure that management strategies are socially acceptable, culturally sensitive, and aligned with local needs and priorities. Participatory approaches also tap into local knowledge and expertise, resulting in more efficient and sustainable outcomes. Research on community-based natural resource management has highlighted the positive effects of community engagement on resource conservation and sustainable use. For instance, community-led watershed management initiatives in India have been successful in enhancing water availability and reducing soil erosion through collaborative planning and execution. However, meaningful community participation requires careful attention to power dynamics, ensuring that marginalized groups are included in the decision-making process.

Effective water governance is essential for managing water resources sustainably and equitably. Water governance encompasses the rules, processes, and institutions that govern water allocation, use, and management. Sound water governance frameworks should promote transparency, accountability, and stakeholder participation. They should also establish clear roles and responsibilities for different government agencies and ensure effective coordination among them. Studies on water governance have highlighted the importance of adaptive management, which involves continuous learning and adjustment of management strategies based on monitoring and evaluation.

Adaptive governance strategies are especially crucial in the context of climate change, as it brings substantial uncertainties to water resource management.

Environmental policies provide the legal and institutional framework for protecting and restoring river ecosystems. Effective environmental policies should set clear water quality standards, regulate pollution sources, and promote sustainable land and water use practices. Enforcement of environmental regulations is crucial for ensuring compliance and preventing further river degradationPolicy analysis is essential for assessing the effectiveness of current policies and identifying potential gaps. This process involves evaluating the social, economic, and environmental impacts of various policy options and proposing reforms to achieve the desired outcomes. For instance, research on the effectiveness of water pollution control policies has demonstrated that market-based approaches, such as water quality trading, can be more cost-efficient than traditional command-and-control regulations.

Economic valuation of ecosystem services provides a framework for quantifying the economic benefits provided by healthy river ecosystems. These benefits can include water supply, flood control, water purification, recreation, and biodiversity conservation. Economic valuation methods, such as contingent valuation and travel cost method, can be used to estimate the monetary value of these services. By quantifying the economic benefits of healthy rivers, it is possible to make a stronger case for investing in river conservation and restoration. Studies on the economic valuation of ecosystem services have demonstrated the significant economic value of wetlands for flood control and water purification. These studies have shown that investing in wetland restoration can be more cost-effective than building engineered infrastructure for flood control and water treatment.

3.8 Water Security: A Multi-Dimensional Perspective

Water security is a broad concept that includes the availability, accessibility, and sustainable management of water resources to support human well-being, economic growth, and environmental health. The United Nations defines water security as "the ability of a population to ensure sustainable access to sufficient, clean water to sustain livelihoods, promote human well-being, and support socio-economic development, while protecting against waterborne pollution and water-related disasters, and preserving ecosystems in a peaceful and politically stable environment." With the rising challenges posed by climate change, population growth, urbanization, and pollution, achieving water security has become an urgent global issue.

Key Aspects of Water Security

1. Availability and Accessibility of Water Resources

Water security fundamentally depends on the availability of freshwater resources, which are influenced by precipitation patterns, river flows, groundwater levels, and surface water bodies. Accessibility, on the other hand, is determined by infrastructure, governance, and socio-economic factors that dictate who gets access to safe and sufficient water. In many developing regions, despite the presence of water resources, inadequate infrastructure and economic barriers limit equitable access to clean water.

2. Water Quality and Pollution Control

Ensuring that available water is of sufficient quality is essential for public health, agriculture, and industry. Contaminants such as industrial effluents, agricultural runoff, and untreated sewage degrade water quality, leading to waterborne diseases and ecosystem disruptions. Effective water treatment, pollution control regulations, and sustainable agricultural practices are crucial in maintaining water security. The self-cleansing capacity of rivers, including factors like Base Flow Index (BFI), is an important consideration in assessing the resilience of a water system.

3. Climate Change and Hydrological Variability

Climate change is a key factor contributing to water insecurity, as it disrupts precipitation patterns, increases the occurrence of extreme weather events, and leads to extended periods of drought and flooding. The hydrological variability linked to climate change impacts both surface water and groundwater recharge, making water supply more unpredictable. This requires the implementation of adaptive water management strategies, such as flood control measures, rainwater harvesting, and enhanced water storage capacity.

4. Groundwater Depletion and Overextraction

Many regions rely heavily on groundwater for drinking water and irrigation. Overextraction, coupled with inadequate recharge, leads to groundwater depletion, land subsidence, and salinization, particularly in coastal areas. The Bharathapuzha River basin, for example, faces challenges due to extensive groundwater exploitation. Sustainable groundwater management, including regulated extraction, artificial recharge, and community-led conservation efforts, is essential for long-term water security.

5. Water Governance and Policy Frameworks

Effective water governance determines how water resources are managed and allocated. Governance frameworks include legal regulations, institutional capacity, and participatory decision-making involving local communities. Integrated Water Resource Management (IWRM) is a commonly advocated approach that encourages coordination among different sectors to ensure the sustainable use of water resources. The role of Central Water Commission (CWC) stream gauging stations, for instance, is crucial in monitoring hydrological parameters and informing policy decisions.

6. Socio-Economic Dimensions and Equity

Water security is closely linked to social and economic stability. Inadequate access to clean water disproportionately affects marginalized communities, leading to health crises and economic hardships. Women and children, particularly in rural areas, bear the burden of water collection, impacting education and productivity. Addressing these inequalities requires investments in water supply infrastructure, community engagement, and education on water conservation.

7. Disaster Risk Reduction and Resilience Building

Water-related disasters, such as floods and droughts, pose significant threats to both water security and human security. To minimize these risks, resilience-building measures like advanced early warning systems, floodplain zoning, and drought mitigation strategies are essential. Nature-based solutions, such as wetland restoration and afforestation, are crucial for regulating water flows and strengthening ecosystem resilience.

3.9 Existing Acts, rules and Policies

National Level

1. **The Water (Prevention and Control of Pollution) Act, 1974:** This act is the primary legislation for preventing and controlling water pollution in India. The Act establishes the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) to oversee water quality, set effluent standards, and enforce regulations. Amendments made in 1988 further reinforced the Act, introducing harsher penalties for violations.
2. **The Water (Prevention and Control of Pollution) Cess Act, 1977:** This act levies a cess (tax) on water consumed by industries and local authorities, incentivizing them to reduce water consumption and treat wastewater.
3. **The Environment (Protection) Act, 1986:** This overarching act provides a framework for environmental protection in India, encompassing water, air, and land. It empowers the central government to set environmental standards, regulate industrial activities, and take action to protect the environment.
4. **National Water Policy (Various versions, latest 2012):** This policy offers a national framework for the planning, development, and management of water resources. It focuses on integrated water resource management (IWRM), promoting efficient water use and community involvement. The policy covers key areas such as water allocation, irrigation management, groundwater regulation, and water quality.
5. **National Mission for Clean Ganga (NMCG) (under the Namami Gange Programme):** This mission aims to rejuvenate the Ganga River and its tributaries through a comprehensive approach encompassing pollution abatement, riverfront development, afforestation, and biodiversity conservation. While focused on the Ganga, the NMCG's principles and approaches are relevant to other river rejuvenation efforts.

6. **National Water Mission (under the National Action Plan on Climate Change – NAPCC):** This mission seeks to enhance water use efficiency, promote water conservation, and ensure the equitable and sustainable management of water resources in response to climate change.
7. **National River Conservation Plan (NRCP):** This plan aims to restore polluted sections of major rivers in India through a range of interventions, such as sewage treatment plants, riverfront development, and public awareness campaigns.
8. **Integrated Watershed Management Programme (IWMP) (now part of Pradhan Mantri Krishi Sinchayee Yojana – PMKSY):** This program aims to develop and manage watersheds sustainably, which is crucial for improving water availability, reducing soil erosion, and enhancing groundwater recharge, all of which benefit river health.
9. **Wetlands (Conservation and Management) Rules, 2017 (under the Environment (Protection) Act, 1986):** These regulations offer a clear legal framework for the conservation and management of wetlands in India. They define wetlands, set criteria for their identification and notification, and regulate activities within and surrounding wetlands to prevent degradation. The rules also establish institutional mechanisms for wetland management at both national and state levels. This is the key policy specifically focused on wetlands.

3.10 Rules, Acts and Policies of Kerala State

1. **Kerala Irrigation and Water Conservation Act, 2003 (and Amendment Act, 2018):**

   Historical Context: Prior to this act, irrigation management in Kerala was governed by older, fragmented legislation. The 2003 Act aimed to consolidate these laws and introduce a more holistic and contemporary approach to water resource management. The 2018 amendment further updated the act to address emerging challenges like groundwater depletion and the need for greater farmer participation.

   Key Provisions:

i. Kerala Irrigation and Water Conservation Authority: This authority is responsible for planning, investigating, constructing, operating, and maintaining major and medium irrigation projects in the state. It also plays a key role in water resource planning and allocation.

ii. Water Allocation and Distribution: The act provides a framework for allocating water among different users, prioritizing drinking water and irrigation needs. It also addresses the issue of water rights and entitlements.

iii. Participatory Irrigation Management: The 2018 amendment introduced provisions for involving farmers in the management of irrigation systems through Water Users' Associations (WUAs). This promotes local ownership and improves the efficiency of irrigation water use.

iv. Groundwater Regulation: The amendment also introduced stricter regulations on groundwater extraction, requiring permits for certain uses and empowering authorities to control over-exploitation.

v. Water Cess and Betterment Levy: The Act allows for the imposition of a water cess on water users and a betterment levy on lands that benefit from irrigation projects, generating revenue for the management of water resources.

Impact and Challenges: The act has contributed to improved irrigation management and increased farmer participation. However, challenges remain in implementing the participatory irrigation management provisions and enforcing groundwater regulations effectively.

2. **Kerala Irrigation and Water Conservation Rules, 2005 (and Amendment Rules, 2018):**

Purpose: These rules provide the operational details for implementing the 2003 Act. They are crucial for translating the broad principles of the act into concrete actions.

Key Provisions:

i. Application for Water Use Licenses: The rules specify the procedures for applying for water use licenses, including the information required, the criteria for granting licenses, and the conditions attached to them.

- Construction and Maintenance of Irrigation Works: The rules establish guidelines for the design, construction, operation, and maintenance of irrigation projects, ensuring their safety and effectiveness.
- Water Allocation and Distribution: The rules provide detailed procedures for allocating water among different users, considering factors such as water availability, crop water requirements, and equity considerations.
- Water Charges and Collection: The rules specify the rates of water cess and betterment levy and the procedures for their collection.
- Participatory Irrigation Management: The 2018 amendment rules provide detailed guidelines for the formation, functioning, and responsibilities of Water Users' Associations (WUAs).
- Groundwater Regulation: The 2018 amendment rules provide more specific guidelines for regulating groundwater extraction, including criteria for declaring over-exploited areas and procedures for granting groundwater permits.

3. **Kerala State Water Policy:**

    - Purpose: This policy provides a long-term vision and framework for water resource management in Kerala, guiding the development of specific plans and programs.
    - Key Principles:
        - Integrated Water Resource Management (IWRM): The policy advocates for a comprehensive approach to water management, recognizing the connections between surface water, groundwater, ecosystems, and human activities.
        - Water as a Basic Human Need: The policy acknowledges access to safe drinking water as an essential human right.
        - Decentralization and Participatory Management: The policy highlights the importance of engaging local communities and stakeholders in water management decision-making.
        - Water Conservation and Efficiency: The policy promotes water conservation practices in all sectors, including agriculture, domestic use, and industry.
        - Protection of Water Quality and Aquatic Ecosystems: The policy acknowledges the significance of preserving water quality and safeguarding river and wetland ecosystems.
        - Traditional Water Management Systems: The policy promotes the revival and integration of traditional water harvesting and management practices.

4. **Kerala Groundwater (Control and Regulation) Act, 2002:**

    - Purpose: This act aims to regulate groundwater extraction to prevent over-exploitation and ensure sustainable groundwater management in Kerala.
    - Key Provisions :

- Groundwater Permit System: The act requires permits for extracting groundwater for certain purposes, such as irrigation and industrial use.
- Declaration of Over-Exploited Areas: The act empowers authorities to declare areas as "over-exploited" based on groundwater levels and extraction rates. Stricter regulations apply in these areas.
- Groundwater Recharge Measures: The act promotes artificial groundwater recharge through various techniques, such as rainwater harvesting and injection wells.
- Groundwater Quality Monitoring: The act also addresses issues related to groundwater quality and pollution.

5. **Kerala Conservation of Paddy Land and Wetland Act, 2008:**

- Purpose: This Act is specifically intended to conserve paddy lands and wetlands in Kerala by limiting their conversion or reclamation. Its goal is to promote agricultural development, ensure food security, and preserve the state's ecological system. The Act recognizes the vital role of paddy fields as wetlands and their significant contribution to water management and biodiversity.
- Key Provisions:
    - Definition of Paddy Land and Wetland: The act provides clear definitions of "paddy land" and "wetland," which is essential for its effective implementation.
    - Restriction on Conversion/Reclamation: The Act strictly forbids the conversion or reclamation of paddy land and wetlands for non-agricultural uses, except in certain circumstances and with prior approval from the appropriate authorities.
    - Local Level Monitoring Committees: The act establishes Local Level Monitoring Committees (LLMCs) at the Panchayat/Municipality level

to monitor paddy lands and wetlands and to receive applications for conversion.

- District Level Authorized Committees: District Level Authorized Committees are established to consider the recommendations of the LLMCs and make decisions on conversion applications.
- State Level Committee: A State Level Committee oversees the implementation of the act and provides guidance to the district and local level committees.
- Penalties for Violations: The Act mandates penalties for violations, including fines and imprisonment.

3.11 Major Governing Agencies and Ongoing Missions

- **District Panchayath, Palakkad:** As the local self-governing body, the District Panchayath plays a pivotal role in overseeing and implementing river rejuvenation projects within its jurisdiction. It is responsible for formulating policies, allocating resources, and monitoring the progress of conservation efforts.
- **Kerala Biodiversity Board:** This state-level agency is mandated to protect biodiversity and conserve ecosystems. It plays a crucial role in assessing the ecological impact of human activities on the river and its tributaries.
- **River Management Authorities:** These specialized authorities are responsible for managing specific river basins, including the Bharathapuzha. They develop and implement plans for river restoration, flood control, and water resource management.
- **Nava Kerala Mission:** This ambitious state government initiative aims to transform Kerala into a developed state. River rejuvenation is one of its key components. *Bharathapuzha Samrakshana Yajnam* is the ongoing mission for the conservation of Bhrathapuzha river
- **NGO:** Non-governmental organizations like *Friends of Bharathapuzha* play a vital role in supporting river conservation efforts. They undertake activities such as:

- Organizing awareness campaigns and educational programs.
- Monitoring water quality and biodiversity.
- Collaborating with government agencies to implement conservation measures and advocating for stronger policies and regulations to protect the river.

4.0 STUDY AREA

The selection of the study area for this research is grounded in a multifaceted evaluation of hydrological, ecological, administrative, and policy-related considerations. Central to this selection is the hydrological significance of the region, which plays a pivotal role in sustaining surface and groundwater resources across the Bharathapuzha River basin. As one of Kerala's major west-flowing rivers, the Bharathapuzha supports diverse land use and livelihoods, particularly those dependent on agriculture. The specific focus on a sub-watershed encompassing parts of Parali Grama Panchayat, Palakkad Municipality, and Elapulli Grama Panchayat reflects a need to examine micro-level hydrological processes that directly influence the basin's base flow regime. This granular approach allows for a nuanced understanding of how land cover transformations and anthropogenic activities shape water availability throughout the year.

The presence of a Central Water Commission (CWC) stream gauging station at Mankara forms a cornerstone for selecting this particular region. Stream gauging stations provide invaluable datasets that facilitate long-term trend analyses, a key requirement for evaluating variations in base flow and river discharge. The Mankara station, in particular, offers a reliable historical dataset that supports the calculation of the Base Flow Index (BFI)—a critical parameter in understanding groundwater contributions to river flow. Access to such a consistent and authoritative source of hydrological data enhances the robustness and scientific credibility of this research. Moreover, the location of the gauge within the study area ensures spatial relevance and minimizes extrapolation errors, thereby strengthening the validity of conclusions drawn.

Another compelling rationale for choosing this area lies in its high drought vulnerability. Classified as one of the most drought-prone zones in the Bharathapuzha River basin, the region frequently experiences water scarcity during dry seasons. This recurrent hydrological stress underscores the urgency of studying groundwater dependence, particularly in the context of reduced surface water availability. The region presents an ideal natural laboratory for investigating the recharge mechanisms that support base flow continuity. Understanding these mechanisms is essential not only for predicting water availability but also for designing adaptive water conservation strategies that are responsive to seasonal and interannual variability.

Irrigation practices within the study area also play a significant role in shaping its hydrological character. The region benefits from water releases managed through the Malampuzha Dam, which has a total storage capacity of approximately 230 million cubic meters. This dam is among the largest in Kerala and plays a crucial role in flood control, irrigation, and drinking water supply. The regulation of water through controlled releases from the reservoir has a pronounced effect on the seasonal flow regime of the river. By modulating flow volumes during lean periods, dam operations alter the natural flow dynamics, influencing both surface water availability and groundwater recharge patterns.

The presence of the Command Area Development Authority (CADA) Scheme in the region adds another layer of relevance. CADA aims to optimize irrigation efficiency and land productivity through improved infrastructure and water management practices. The inclusion of this policy instrument within the study area allows for an integrated assessment of agricultural water demand and supply. It also creates an opportunity to analyze the socio-economic dimensions of water use, particularly the equity of water distribution, adoption of water-saving

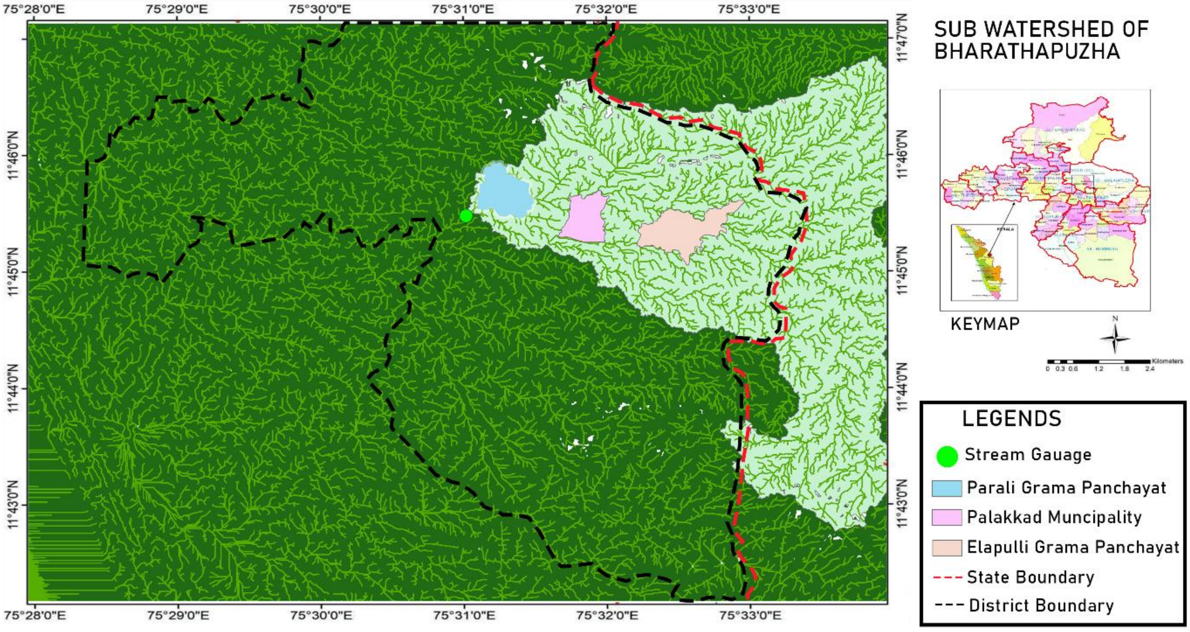

Figure 7 Site selected

Source: Author

technologies, and institutional arrangements for participatory irrigation management. Through this lens, the research can contribute valuable insights into sustainable river basin management and water governance.

Geographically, the study area lies at a critical ecological and administrative intersection. The region straddles the border between the states of Kerala and Tamil Nadu, a factor that introduces complex dynamics in watershed governance. The red dashed line shown on the attached map indicates this interstate boundary, which holds significant implications for resource sharing and policy harmonization. Managing a transboundary watershed involves coordination among multiple administrative jurisdictions, each with its own priorities and regulatory frameworks. This borderland setting magnifies the challenges of integrated water resource management while also offering opportunities for inter-state cooperation and collaborative policy design.

The attached map serves as a spatial anchor for this research, visually delineating the study area's hydrological and administrative components. It showcases the intricate network of streams and tributaries within the sub-watershed, many of which play a critical role in sustaining base flow during dry months. These minor streams are often the first to reflect the impacts of land use change, sedimentation, and groundwater extraction, making them valuable indicators for hydrological health assessments. The map also highlights three key local governance units—Parali, Elapulli, and Palakkad Municipality—each shown in a distinct color. These units serve as the focal points for data collection, field surveys, and stakeholder interactions.

District boundaries, also shown on the map, further emphasize the administrative complexity of the region. The interaction between district-level planning and watershed-scale hydrology necessitates an interdisciplinary approach that bridges geography, hydrology, and policy studies. This administrative layering can sometimes result in fragmented decision-making, but it also provides multiple entry points for stakeholder engagement and localized interventions. By understanding the interplay between district governance and water resource management, this study can propose more coherent and coordinated strategies for base flow preservation and sustainable land use.

An inset key map included in the visual material provides broader geographical context, situating the study area within the Palakkad district and the wider Kerala-Tamil Nadu landscape. Palakkad's unique physiographic setting—characterized by the Palakkad Gap—enables significant climatic and hydrological exchange between the two states. This broader contextualization is essential for understanding the climatic drivers of hydrological variability and their cascading effects on local water resources. It also sets the stage for exploring the role of mesoscale meteorological phenomena in shaping base flow dynamics and drought resilience.

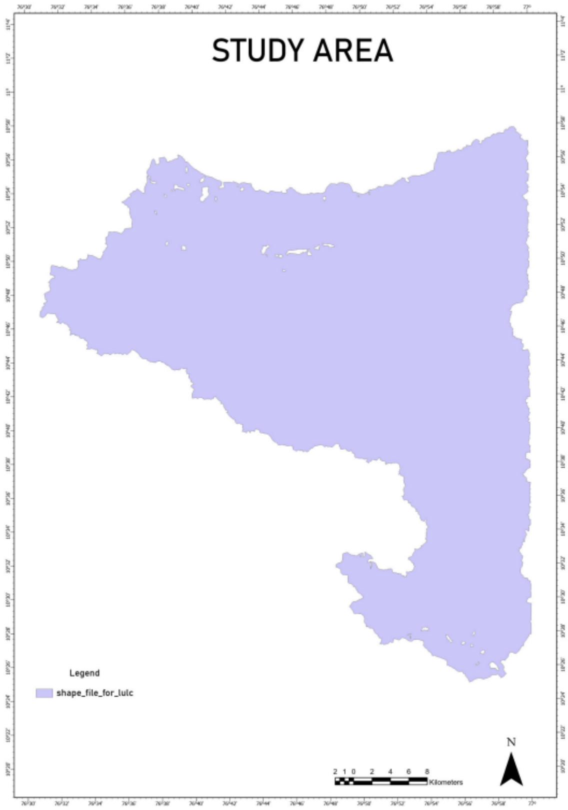

Figure 8 Study Area Demarcation

Source: Author

In summary, the study area's selection is a deliberate and strategic choice that aligns with the objectives of analyzing base flow variability in the context of changing land use and water management practices. It brings together key features—reliable hydrological data, drought sensitivity, irrigation infrastructure, and interstate governance—that collectively offer a comprehensive platform for integrated watershed research. By focusing on this dynamic and multifaceted region, the study aims to generate actionable insights that can inform sustainable water policy, enhance local governance capacities, and contribute to the broader discourse on transboundary watershed management in South India.

4.1 Data Collection Strategies

The sampling rationale is based on the demographic distribution across Parali, Palakkad, and Ellapully, ensuring a representative sample that reflects population density, settlement patterns, and potential impacts on water resources. Given the 2011 population data, Parali has the highest population (34,451), followed by Palakkad (22,037) and Ellapully (18,732). To maintain proportional representation, the sample distribution is aligned with these population figures.

Parali, being the most populated region, is allocated the largest sample size, ensuring adequate representation of its diverse socio-economic and hydrological influences. The sampling size assigned is 38, accounting for its high residential density and potential impacts on water demand and land use changes. Palakkad, with a lower population, is assigned a sample size of 26, proportionate to its demographic share. This allows for capturing insights into its moderate growth trends and associated water consumption patterns. Ellapully, which falls in between the other two locations in terms of population, is assigned a sample size of 16, reflecting its share of the total demographic composition. The sampling approach ensures that each region is proportionally represented in relation to its population size while also capturing variations in household structures, water use patterns, and local environmental conditions. This distribution allows for a balanced assessment of community perceptions, hydrological challenges, and potential solutions for river rejuvenation in the Bharathapuzha River watershed.

5. DATA ANALYSIS

5.1 To understand the core Hydrological concepts and principles of Sustainable River Management

The imperative for effective river rejuvenation and sustainable management necessitates a comprehensive understanding of core hydrological concepts. This foundational knowledge forms the bedrock upon which successful interventions are built, enabling us to address the complex challenges facing our river systems. The primary objective, therefore, is to delve into these hydrological principles, establishing a robust framework for informed decision-making and practical implementation. Central to this understanding is the identification and analysis of key hydrological parameters. Streamflow, which measures the volume of water flowing through a river channel, is a key indicator of the river's capacity and overall health. Sediment load, the amount of solid material carried by the river, offers insights into erosion and deposition processes, which are vital for maintaining channel morphology and ecological balance. Water quality, covering a range of chemical, physical, and biological factors, is essential for both human health and ecosystem well-being, reflecting pollution levels and the river's ability to sustain life. Recharge rates, which refer to the replenishment of groundwater reserves, and groundwater fluctuations, indicating changes in groundwater levels, emphasize the interconnection between surface and subsurface water systems. Rainfall, as the main source of water input, and evapotranspiration, the loss of water through evaporation and plant transpiration, shape the water balance of a watershed, influencing both streamflow and groundwater availability. When analyzed together, these parameters offer a comprehensive understanding of the river system's dynamics and health.

The acquisition of reliable and comprehensive data is indispensable for accurate hydrological assessment. Data collection methodologies employ a suite of advanced and conventional techniques. Remote sensing, utilizing satellite imagery and aerial photography, offers a synoptic view of large areas, enabling the monitoring of land cover changes, vegetation health, and water surface extent. Geographic Information Systems (GIS) facilitate the spatial analysis of hydrological data, integrating diverse datasets and enabling the visualization of complex relationships. Ground-based stations, equipped with sensors and monitoring devices, provide continuous, real-time measurements of streamflow, water quality, and meteorological parameters. Existing databases, repositories of historical data, offer valuable long-term perspectives and enable the identification of trends and patterns. The raw data collected from these sources often require pre-processing to ensure accuracy and consistency. Cleaning involves the removal of erroneous or anomalous data points, while interpolation techniques are used to estimate values for missing data. Standardization ensures that data from different sources are comparable, facilitating integrated analysis. This meticulous pre-processing stage is essential for generating reliable inputs for subsequent modelling and interpretation. Hydrological modelling plays a pivotal role in translating raw data into meaningful insights. GIS-based watershed analysis enables the delineation of drainage basins, the calculation of topographic parameters, and the simulation of runoff generation. Statistical analysis, employing a range of techniques, is used to identify trends in streamflow and other parameters, quantify flow variations, and determine correlations between different hydrological variables. These models, by simulating the complex interactions within the river system, provide a basis for predicting future behaviour and evaluating the impacts of various management scenarios. The integration of different modelling approaches, such as physically based and empirical models, enhances the robustness and accuracy of the analysis.

The ultimate goal of hydrological assessment is to derive actionable insights that inform river rejuvenation and sustainable management strategies. Interpretation of the results obtained from data analysis and modelling involves identifying the causes of river degradation, whether they be anthropogenic, such as pollution and over-abstraction, or natural, such as climate variability and geological factors. The assessment of rejuvenation potential involves evaluating the feasibility and effectiveness of various restoration measures, considering factors such as ecological resilience, social acceptability, and economic viability. Understanding seasonal fluctuations in hydrological parameters, such as streamflow and water quality, is vital for effective water resource management and for mitigating the impacts of extreme events like floods and droughts. Analyzing river-groundwater interactions, including the movement of water and solutes between surface and subsurface systems, is crucial for sustainable groundwater management and safeguarding baseflow in rivers. By thoroughly examining these fundamental hydrological concepts, a comprehensive understanding of the river system's functioning can be developed, enabling the identification of the most effective strategies for its restoration and long-term management. This knowledge-based approach ensures that interventions are scientifically valid, ecologically mindful, and socially responsible, promoting the health and resilience of our valuable river ecosystems over time.

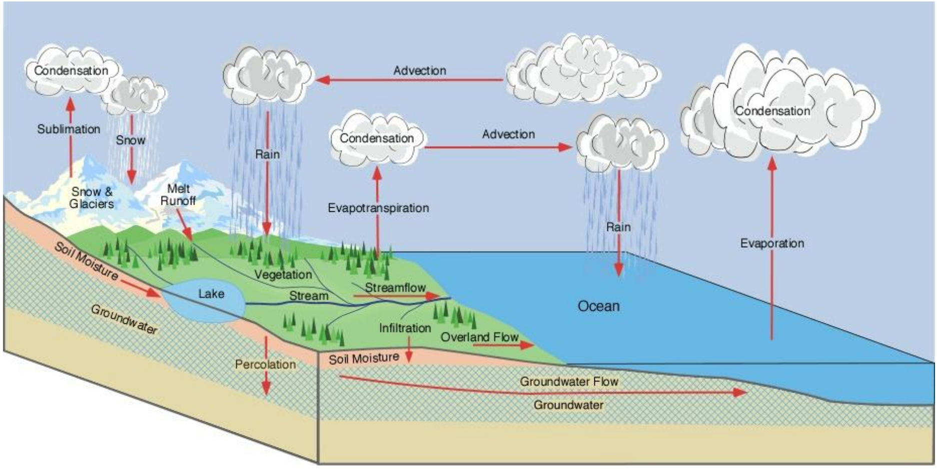

Figure 9 Hydrological Cycle

Source: PhysicalGeography.net

5.2 To determine the 30-year trend of baseflow index (BFI) and ground water levels sub watershed of Bharathapuzha river and water quality improvement

This analysis delves into the temporal dynamics of land cover changes and agricultural land use within [Specific Region, e.g., Kerala], focusing on the period from 1993 to 2023. The data presented in the accompanying figures provide a comprehensive overview of the transformations that have occurred, highlighting key trends and potential implications for environmental sustainability and resource management.

5.3 Land Cover Changes: A Shift in Landscape Composition

The first figure, "Land Cover Changes," illustrates the fluctuations in various land cover categories over the past three decades. Notably, a significant decrease is observed in Agricultural Land, demonstrating a consistent decline from 1993 to 2023. This trend indicates a possible shift from traditional agricultural practices, likely influenced by factors such as urbanization, industrial development, or evolving economic incentives.

Conversely, Built-up areas exhibit a substantial increase, indicating rapid urbanization and infrastructural expansion within the region. This expansion can lead to habitat fragmentation, increased impervious surfaces, and altered hydrological regimes, impacting local ecosystems and water resources.

Wetland/Forest areas also show a decline, albeit less pronounced compared to agricultural land. This reduction in natural vegetation cover can have significant consequences for biodiversity, carbon sequestration, and climate regulation. The Barren Land category shows a slight increase, possibly reflecting land degradation or the conversion of previously vegetated areas.

River/Water Body areas also demonstrate a marginal decrease, indicating potential pressures on aquatic ecosystems. This decline could be attributed to factors such as water extraction, pollution, or changes in precipitation patterns.

Quantitative Analysis of Percentage Changes

The table accompanying the land cover change graph provides quantitative data on the percentage changes in each category from 1993. The most striking change is the dramatic increase in Built-up areas, with a 43% rise by 2003, followed by further increases of 56% and 61% by 2013 and 2023, respectively. The rapid pace of urbanization highlights the importance of sustainable urban planning and infrastructure development to minimize potential environmental impacts.

dIn contrast, Agricultural Land shows a consistent decline, with reductions of 22%, 41%, and 54% by 2003, 2013, and 2023, respectively. This trend raises concerns about food security, rural livelihoods, and the preservation of traditional agricultural landscapes.

Wetland and Forest areas also exhibit a decrease, with a notable 38% reduction by 2023. This loss of natural habitats can have cascading effects on ecosystem services and biodiversity.

Barren Land shows a slight increase, while River/Water Body areas experience a marginal decline. These changes, though seemingly small, can have cumulative impacts on the overall ecological balance of the region.

Agricultural Land Use: A Focus on Paddy Cultivation

The second figure, "Land Area of Agricultural Crops," provides insights into the changing patterns of agricultural land use. Notably, Paddy Cultivation dominates the agricultural landscape, with a significantly larger area compared to other crops. However, the data reveals a decline in paddy cultivation over time, mirroring the overall reduction in agricultural land.

Other agricultural activities, such as Coconut Farm, Arecanut Farm, Rubber Plantation, Vegetables, Banana Plantation, and Spices and Others, occupy relatively smaller areas. The temporal trends for these crops are not explicitly presented in the graph, but they likely reflect shifts in market demands, economic incentives, and agricultural policies.

The Kerala Wetlands and Paddy Conservation Act, 2008

The mention of the "Kerala Wetlands and Paddy Conservation Act, 2008" highlights the policy framework in place to address the declining trends in paddy cultivation and wetland conservation. This act underscores the recognition of the ecological and socio-economic importance of these ecosystems. However, the continued decline in paddy cultivation and wetland areas suggests potential challenges in the effective implementation of the act.

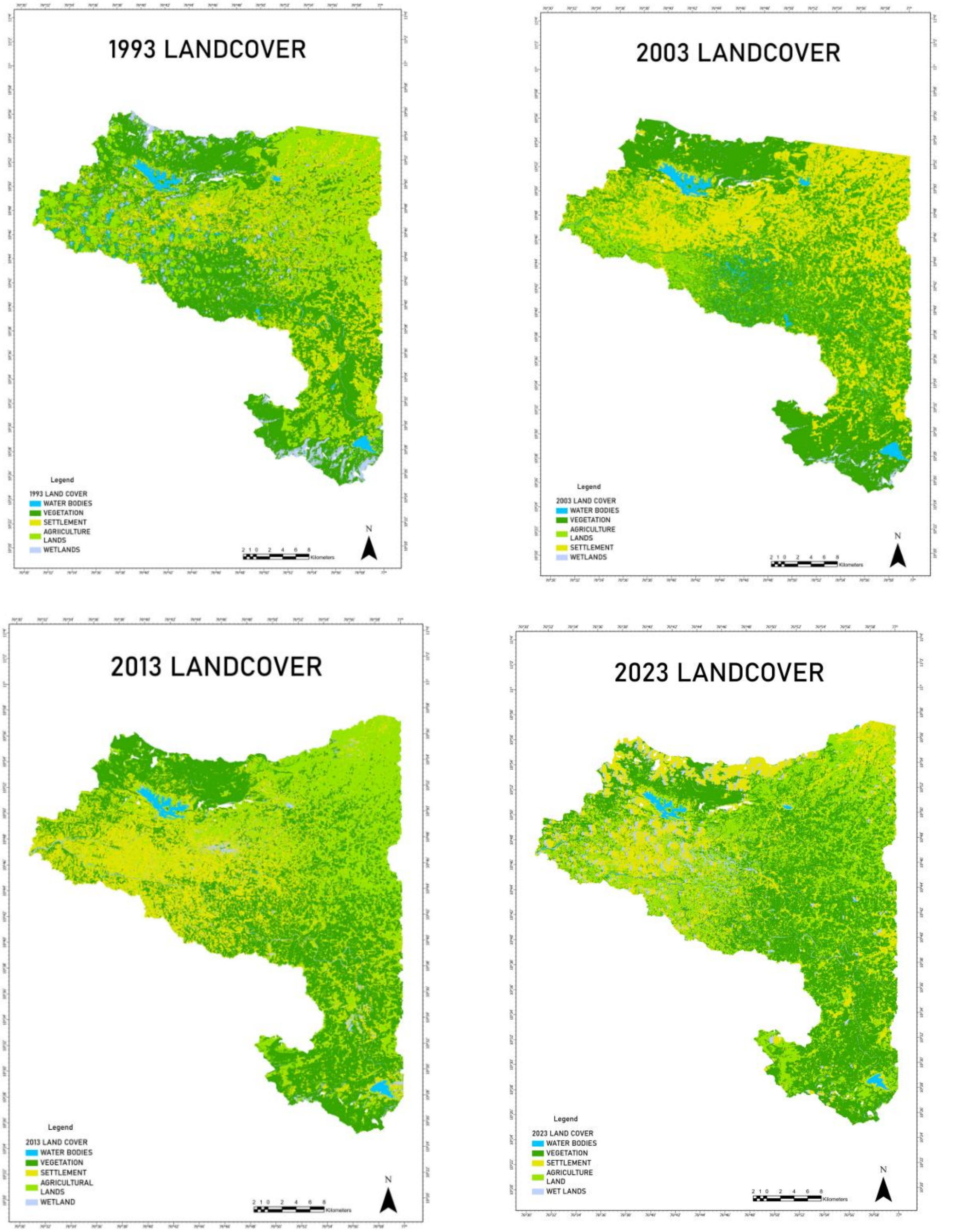

Figure 10 Landcover of 2003 to 2023

Source: Author

Table 1 Change in Landcover From 1993 -2023

YEAR	BFI	AGRICULTURAL LU-SQ KM	PERCENTAGE	WATERBODY LU-SQ KM	PERCENTAGE	BUILTUP LU -SQ KM	PERCENTAGE	WETLAND LU -SQKM	PERCENTAGE	VEGETATION LU -SQKM	PERCENTAGE	TOTAL
1993	0.2	432.7777487	25.55417494	115.6584321	6.829269332	352.1627499	20.79411093	35.26396163	2.082226841	757.7067485	44.74021795	1693.569641
2003	0.19	415.7604066	25.03551819	106.9263773	6.438701766	361.0879764	21.74335135	28.62516436	1.723699062	748.2823249	45.05872963	1660.68225
2013	0.052	373.3503969	22.23756949	91.54832145	5.452819059	450.8439039	26.85325294	23.56482423	1.403572678	739.6098338	44.05278583	1678.91728
2023	0.058	237.4627393	15.42317971	78.63619547	5.107412548	500.9791369	32.53854176	19.32619509	1.255234319	703.2441313	45.67563167	1539.648398

Table 2 Variable, Coefficient and Significance Percentage

Variable	**Correlation with BFI**	**Interpretation**
Waterbody_LU_Sq.km	+0.92	Very strong positive effect on BFI
Rainfall_mm	+0.93	Very strong positive effect
Wetland_LU_sq.km	+0.88	Strong positive correlation
Agricultural_LU_sq.km	+0.78	Moderate to strong positive

Open_Green_Cover_sq.km	+0.73	Moderate positive
Buildup_LC_sq.km	−0.95	Very strong negative correlation
Temperature_C	−0.97	Very strong negative correlation

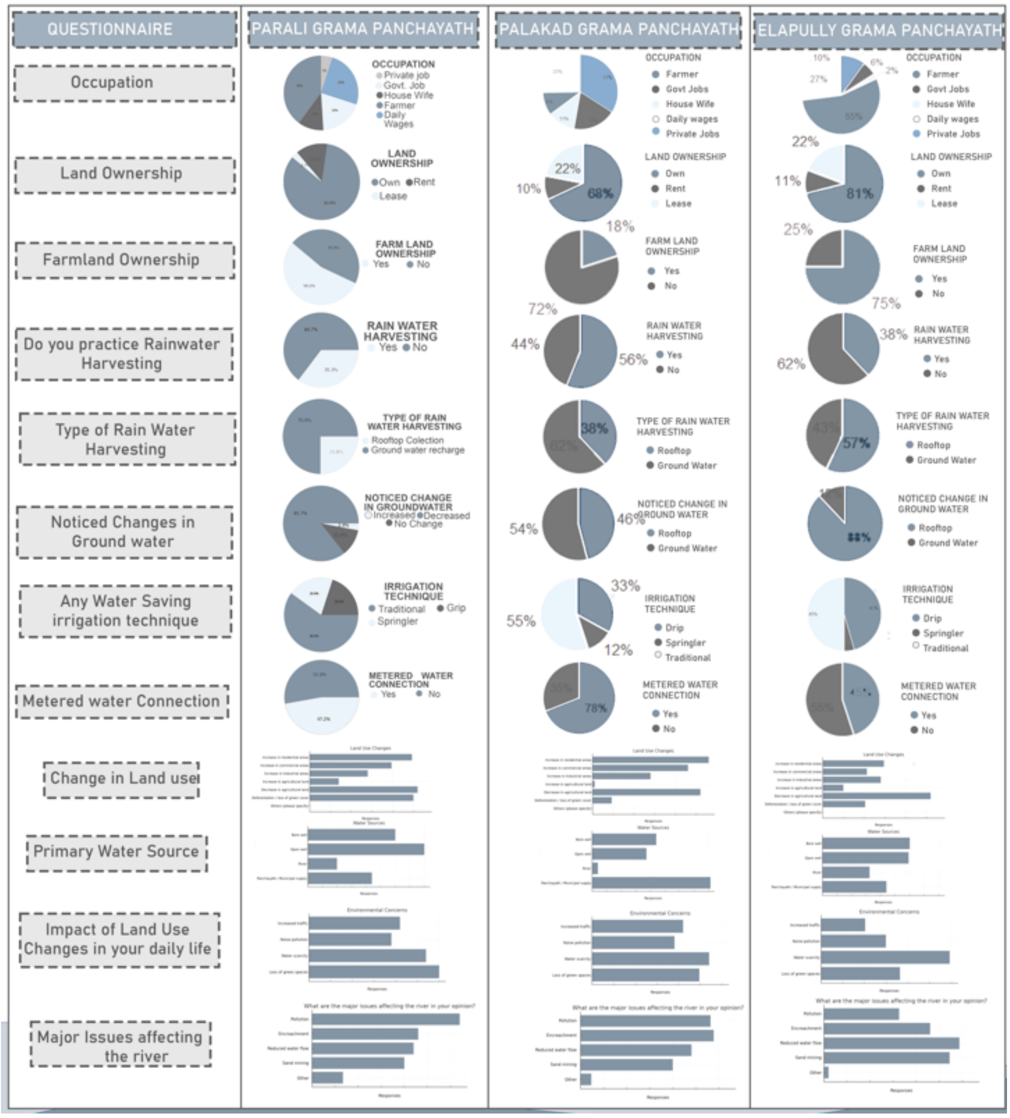

Figure 11 Perception Survey Result Analysis

Source: Author

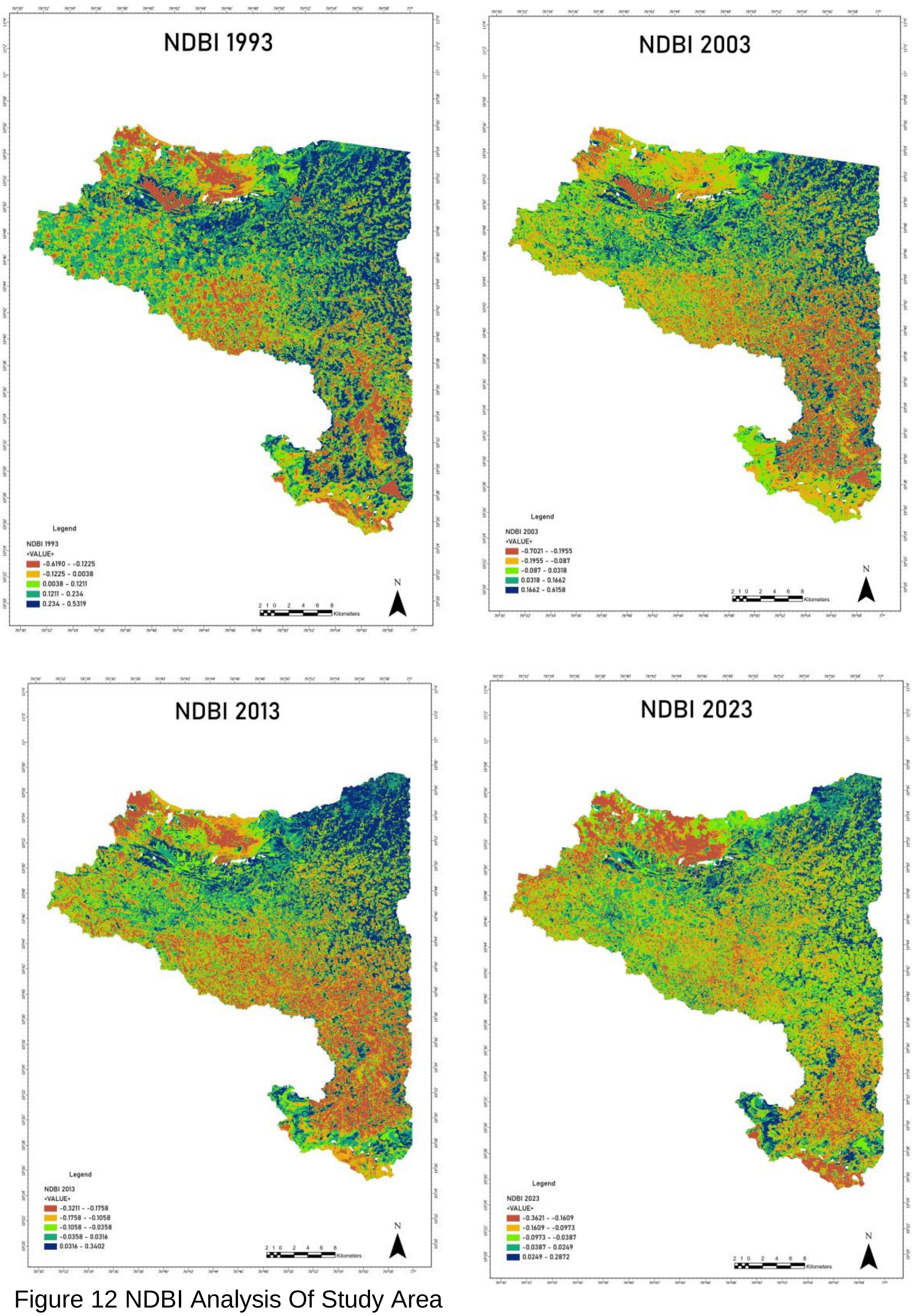

Figure 12 NDBI Analysis Of Study Area

Source: Author

Wetlands and waterbodies demonstrate the most significant influence on the baseflow index (BFI), with their loss leading to substantial reductions. Similarly, built-up areas notably decrease BFI, reinforcing NDBI findings. While vegetation and rainfall contribute positively, their impact is less pronounced. Temperature and rainfall exhibited minimal influence in the regression analysis. The increasing NDBI values from 1993 to 2023 highlight urban expansion and the rapid growth of built-up areas. This expansion coincides with a decline in vegetative cover, resulting in reduced infiltration zones and increased dominance of impervious surfaces. Consequently, this increased imperviousness has intensified hydrological stress by reducing groundwater recharge, elevating surface runoff, and causing a corresponding decline in base flow, thereby exacerbating seasonal water stress

5.4 Flow Regime Shift And BFI Index Change Interpretation

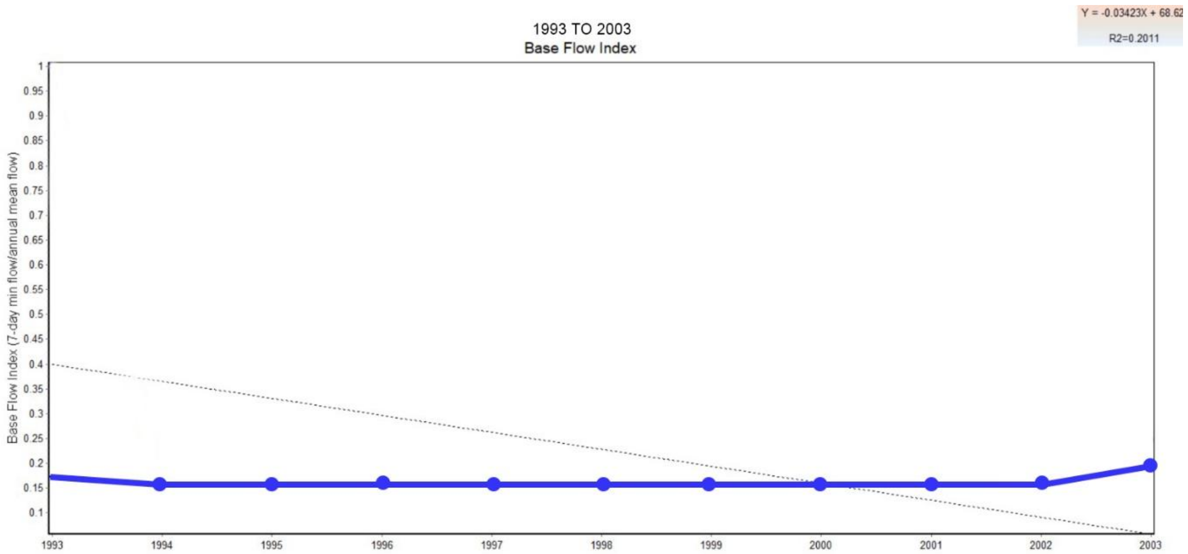

Figure 13 Base flow index 1993 to 2003

Source: Author

Considering over all summary for the 30 years from 1993 to 2023 from the above given values Analysing the baseflow index (BFI) data for the Bharathapuzha River in Palakkad district across the 30-year period from 1993 to 2023 reveals distinct patterns and shifts in groundwater contribution to the river's flow. The initial year, 1993, stands out with a notably higher BFI, suggesting a period of significant groundwater influence. This, however, was followed by a prolonged phase, spanning from 1994 to approximately 2011, characterized by consistently low BFI values. This extended period indicates a dominance of surface runoff in the river's flow, with minimal contributions from groundwater sources. A notable shift occurred around 2012 and 2013, with a marked increase in BFI, signalling a resurgence in groundwater influence. This surge, however, proved to be temporary, as the BFI subsequently declined and stabilized within a slightly elevated, yet still relatively low range, from 2014 to 2022. Finally, 2023 saw a more significant increase in BFI, suggesting a renewed, though potentially transient, rise in groundwater contribution.

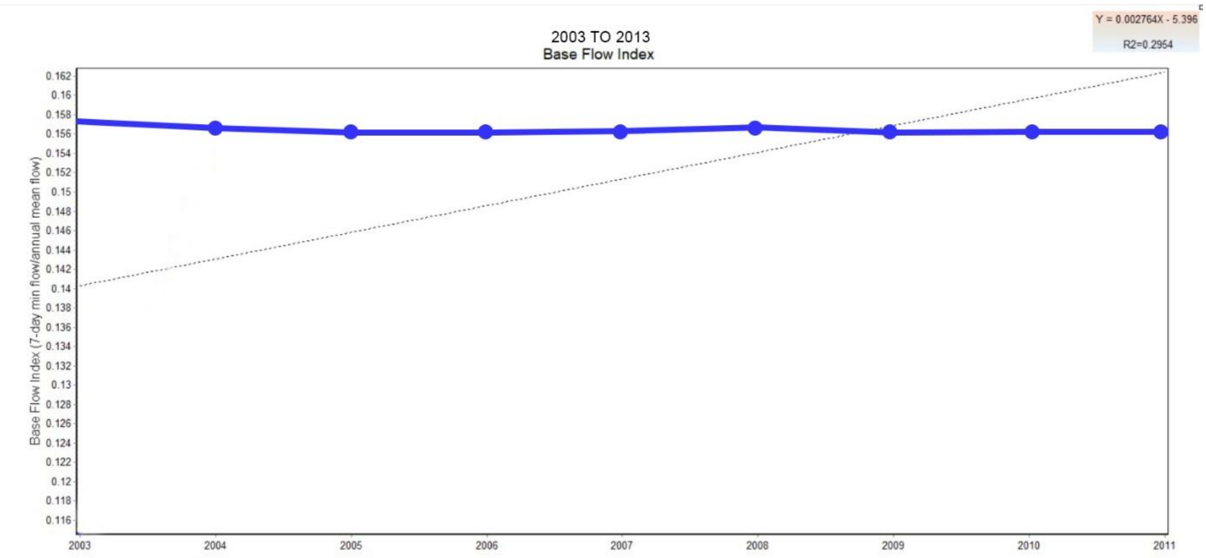

Figure 14 Base flow index 2003 to 2013

Source: Author

Overall, the 30-year dataset paints a picture of a river system with fluctuating groundwater influence. The initial high BFI was followed by a prolonged period of low groundwater contribution, punctuated by brief periods of increased influence. These fluctuations likely reflect variations in rainfall patterns, land use changes, and groundwater extraction activities within the Bharathapuzha River basin. A comprehensive understanding of these variations necessitates further investigation, incorporating additional hydrological and meteorological data to inform effective water resource management strategies for the region.

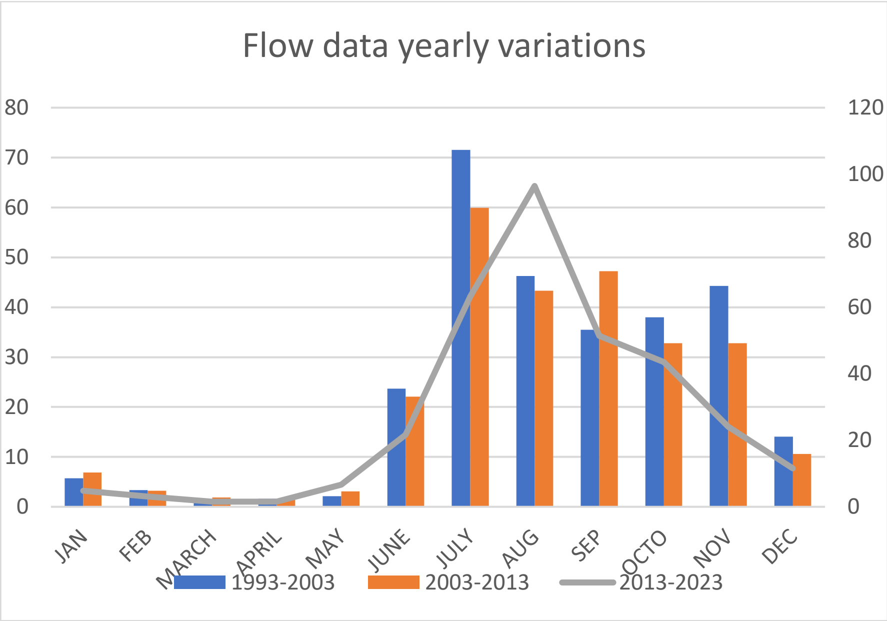

Figure 15 Flow Data yearly variation

Source: Author

5.5 Analysis of Flow Data Yearly Variations (1993–2023)

The provided chart illustrates the yearly variations in flow data over three distinct time periods: 1993–2003, 2003–2013, and 2013–2023. The bar graph represents the monthly flow data for the first two decades (1993–2003 and 2003–2013), while the green line represents the flow pattern observed in the most recent decade (2013–2023). This comparative analysis highlights key trends in flow variations, seasonal fluctuations, and long-term changes, shedding light on the evolving hydrological dynamics over three decades.

General Observations and Seasonal Trends

Across all three time periods, the data exhibits a clear seasonal pattern, with flow values reaching their peak during the monsoon months (June to September), followed by a gradual decline towards the dry season (October to May). This pattern is characteristic of river systems in monsoon-dominated regions, where precipitation governs the majority of surface water flow. The flow remains minimal during the dry months, with the lowest values observed from January to April.

The monsoon-driven increase in flow is most prominent in July, where all three datasets show a significant surge. However, the extent of this peak and the subsequent post-monsoon decline differ across the three time periods, indicating shifts in hydrological response over the years.

Comparative Analysis of Decadal Flow Trends

1993–2003 (Blue Bars): High Monsoonal Peaks with Strong Flow Resilience

During this decade, flow levels were significantly higher, particularly in the peak monsoon months (June to September). July records the highest flow, exceeding 70 units, followed by August and September with substantial flow contributions. This suggests a robust monsoonal impact with effective catchment response, likely aided by a well-functioning natural hydrological cycle, minimal anthropogenic interference, and strong groundwater-surface water interaction.

In the post-monsoon months (October–December), the flow remains relatively high, suggesting a sustained baseflow contribution, possibly from groundwater recharge. Even in the dry months (January–April), although the values are low, they indicate a stable perennial system, demonstrating the river’s ability to maintain some level of flow throughout the year.

2003–2013 (Red Bars): Decreasing Monsoonal Peaks and Reduced Post-Monsoon Flow

In the second decade, a noticeable reduction in flow values is observed across most months, particularly during the monsoon season. The peak monsoonal flow (July) declines compared to the previous decade, with a drop of nearly 10–15 units. While the seasonal pattern remains the same, the overall magnitude of flow has reduced, indicating possible alterations in rainfall-runoff relationships, land use changes, or increased water extractions.

One of the most significant observations is the reduced post-monsoon flow (October–December) compared to the earlier decade. This decline suggests that the river system is experiencing reduced groundwater contributions or that water retention within the basin is diminishing. The dry-season flows (January–April) also show a slight reduction, hinting at increasing stress on baseflow components, possibly due to declining groundwater levels or increased surface water withdrawals.

2013–2023 (Green Line): Shift Towards More Concentrated Monsoonal Flow and Extended Dry Periods

The green line representing the most recent decade (2013–2023) showcases a significant transformation in flow dynamics. While the monsoonal peak remains evident, the flow appears to be more concentrated, with a steeper rise and fall. The July peak is lower compared to previous decades, suggesting either a decrease in rainfall intensity or a reduction in runoff efficiency due to landscape modifications (such as urbanization, deforestation, or water retention structures).

A striking observation is the steeper decline in post-monsoon flow (October–December). Unlike the previous decades, where flow tapered off gradually, the recent trend shows a more abrupt decline, indicating reduced water storage within the system.

This pattern suggests a diminished capacity of the basin to retain and release water over extended periods, likely due to increased impervious surfaces, declining groundwater recharge, or upstream interventions (such as reservoirs and diversions).

Additionally, the dry-season flow (January–April) is at its lowest levels in three decades. This could be attributed to increased water extractions, decreased groundwater contribution, or shifting climatic patterns affecting baseflow conditions. The overall trend points toward an increasingly seasonal flow regime, where monsoonal flows dominate, but dry-season flows become progressively scarcer, raising concerns about water availability during non-monsoonal months

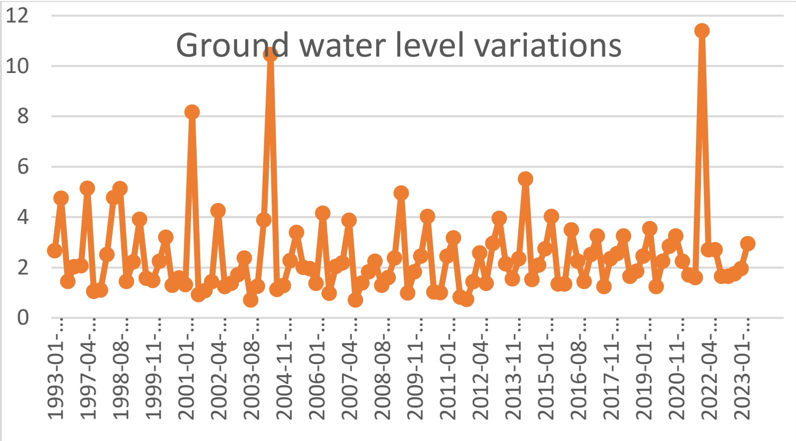

Figure 16 Graph of ground water level variation

Source: Author

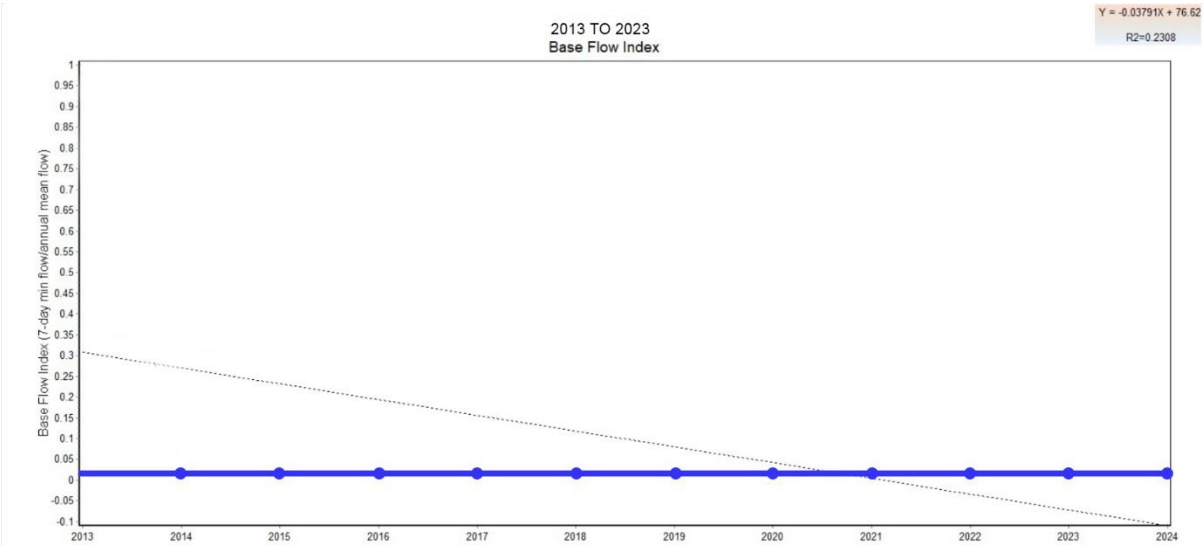

Figure 17 Base flow index 2013 to 2023

Source: Author

Table 3 Baseflow quantity with respect to decade

Decade	BFI	Baseflow quantity (m^3/s)
1993-2003	0.21	0.5817
2003-2013	0.052	0.1278
2013-2023	0.058	0.19

This table presents the decadal trends of the Baseflow Index (BFI) and corresponding baseflow quantity in cubic meters per second (m^3/s) for the period 1993 to 2023. The BFI, an indicator of the proportion of total streamflow contributed by groundwater, shows a significant decline from 0.21 during 1993–2003 to 0.052 in 2003–2013. A marginal improvement is observed in 2013–2023, where the BFI slightly rises to 0.058. Similarly, the baseflow quantity follows a decreasing trend from 0.5817 m^3/s in the first decade to 0.1278 m^3/s in the second, with a modest increase to 0.19 m^3/s in the final decade. This decline highlights the reduction in groundwater contribution to streamflow over time, possibly due to land use changes, declining recharge, and increasing anthropogenic pressures within the watershed.

5.6 Groundwater Level Trend Analysis (1993–2023): A Detailed Assessment

The groundwater level data from 1993 to 2023 provides critical insights into the long-term variations in groundwater availability, reflecting both natural and anthropogenic influences. Over this thirty-year period, significant fluctuations in groundwater levels have been observed, highlighting distinct seasonal variations as well as an overarching declining trend. Analyzing these changes in the context of urbanization, land use, climate variability, and water management practices offers valuable perspectives on the sustainability of groundwater resources, particularly in relation to river rejuvenation efforts.

Overall, Groundwater Trends and Seasonal Variations

The data exhibits a cyclical pattern of groundwater fluctuation, with noticeable seasonal peaks and troughs. Groundwater levels tend to rise in the months following the monsoon, particularly in April, when water tables are at their highest. This trend suggests that groundwater recharge is primarily dependent on monsoonal precipitation, contributing to temporary increases in water levels. Conversely, the lowest values are typically recorded between August and November, indicative of excessive groundwater extraction during the dry season, coupled with natural depletion. This seasonal pattern is consistent across the dataset, underscoring the monsoon-driven recharge mechanism.

Although short-term variations are evident, the long-term trajectory of groundwater levels reveals a progressive decline. While some years exhibit significant recharge events leading to temporary peaks, the overall trend suggests that groundwater levels have been consistently decreasing over the decades. This decline is particularly prominent in recent years, suggesting an imbalance between recharge and extraction, likely exacerbated by increasing urban water demand and reduced infiltration due to land-use changes.

Decadal Analysis: From Stability to Decline

Between 1993 and the early 2000s, groundwater levels remained relatively stable, with fluctuations occurring within a predictable range. The highest recorded levels during this period indicate a healthy recharge capacity, with certain years, such as 2001 and 2004, showing exceptional peaks in April. The recorded groundwater level in April 2004, reaching 10.46 meters, is one such example of a strong recharge event. However, this period also marks the beginning of increasing variability, with occasional dry-season records showing lower levels than in previous years.

As the dataset progresses into the 2003–2012 period, a gradual but noticeable decline in groundwater levels becomes evident. While seasonal peaks continue to occur, their magnitude is reduced compared to earlier years. This suggests that recharge events, though present, are no longer sufficient to compensate for the increasing rate of depletion. By the late 2000s, the lowest recorded values during dry months indicate a more pronounced decline, pointing to excessive groundwater abstraction, possibly linked to growing urban and agricultural water demands. The reduction in water table recovery in April further supports this trend, demonstrating that natural recharge is becoming increasingly insufficient.

From 2013 onwards, the rate of groundwater decline appears to accelerate. Seasonal variations continue, but the depth to groundwater during peak depletion months reaches critical levels, signalling stress on the resource. A particularly alarming instance is observed in early 2022, where the water table drops to 11.4 meters, the lowest recorded level in the entire dataset. This extreme decline suggests a combination of factors, including prolonged dry spells, increased water extraction, and possibly lower-than-average monsoonal recharge. Despite minor recoveries in subsequent years, groundwater levels do not return to their previous highs, reflecting a long-term pattern of diminishing water availability.

Potential Causes of Groundwater Decline

Several factors contribute to the observed depletion of groundwater levels over the thirty-year period. The most significant influence appears to be urbanization and the corresponding increase in impervious surfaces, which restrict natural groundwater recharge. The expansion of infrastructure, roads, and built-up areas reduces the capacity of rainfall to percolate into the soil, thereby limiting the replenishment of aquifers. This is particularly concerning in urban regions where the demand for groundwater extraction is simultaneously rising due to population growth and increased industrial activities.

Climate variability further exacerbates this decline, as the monsoonal recharge cycle is not consistent year after year. Variations in rainfall patterns, including years of deficient precipitation, result in reduced recharge, leading to a cumulative depletion effect over time. While certain years' experience significant groundwater recovery, these instances are becoming less frequent, highlighting the vulnerability of groundwater systems to climatic fluctuations.

Over-extraction for domestic, agricultural, and industrial use remains another key driver of groundwater depletion. The observed data indicates that post-monsoon water levels, which typically signify the highest recharge, are consistently lower in recent decades than in the early 1990s. This suggests that even during peak recharge periods, excessive withdrawal prevents full recovery of the water table. The pattern of declining water levels in August and November further supports this assertion, as these months frequently exhibit critically low levels indicative of prolonged stress on groundwater reserves.

Implications for River Rejuvenation and Ecological Balance

The declining groundwater levels have significant implications for river rejuvenation efforts, particularly in urban tributaries such as the Kalpathy Puzha. Groundwater plays a crucial role in maintaining baseflow in rivers, especially during dry seasons when surface water contributions diminish. As the groundwater table continues to decline, the capacity of aquifers to sustain river flow during non-monsoonal periods is significantly reduced. This not only affects the hydrological balance of the river system but also has broader ecological consequences, impacting aquatic life, riparian vegetation, and overall water quality.

Furthermore, reduced groundwater availability increases dependence on alternate water sources, leading to further exploitation of both surface and groundwater resources. The continued depletion of groundwater reserves poses long-term sustainability challenges, necessitating urgent intervention through improved water management strategies. Implementing measures such as artificial recharge, rainwater harvesting, and regulated groundwater extraction can help mitigate further decline and support the restoration of riverine ecosystems.

5.7 Pollution Level Analysis

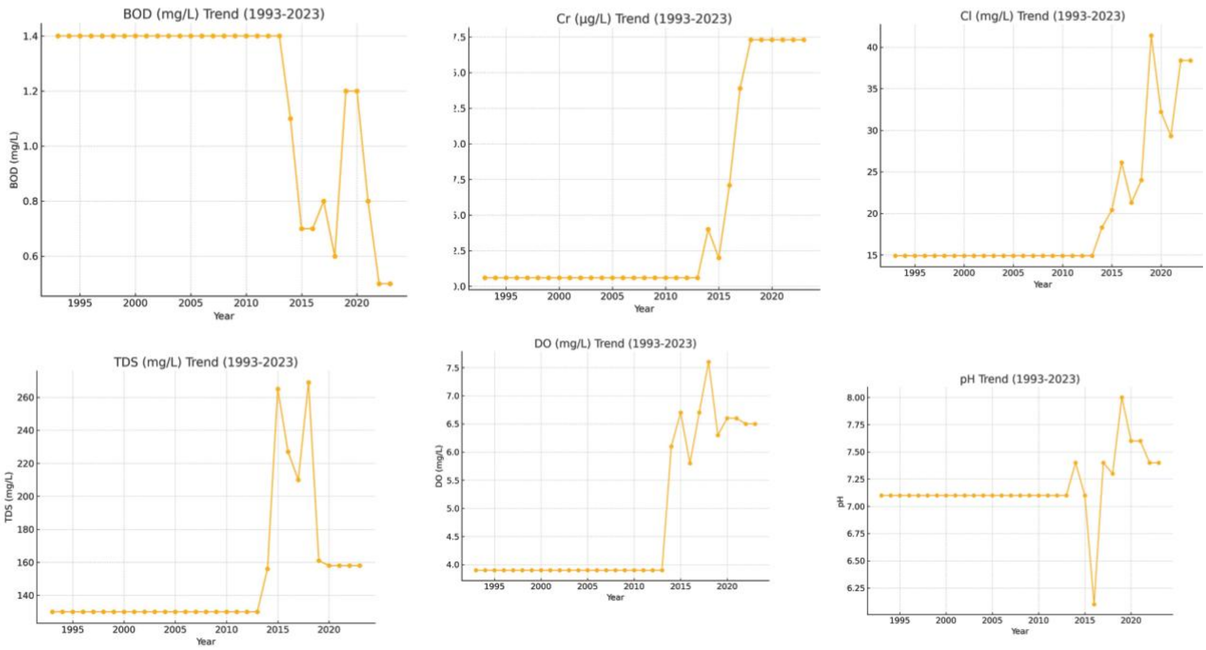

Figure 18 Graph of pollution level analysis

Source: Author

The pollution level analysis from 1993 to 2023 for Bharathapuzha provides critical insights into water quality changes over three decades. The trend for Biological Oxygen Demand (BOD) remained stable at around 1.4 mg/L until a sharp decline after 2015, indicating a reduction in organic pollution. However, fluctuations in recent years suggest periodic pollution events. Chromium (Cr) levels were negligible until 2015, after which there was a steep rise, stabilizing at around 7.5 µg/L. This points to potential industrial discharge or other anthropogenic sources. Chloride (Cl) concentration saw a marked increase post-2015, peaking above 40 mg/L, indicating rising salinity, possibly due to urban runoff or industrial effluents. Total Dissolved Solids (TDS) levels remained stable until 2015 but showed a sharp increase, exceeding 260 mg/L before stabilizing. This suggests contamination sources affecting dissolved mineral content. Dissolved Oxygen (DO) levels, essential for aquatic life, showed an increasing trend post-2015, reaching about 7 mg/L, suggesting improved aeration and self-cleansing mechanisms in the river. The pH levels, previously stable, showed significant fluctuations post-2015, with a peak above 7.75, indicating changing chemical dynamics in the river water.

5.8 Focussed Group Discussion

Figure 19 Focussed group discussion

Source: Author

The focused group discussion was conducted under the convenorship of the Bharathappuzha Conserving Mission, bringing together a diverse group of stakeholders, including farmers, government officers, environmental experts, and local community representatives. This collaborative effort aimed to address the pressing concerns surrounding the degradation of the Bharathapuzha River in Palakkad and to develop actionable strategies for its rejuvenation. The discussion provided a platform for various perspectives, blending traditional knowledge with scientific expertise to ensure a holistic approach to river conservation. A key theme that emerged was the urgent need to strengthen community awareness and participation in river conservation efforts. Many participants emphasized that while the Bharathapuzha River holds immense cultural and ecological significance, public consciousness regarding its declining health remains inadequate. Experts stressed that without widespread community engagement, even the most well-planned conservation initiatives would struggle to succeed. Suggestions included integrating river conservation themes into school education, organizing awareness campaigns, and fostering active community-led monitoring groups to oversee riverine activities and prevent further degradation. Another crucial aspect of the discussion revolved around expanding conservation measures such as bio-fencing, wetland restoration, and the construction of check dams. Experts pointed out that bio-fencing with native vegetation along riverbanks could prevent soil erosion, stabilize embankments, and mitigate encroachments. Farmers voiced concerns about the loss of natural wetlands, which historically played a vital role in maintaining water balance and filtering pollutants. Restoring these wetlands was proposed as a long-term measure to enhance water retention capacity. Additionally, check dams were identified as an effective intervention to regulate seasonal river flow and facilitate groundwater recharge. However, experts cautioned against their indiscriminate construction, advocating for site-specific hydrological assessments to optimize benefits while avoiding disruptions in sediment transport.

The discussion also brought to light the critical need for stricter regulation of land use and water management policies. Officers from various government departments highlighted the challenges posed by unchecked urban expansion, which has led to the encroachment of natural floodplains and disrupted the river's drainage system. The lack of enforcement of buffer zone regulations was flagged as a major issue, with calls for stricter implementation to prevent further encroachments. Experts emphasized the importance of integrating sustainable land use planning with water resource management to ensure that urban development does not come at the cost of ecological integrity. Waste management also emerged as a pressing concern, with stakeholders pointing out that improper disposal of sewage and industrial effluents has significantly contributed to the river's pollution levels. Several participants proposed decentralized wastewater treatment systems and community-driven waste management initiatives to curb pollution at its source. Farmers, as primary stakeholders, played a pivotal role in the discussion by sharing insights on the historical agricultural practices that once maintained a sustainable relationship between farming and the river ecosystem. Many expressed concerns over the shift towards water-intensive crops and excessive groundwater extraction, which have exacerbated the depletion of both surface and groundwater resources. Experts and officers encouraged a return to traditional, sustainable agricultural practices such as organic farming, crop diversification, and the adoption of water-efficient irrigation methods. The discussion highlighted the importance of policy incentives to support farmers in transitioning to sustainable agricultural models while ensuring their economic viability.

Rainwater harvesting and groundwater recharge were widely acknowledged as essential measures to counteract declining water availability. Experts suggested implementing large-scale rainwater harvesting projects at the household and community levels, while officers recommended the revival of traditional water conservation structures such as temple ponds and village tanks. Stakeholders unanimously agreed on the need for a scientific approach to groundwater management, emphasizing the role of hydrological studies in guiding conservation efforts. The officers present committed to exploring policy mechanisms to support these initiatives through government programs and public-private partnerships.

Ultimately, the focused group discussion served as a crucial step in formulating a comprehensive strategy for the rejuvenation of the Bharathapuzha. By bringing together diverse stakeholders under the leadership of the Bharathapuzha Conserving Mission, the dialogue ensured that conservation strategies were rooted in both local knowledge and scientific understanding. The insights and recommendations from this discussion will inform future action plans, guiding policy decisions and community-driven initiatives to restore the ecological health and cultural heritage of the river.

6. PROPOSALS

6.1 Identification of Ground Water Recharge Potential Zones.

6.1.1 Factors Influencing Groundwater Potential

The potential for groundwater availability in a region is influenced by a mix of natural and human-induced factors that impact the infiltration, storage, and movement of subsurface water. In the Bharathapuzha Basin, the geomorphological features such as valley fills and floodplains serve as natural reservoirs where water infiltrates and gets stored within the soil and weathered rock layers. These features are particularly prominent in the central and eastern parts of Palakkad, where alluvial deposits enhance infiltration.

Geologically, the region is underlain by a combination of hard crystalline rocks such as charnockites and gneisses, along with lateritic covers that are prevalent in elevated regions. The weathered and fractured portions of these rock types often act as aquifers, especially where secondary porosity is present due to tectonic activity. Soil types also play a crucial role, as red loamy and lateritic soils have varying capacities for water retention and percolation.

Land Cover are significant anthropogenic factors that influence recharge. Agricultural fields and forested areas generally promote groundwater recharge by allowing rainfall to percolate into the subsurface. In contrast, developed areas with impervious surfaces, like roads and buildings, hinder infiltration and increase surface runoff, which in turn diminishes groundwater potential. In Palakkad, the growth of urban and semi-urban areas over time has significantly affected recharge patterns.

Topographic slope further affects groundwater accumulation. Gentle slopes allow for longer residence time of water on the surface, enhancing infiltration. In contrast, steep slopes—particularly those near the fringes of the Western Ghats—encourage rapid runoff, limiting the potential for recharge. The drainage network, which defines how water flows across the land surface, also influences the distribution of groundwater. Areas with high drainage density tend to experience more runoff, while lower drainage density is often associated with better infiltration.

Rainfall patterns in Palakkad, driven by the southwest monsoon, are critical to natural groundwater recharge. While the district receives moderate to high rainfall annually, the spatial and temporal concentration of rainfall affects recharge effectiveness. Heavy, short-duration rainfall may result in more runoff than infiltration, especially in regions lacking vegetation cover or with compacted soils.

Another key factor is the presence of lineaments—linear features in the landscape that represent fractures or faults in the subsurface geology. These features often act as conduits that facilitate the movement and storage of groundwater. The intersection of multiple lineaments can indicate zones of enhanced groundwater potential. In the Palakkad region, several such lineaments have been identified through remote sensing and geophysical studies.

1. Geology

Geology is a foundational factor in determining the occurrence and movement of groundwater. The type of underlying rock, its weathering characteristics, and structural features directly influence the porosity and permeability of the subsurface, which are key parameters in groundwater storage and flow. In the Bharathapuzha Basin, the geological setup is primarily composed of hard crystalline rocks such as charnockites and gneisses, which dominate the Palakkad region. These rocks, by nature, have low primary porosity; however, groundwater storage occurs in their weathered zones and fracture networks, where secondary porosity is developed.

In areas where the bedrock is deeply weathered, the capacity to store and transmit groundwater increases significantly. These zones act as unconfined aquifers and are essential for sustaining wells and borewells. Additionally, lateritic formations, which are common in parts of Palakkad, also influence groundwater availability, especially where laterites are porous and permeable. Thus, mapping geological formations helps in identifying regions with favourable conditions for groundwater accumulation and movement.

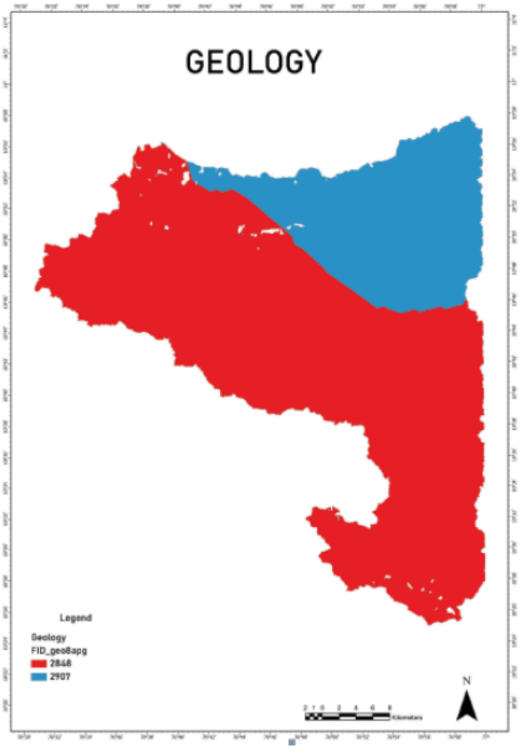

Figure 20 Geology Map

Source: Author

2. Soil

Soil type plays a crucial role in groundwater recharge by influencing the rate of infiltration of surface water into the subsurface. Different soils have varying textures, porosity, and permeability, which affect how easily water percolates through the soil profile. In Palakkad, the prominent soil types include lateritic soils, red loamy soils**,** and alluvial soils along the river valleys.

Alluvial soils, often found in the floodplains and valley bottoms of the Bharathapuzha Basin, are highly permeable and support good infiltration, making them conducive to groundwater recharge. Red loamy soils, which are moderately permeable, also support recharge but to a lesser extent. On the other hand, lateritic soils, while sometimes porous, can become compacted or indurated (hardened), especially in upland regions, reducing their permeability and thereby limiting groundwater recharge.

Therefore, areas with deep, permeable soils are generally classified as higher potential zones for groundwater accumulation, while shallow or compacted soils are considered lower potential zones.

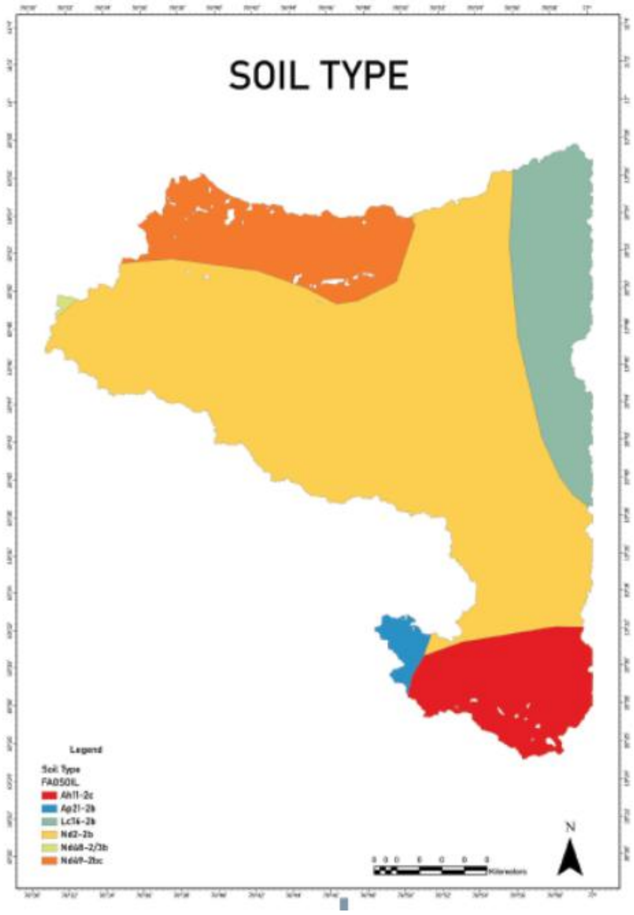

Figure 21 Soil Type Map

Source: Author

3. Drainage Density

Drainage density is the total length of streams and rivers within a given area of the basin. It serves as an indicator of how the surface water is distributed and how it behaves in response to rainfall events. In the context of groundwater potential, low drainage density areas are often associated with higher infiltration rates and lower surface runoff, allowing more water to percolate into the ground. These areas tend to be favourable for groundwater recharge.

In contrast, areas with high drainage density suggest that the terrain is either highly impermeable or steep, leading to faster surface runoff and reduced infiltration. In the Bharathapuzha Basin, particularly within the Palakkad region, variations in drainage density can be observed across the landscape. Upland regions and rocky terrains show high drainage densities and are generally less suitable for groundwater recharge, while plains and low-lying areas exhibit lower drainage densities and are more favourable for groundwater accumulation.

Evaluating drainage density using satellite-derived data helps in delineating zones where recharge is naturally higher due to slower overland flow and better infiltration conditions.

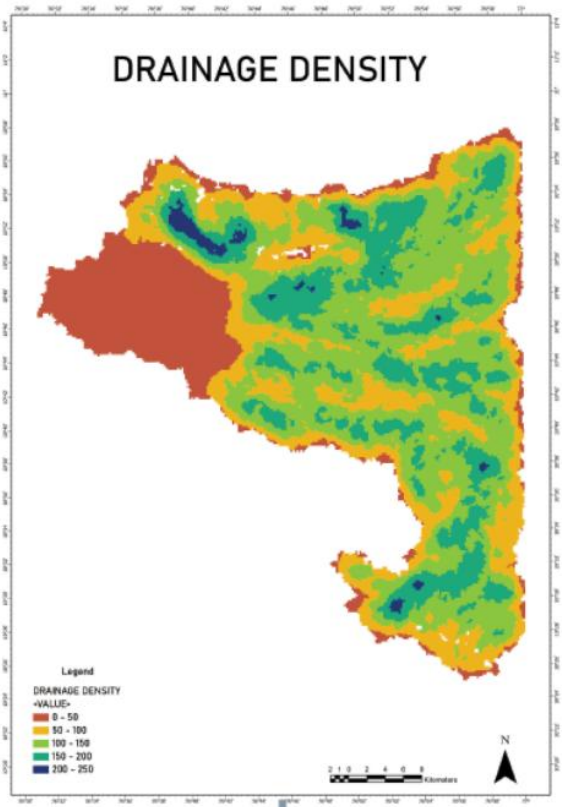

Figure 22 Drainage Density Map

Source: Author

4. Slope

The terrain's slope plays a key role in determining the speed at which water flows across the land surface. Slope is directly related to runoff and infiltration: gentler slopes allow more time for water to infiltrate, enhancing the recharge of groundwater, whereas steep slopes promote rapid runoff, limiting the time water is in contact with the surface, thus reducing infiltration.

In Palakkad, the terrain gradually transitions from the foothills of the Western Ghats in the east to the plains in the west. The eastern zones are characterized by moderate to steep slopes, particularly near the Western Ghats, which are less conducive for groundwater recharge due to high runoff. Conversely, the central and western parts of the district, including river valleys and lowlands, have gentle slopes, making them ideal zones for infiltration and hence suitable for the development of groundwater resources. Slope maps generated using Digital Elevation Models (DEMs) are thus instrumental in identifying areas where recharge is likely to be high due to favourable topographic conditions.

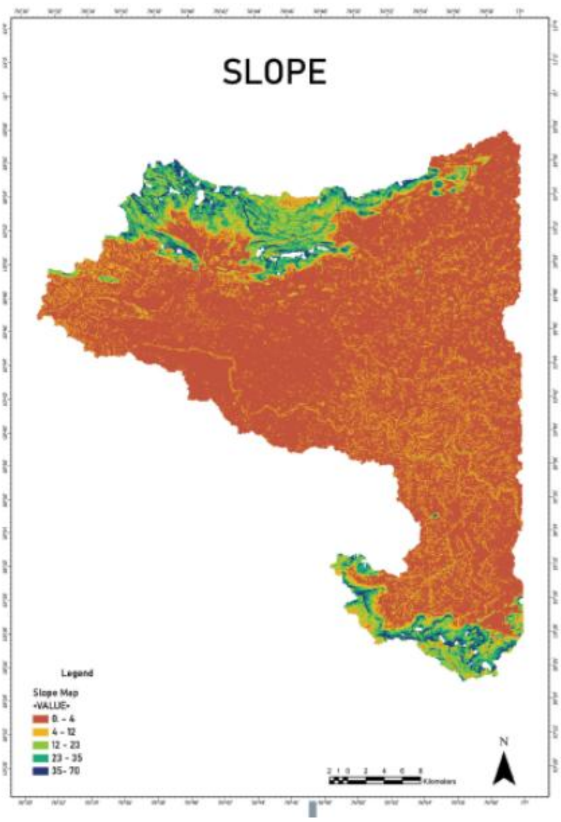

Figure 23 Slope Map

Source: Author

5. Lineament Density

Lineaments are linear features on the Earth's surface that typically indicate fractures, faults, joints, or shear zones in the underlying subsurface. dThese features are critical in hard rock terrains, such as those found in the Bharathapuzha Basin, where groundwater movement is predominantly controlled by secondary porosity. Areas with high lineament density often correspond to zones of enhanced permeability, where groundwater can easily accumulate and flow.

The intersection of multiple lineaments creates convergence zones, which are particularly favourable for groundwater storage and can serve as good sites for well or borewell drilling. In the Palakkad region, several such lineaments have been identified through satellite imagery and remote sensing analysis. These areas, especially where lineaments coincide with valley fills or low-lying zones, are marked as high groundwater potential zones. Mapping and analysing lineament density using remote sensing tools helps in identifying structurally controlled aquifers, which are otherwise difficult to detect through conventional geological mapping.

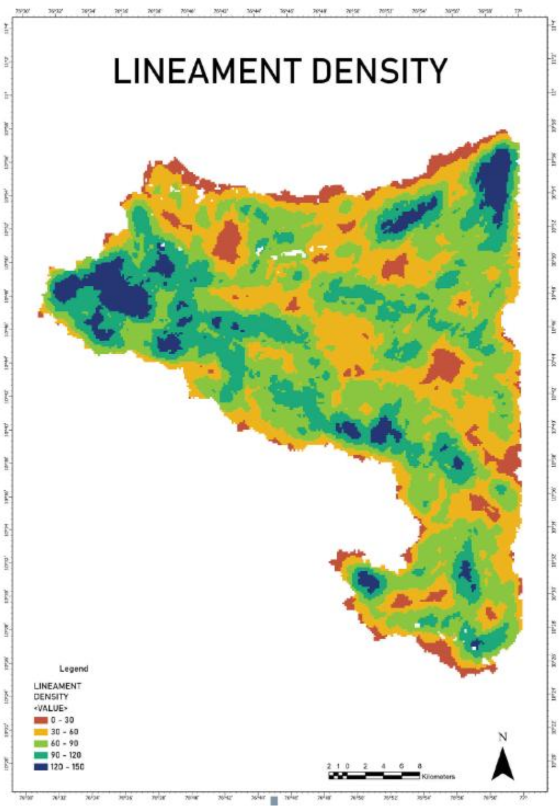

Figure 24 Lineament Density Map

Source: Author

6. Rainfall

Rainfall is the main source of groundwater recharge, especially in areas relying on natural infiltration and percolation. The volume, intensity, and distribution of rainfall dictate how much water is available for replenishing groundwater. In Palakkad, the southwest monsoon provides the bulk of the annual rainfall, which varies between 2000 mm and 2500 mm depending on the location and elevation. However, high rainfall alone does not guarantee effective recharge. The timing, duration, and intensity of rainfall events matter. For example, prolonged moderate rainfall is more favourable for infiltration than intense short-duration showers, which may lead to increased runoff. The land cover and slope also play a role in determining whether rainfall will recharge aquifers or simply flow away as runoff.

The Palakkad region, due to its location near the Palakkad Gap, experiences relatively distinct rainfall patterns compared to the neighbouring districts. Mapping rainfall distribution and correlating it with geological and land use characteristics allows for the identification of zones where natural recharge is more effective, thereby helping delineate groundwater potential zones more accurately.

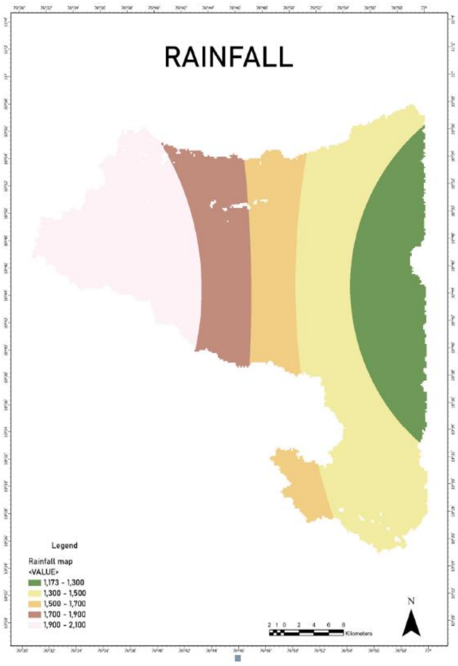

Figure 25 Rainfall Map

Source: Author

6.2 Groundwater Recharge Potential Zones – An Elaboration

Groundwater Potential Zones (GWPZs**)** are specific areas within a landscape that possess favourable conditions for the occurrence, storage, and movement of groundwater. These zones are identified based on the integration of several physical, geological, hydrological, and climatic parameters that influence the recharge, accumulation, and yield of groundwater resources. The primary aim of delineating GWPZs is to guide sustainable groundwater extraction, support water resource planning, and identify regions suitable for artificial recharge.

In the Bharathapuzha River Basin, particularly in Palakkad district, the need for mapping Groundwater Potential Zones (GWPZs) has become increasingly important in recent decades due to rising water demand, seasonal river drying, falling water tables, and fluctuating rainfall patterns. The river, the second longest in Kerala, originates in the Western Ghats and flows westward through varied landscapes. Its flow regime, especially baseflow during dry periods, is intricately linked to the underlying groundwater system. Therefore, identifying and managing groundwater potential zones is crucial for preserving both the river's ecological health and the region's water security. Groundwater potential in any area depends on a complex interaction of factors such as geology, soil type, slope, drainage characteristics, lineament patterns, and rainfall. Each of these parameters either enhances or inhibits the movement and storage of water beneath the surface. For instance, porous soils and fractured rocks allow greater infiltration, while steep slopes and impervious urban surfaces reduce the likelihood of groundwater recharge.

In Palakkad, where the terrain ranges from undulating highlands to flat alluvial plains, groundwater potential zones are unevenly distributed. The valley bottoms, floodplains, and gently sloping agricultural lands often serve as the most promising recharge zones, especially where weathered rock or alluvial deposits enhance permeability. In contrast, the rocky uplands near the Western Ghats**,** characterized by steep slopes and limited soil cover, generally show poor recharge potential.

To systematically delineate these zones, modern technologies like Remote Sensing (RS) and Geographic Information System (GIS) are utilized. These tools enable the integration of multiple thematic layers—such as land use/land cover, slope, geology, drainage density, soil type, and rainfall—into a composite index of groundwater potential. By assigning weights and rankings to these factors based on their influence, a groundwater potential map can be created, categorizing the region into zones with varying levels of potential: very high, high, moderate, low, and very low**.** The identification of GWPZs serves multiple applications. It helps farmers plan irrigation more effectively, enables water resource managers to site wells and recharge structures optimally, and supports long-term water conservation efforts. Moreover, in the case of the Bharathapuzha Basin, protecting and enhancing recharge in high-potential zones also supports the baseflow of the river**,** which is crucial for maintaining flow during dry months. In essence, the delineation and understanding of groundwater potential zones provide a scientific and spatially explicit approach to managing groundwater sustainably. In a region like Palakkad, where monsoon dependency and land use pressures are high, such an approach becomes indispensable for balancing human needs with ecological sustainability.

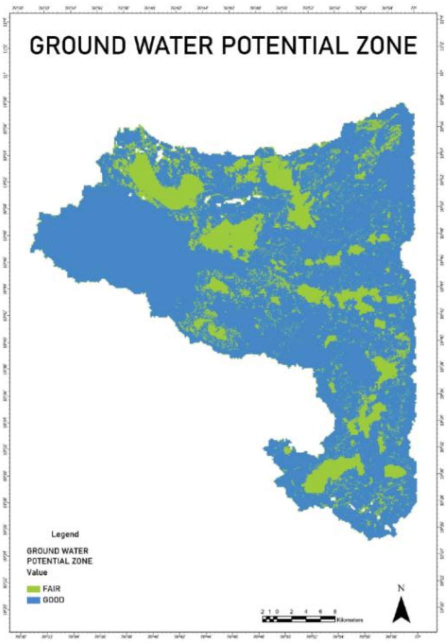

Figure 26 Ground Water Recharge Potential Zones

Source: Author

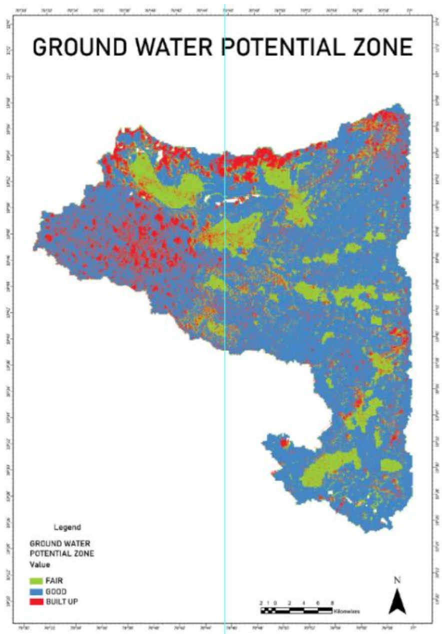

Figure 27 Ground Water Recharge Potential Zones with Built-up

Source: Author

1. **Mandatory Implementation:** Rainwater harvesting (RWH) systems, including check dams and surface/subsurface methods, should be made mandatory on public and government lands, schools, colleges, and office complexes.

2. Focus on High Groundwater Potential Areas: RWH systems should be prioritized in regions with high groundwater potential and slopes less than 45 degrees for maximum impact.

3. Large-Scale Adoption: A large-scale approach to RWH will significantly contribute to water conservation, sustainable management, and groundwater recharge, addressing regional water scarcity effectively.

6.3 Monitoring and Evaluation of Urban River Management Plan of NIUA

This is based from the Analysis on Palakkad Municipality

Table 4 Indicator 1: Flood Plain Management Score

No.	Desirable Feature	Floodplain Management Points
1	Floodplain boundaries clearly demarcated	4
2	Floodplain boundaries protected through embankments, roads, or other means	1
3	Demarcation of no development zone adjacent to the river in the active floodplain	4
4	Strict enforcement in no development zone	5
5	Updated database of existing land use in floodplain available	1

6	Master Plan has clearly indicated permissible and non-permissible activities in the floodplain/river zone	5
7	All regulations in the Master Plan are enforced (10 points if at least 50% of the regulations are enforced)	6
8	Presence of river friendly landscaping (e.g. constructed wetlands, bioswales, etc.)	10
9	Strict monitoring mechanism in place	3
10	No solid waste dumping on river banks	6
11	Only organic farming practiced in river zone	1
	TOTAL	**46**

Table 5 Calculation of Eco-friendly riverfront points

No.	Desirable feature	Eco-friendly riverfront points
1	The riverfront project is a source of revenue for the ULB	5
2	The riverfront project supports commercial activities like shops, stalls, etc	5
3	The riverfront project has a footfall of more than 100 people/day	5
4	The riverfront project is listed as an attraction spot on travel-related websites	10

5	The riverfront project has good waste management facilities	8
6	The riverfront project is made up of predominantly natural material	5
7	The riverfront project has soft landscaping elements	8
8	The riverfront project does not block the natural path of the river	8
	Total Points	**54**

Table 6 Calculation of citizen sensitization points

No.	Desirable feature	Citizen sensitization points
1	Dedicated Information, Education and Communication (IEC) program for the river-related aspects	15
2	River related sensitization is part of existing citizen awareness raising program	12
3	Presence of a dedicated website for river-related aspects	4
4	Use of traditional sensitization media (e.g. hoardings, murals, competitions, radio)	10
5	Use of social media for river-related sensitization	8
6	A dedicated river day for the city	2

7	Earmarked budget for citizen sensitization	2
8	Sensitization of school children through special events	8
	Total Points	**61**

Formula for NET URM index

$$NET\ URM_{INDEX} = \frac{I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7}{7}$$

= 24/7 = 3.43

Table 7 Total Indicators and URM

INDICATORS	**SCORE**
Floodplain management	2
Net DO score	4
Water Body Revival Score	5
Riparian Buffer Factor	3
Eco Friendly River front points	3
River economy score	2
Calculation of Citizen Sensitization points	5
OVERALL URM SCORE	3.43

2.6-3.5: Average level of urban river management - The city has a satisfactory urban river management system. However, some dimensions of urban river management are still a cause of concern.

6.4 Analysis of Water Source Management Policies and Missions in Kerala: Challenges and Proposed Improvements

Table 8 Water Management Policies and Missions in Kerala

Policy/Mission	Key Features	Challenges	Proposed Improvements
Kerala Groundwater Control Act, 2002	Mandatory well registration, extraction limits	Weak enforcement, low awareness	Strengthen audits, digital monitoring, capacity building
Kerala State Water Policy, 2008	Promotes conjunctive use and sustainability	Lacks focus on recharge and climate impacts	Update with recharge targets and climate resilience
Jalanidhi Mission	Community-based rural water supply, RWH	Implementation and maintenance issues	Standardize practices, enhance capacity building
Atal Bhujal Yojana	Community-led sustainable groundwater management	Limited local adaptation, integration hurdles	Localize programs, enhance technical support
Sajalam 2024–25	Water resource plan for semi-critical blocks	Lacks micro-watershed focus, real-time data	Create micro-watershed plans, local committees
Bharathapuzha Rejuvenation Mission	Desilting, bank stabilization, protect water bodies	Fragmented, unsustainable efforts	Form councils, continuous monitoring, remove encroachments

KMBR Rule	Mandatory rooftop RWH for new constructions	Poor compliance, weak enforcement	Integrate with urban planning, promote green infrastructure
Wetland & Paddy Land Act	Prohibits unauthorized conversion of paddy/wetlands	Exploitable land classification loopholes	Digitize land bank, enforce audits

Table 9 Building bylaws and Assessment

Aspect	Description
Existing Regulations	
Mandatory RWH	All new buildings >100 m² or plots >200 m² must have RWH systems
Storage Capacity Requirement	Minimum 25 liters per m² of roof area storage or equivalent recharge
Occupancy Compliance	RWH required for completion certificate; enforced by local bodies
Groundwater Regulation	Permission required for extraction in notified areas; recharge encouraged
Urban Local Body Role	Municipalities enforce rules and inspect systems
Recommended Improvements	
Compliance & Enforcement	Stricter post-occupancy checks and penalties for non-functional RWH
Retrofitting Old Buildings	Mandate retrofitting during major renovations of old buildings
Combination Systems	Use both storage and recharge systems for better sustainability
Standardized Designs	Provide approved RWH designs for various soil types and plot sizes

Recharge in Open Spaces	Mandate percolation pits in parks, campuses, and open lands
Public Awareness	Sensitize public through schools, local groups, and campaigns
Incentives	Offer tax rebates or tariff discounts for functional RWH systems
Rain Centres	Establish centres for technical RWH guidance and support

1. **Injection Wells**

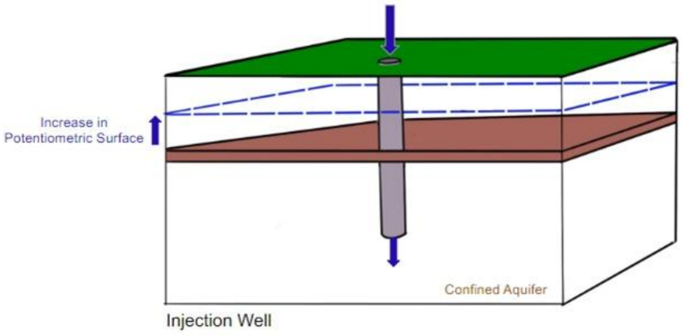

Figure 28 Injection Wells and Sub surface ground water recharging

Source: ITRCweb.org

How it Works:

Injection wells are engineered vertical structures used to directly inject surface water, such as rainwater or treated wastewater, into deep underground aquifers. They bypass the surface and unsaturated soil layers, allowing water to recharge deeper groundwater systems rapidly.

Conditions for Use:

Injection wells are effective in areas where the upper soil layer is impermeable (e.g., clay-rich soils), which would otherwise prevent natural infiltration. They are particularly useful in urban areas with limited open land and high surface runoff.

Working Mechanism:

Collected rainwater or treated greywater is filtered and passed through the injection well, which penetrates impermeable strata to reach permeable aquifers. The water then disperses laterally within the aquifer, increasing the groundwater table. The well structure typically includes a filter media chamber, perforated casing pipe, and a gravel backfill to maintain structure and filtration.

Elaborated Use:

Injection wells help combat urban flooding, increase the groundwater reserves, and sustain baseflow during dry seasons by replenishing deep aquifers that feed into rivers and streams.

2. Subsurface Groundwater Recharge (Trench/Filter Beds)

Figure 29 Sub surface groundwater recharge

Source: Flickr.com

How it Works:

Subsurface groundwater recharge involves infiltrating surface water into the ground through trenches or filter beds, allowing it to percolate into shallow aquifers. Unlike injection wells, it uses natural percolation through soil layers to filter and store water.

Conditions for Use:

Best suited for areas with permeable soil layers like sandy loam or gravel and moderate-to-high rainfall. It's also effective in semi-urban or peri-urban areas where space is available for such infrastructure.

Working Mechanism:

Water is directed into shallow trenches or beds filled with layers of sand, gravel, and pebbles. As the water passes through, suspended solids and pollutants are filtered out. The filtered water then percolates through the soil into the shallow aquifers, raising the local groundwater table.

Elaborated Use:

This method improves soil moisture, supports vegetation, and recharges groundwater in a way that indirectly supports stream baseflow. It is a low-cost, low-maintenance solution ideal for community-based water conservation projects.

<u>3. Bioswales</u>

How it Works:

Bioswales are landscape elements designed to concentrate, convey, and infiltrate stormwater runoff while filtering out pollutants. They resemble shallow, vegetated ditches or channels and combine both hydraulic and biological filtration.

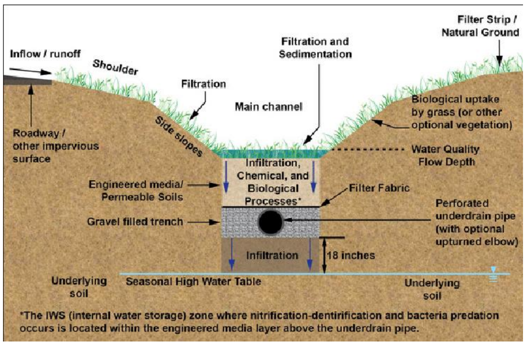

Figure 30 Bioswale

Source: Ekka, S, Hunt, B, (2020), *Swale Terminology for Urban Stormwater Treatment*, NC State

Conditions for Use:

Ideal in urban and suburban areas with impervious surfaces (roads, parking lots) where managing stormwater runoff is a challenge. They are especially beneficial in areas with occasional but intense rainfall.

Working Mechanism:

Rainwater is diverted into bioswales where it slows down, spreads out, and infiltrates through vegetation and engineered soil layers. The vegetation absorbs nutrients, while the soil and gravel layers trap sediments and allow water to percolate into the ground.

Elaborated Use:

Bioswales reduce surface runoff, enhance groundwater recharge, improve water quality, and prevent erosion. They serve both ecological and aesthetic functions in urban landscape design.

4. Rainwater Recharging System

Figure 31 Rain water recharging system

Source: The Hindu

How it Works:

Rainwater harvesting systems collect and store rainwater from rooftops or other surfaces, and channel it into recharge pits, percolation tanks, or subsurface systems to replenish groundwater.

Conditions for Use:

Effective across both urban and rural areas, particularly where water scarcity is a concern and there is a need to manage stormwater. Works best in regions with distinct rainy seasons.

Working Mechanism:

Rainwater collected from catchment areas like rooftops is first filtered to remove debris and then directed to a recharge structure. Depending on the design, the water either percolates into the soil or is injected deeper into aquifers.

Elaborated Use:

This method not only reduces dependency on external water sources but also helps maintain the groundwater table. Over time, it contributes to increased baseflow in nearby streams and rivers by sustaining the groundwater reserves.

6.5 Effective Regulation of Activities

Modified Land use plan of Palakkad District

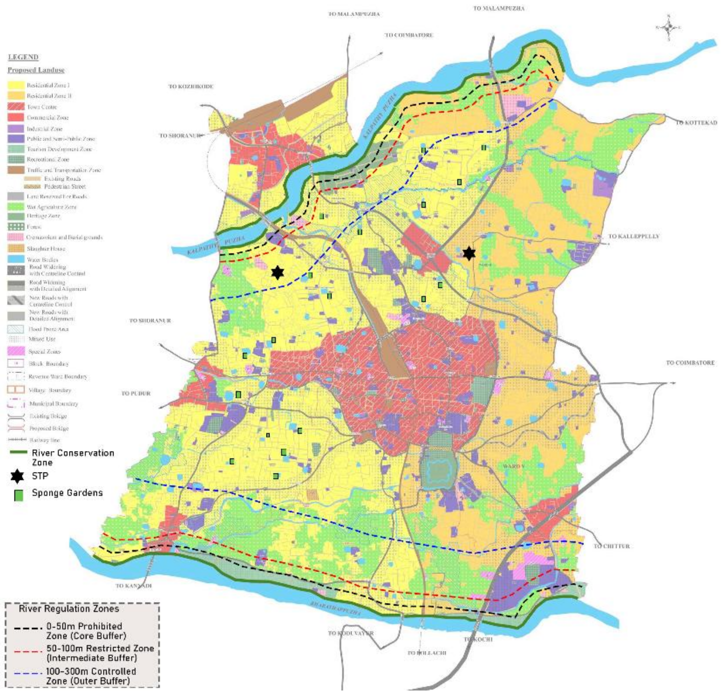

Figure 32 Modified Land use plan of Palakkad District

Source: Author

Introducing zoning category river conservation zone. (RCZ)

1. 15m of Riparian Green Buffer

Creating a 15-meter-wide riparian green buffer along the riverbanks is essential for preserving ecological balance and safeguarding water quality. This vegetated area serves as a natural filter, capturing sediments, nutrients, and pollutants before they can reach the river. Additionally, it supports native biodiversity, stabilizes the banks, and mitigates erosion. The buffer zone also serves as a transitional space between the aquatic and terrestrial ecosystems, playing a key role in preserving the ecological integrity of the river corridor.

2. **Demarcation of Active Floodplain and Regulation Zones**

Clearly defining and demarcating the active floodplain and adjacent regulation zones is a foundational step in river basin management. This ensures that developmental activities are restricted in areas prone to seasonal flooding, reducing risks to life and infrastructure. By maintaining the natural floodplain, rivers retain their ability to absorb and dissipate floodwaters, thereby enhancing flood resilience. Regulatory zoning prevents encroachment and promotes informed land-use planning that aligns with hydrological realities.

3. **Ecological Redesign of River Fronts**

The ecological redesign of riverfronts involves transforming degraded or urbanized riverbanks into sustainable, resilient spaces that balance human use with ecological health. This includes the reintroduction of native vegetation, creation of bioengineered banks, wetland pockets, and public green spaces that maintain ecological functions while enhancing aesthetic and recreational value. Such redesign efforts help restore the river's natural flow dynamics, improve water quality, and reconnect communities to their riverine heritage in an environmentally responsible manner.

4. **Implementation of Green Corridors**

Green corridors along rivers are linear landscapes composed of forests, wetlands, and grasslands that connect fragmented habitats and promote ecological continuity. Implementing these corridors within the river conservation zone (RCZ) supports wildlife movement, enhances biodiversity, and strengthens climate resilience. These corridors act as natural infrastructure that facilitates carbon sequestration, moderates microclimates, and provides refuge for species, particularly in urban and semi-urban stretches where ecological pressures are high. Their implementation is essential for a holistic river conservation strategy.

Figure 33 Paved Walkways and Amphitheatre

Source: Master Plan for Palakkad Municipality

Figure 34 Transformation of stream banks into recreational spaces and Bank protection

Source: Master Plan for Palakkad Municipality

5. **Proposal for Practising Sponge City Concept**

The Sponge City concept is a sustainable urban water management approach aimed at enhancing a city's capacity to absorb, store, purify, and release rainwater in a controlled manner. Originally popularized in China, this concept is increasingly relevant in Indian contexts, particularly in river basins like the Bharathapuzha, where changing land use and increasing surface runoff have reduced natural infiltration and groundwater recharge. Adopting the Sponge City concept involves incorporating green infrastructure—such as rain gardens, wetlands, bioswales, permeable pavements, and green rooftops—into urban and peri-urban areas. These systems emulate natural hydrological processes, slow down surface runoff, allow infiltration, and store excess water for dry periods. In the context of the Bharathapuzha sub-watershed, this approach can be tailored to include agricultural and rural hydrological interventions, promoting climate-resilient landscapes that support both human needs and ecological integrity.

5.1 Paddy Field Dam

A Paddy Field Dam is an innovative application of the Sponge City concept in rural agricultural settings. This intervention utilizes existing or abandoned paddy fields as temporary water retention structures during monsoon periods. By slightly modifying field bunds and introducing controlled inlet-outlet structures, rainwater and surface runoff can be captured and retained in these low-lying fields. This stored water gradually infiltrates into the subsurface, enhancing local groundwater recharge while also reducing flood peaks downstream. Paddy field dams can be integrated with traditional irrigation systems, ensuring dual benefits of flood moderation and improved water availability for dry-season cropping. Additionally, this method helps preserve agricultural heritage, utilizes underused land sustainably, and supports the overall hydrological health of the watershed. In regions like the Bharathapuzha basin, where paddy cultivation is declining, this concept can offer a multifunctional landscape solution aligned with both water conservation and livelihood support.

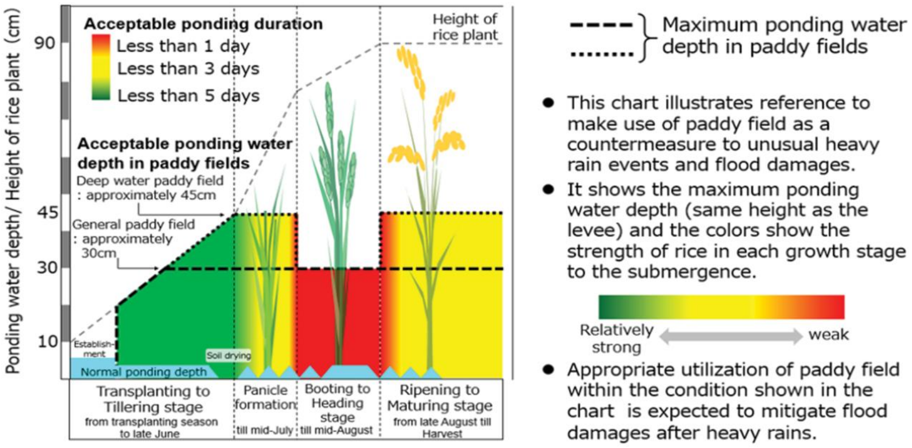

Figure 35 Ponding duration for paddy field dams, Source: NARO 2020

5.2 Community Farms on Vacant Lands with the Integration of Urban Green Cover

The conversion of underutilized urban or peri-urban lands into community farms represents a strategic adaptation of the Sponge City model that supports both hydrological sustainability and food security. These urban farms make use of otherwise vacant plots for agriculture while also contributing significantly to water absorption, infiltration, and carbon sequestration. By incorporating urban green spaces like agroforestry belts, rain gardens, and permeable pathways, these areas improve the city’s ability to manage stormwater, provide microclimatic benefits, and mitigate the urban heat island effect. Community involvement in the management of these farms fosters environmental stewardship and ensures the long-term viability of the intervention. In the context of the Bharathapuzha basin, such community farms can serve as decentralized water sinks, reduce surface runoff, and provide localized food systems that are climate-resilient and socially inclusive.

5.3 Riparian Conservation

Riparian conservation involves the restoration and protection of the natural vegetation and ecological integrity along riverbanks. These zones are ecologically sensitive transition areas between terrestrial and aquatic systems and play a crucial role in maintaining river health. Conserving riparian zones includes the replanting of native vegetation, removing invasive species, controlling encroachments, and protecting the natural contours and soil structure of riverbanks. Healthy riparian buffers reduce sedimentation, filter pollutants, provide wildlife habitats, and improve the aesthetic and recreational value of rivers. In the Bharathapuzha basin, where riparian zones are increasingly degraded due to urbanization, agriculture, and sand mining, dedicated riparian conservation initiatives are vital for baseflow restoration, erosion control, and biodiversity revival. These zones can also be designated as protected areas under a broader River Conservation Zoning (RCZ) framework.

6. **Proposals for Culverts and Water Balancing Canals to Prevent Excess Water Accumulation and Ease Excess Runoff**

   To manage excess surface runoff and prevent urban flooding, the strategic design and placement of culverts and water balancing canals are essential. Culverts enable the safe passage of water under roads and built-up infrastructure, preventing waterlogging during intense rainfall events. When correctly sized and maintained, they also facilitate the natural connectivity of stormwater flow paths, reducing obstructions and erosion. Water balancing canals, on the other hand, serve as dynamic conduits that collect, store, and redistribute excess runoff from high-flow zones to low-lying recharge areas, wetlands, or detention basins. These canals help equalize the hydrological pressure across the watershed, reducing flash floods and enhancing infiltration. In the Bharathapuzha catchment, particularly in urbanizing areas and zones prone to drainage congestion, such hydraulic interventions would be critical in aligning built infrastructure with natural drainage patterns, thus supporting flood resilience and water sustainability.

6.6 To Ensure Good Quality Return Flow

Return flow interventions and Water reuse Strategy

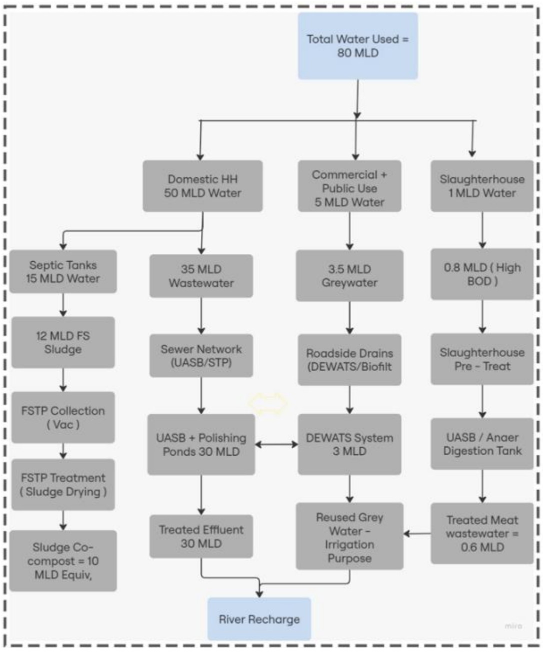

Figure 36 Water usage analysis

Source: Author

Table 10 Categories of Riverine Buffers

System	Purpose	Suitable Areas	Key Components	Advantages	Limitations
STP (Sewage Treatment Plant)	Treats centralized sewerage (blackwater & greywater)	High-density urban zones with sewer networks	Primary, secondary, tertiary treatment units	High treatment efficiency, handles large volumes	High cost, land requirement, needs sewer network
FSTP (Faecal Sludge Treatment Plant)	Treats septage from on-site sanitation systems (OSS)	Areas with septic tanks, no sewerage	Sludge drying beds, anaerobic digesters, dewatering	Decentralized, cost-effective, quick setup	Periodic desludging needed, varied input quality
DEWATS (Decentralized Wastewater Treatment System)	Localized treatment of domestic wastewater	Peri-urban or cluster-based areas	Settler, anaerobic baffled reactor, planted gravel filter	Low maintenance, low energy	Needs regular monitoring, space for modules
Constructed Wetlands	Nature-based wastewater treatment	Low-density or peri-urban zones	Vegetated beds, settling tanks	Eco-friendly, low operational cost	Larger land area needed, seasonal performance
UASB (Upflow Anaerobic Sludge Blanket Reactor)	Anaerobic treatment of sewage	Medium- to large-scale STPs	Reactor tank, gas collection dome	Energy recovery (biogas), compact	Less effective for high-strength or toxic waste

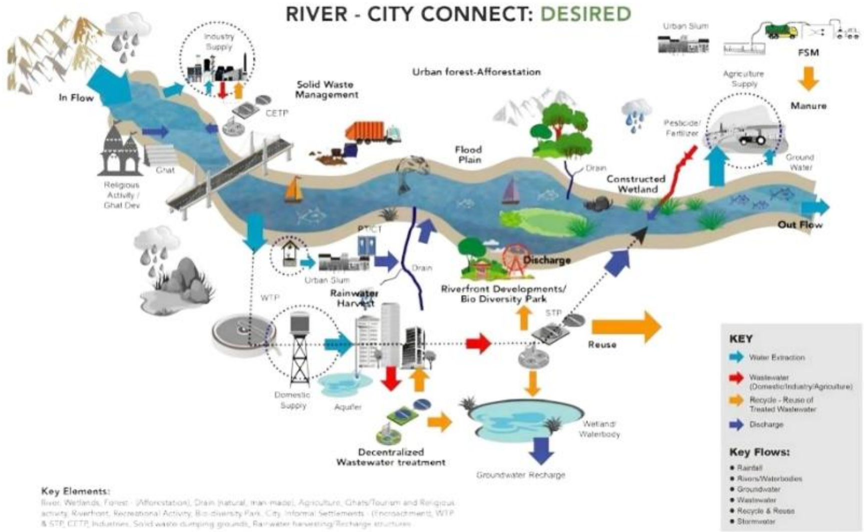

Figure 37 Desired River city connections

Source: A Strategic Framework for Managing Urban River Stretches in the Ganga River Basin, Urban River Management, Namami Gange

6.7 Sustainable Watershed Management Strategies

- **Promote Low Impact Development (LID) and Sustainable Land Use to Safeguard Floodplains, Wetlands, and Recharge Zones**
  Low Impact Development (LID) is a strategic planning and design approach that mimics natural hydrological processes to manage stormwater close to its source. Promoting LID practices helps safeguard ecologically sensitive areas such as floodplains, wetlands, and groundwater recharge zones by minimizing disruption to natural drainage patterns. Sustainable land use planning that incorporates LID principles ensures that development is balanced with the preservation of areas critical for water retention and infiltration, thereby protecting long-term watershed health and enhancing baseflow sustainability.

- **Restrict Clusters of Impervious Developments in Critical Reserve Areas**
  Uncontrolled clustering of impervious surfaces such as concrete and asphalt in environmentally sensitive areas can severely hinder infiltration and increase surface runoff. By imposing restrictions on such developments

in critical reserve zones—especially near aquifer recharge areas, riparian buffers, and wetland peripheries—urban planners can prevent long-term hydrological imbalance. Zoning regulations and land-use bylaws must actively discourage dense construction in these zones to maintain their natural permeability and hydrological functions.

- **Plan and Implement Urban Recharge Structures: Recharge Wells, Percolation Pits, Infiltration Parks, Bioswales, etc.**
  Urban recharge structures are vital for enhancing groundwater levels and mitigating the effects of rapid urbanization. Planning for recharge interventions such as recharge wells, percolation pits, infiltration parks, and bioswales should be embedded in urban design standards. These structures facilitate the capture and infiltration of rainwater and runoff, replenishing groundwater and reducing flood risk. Their implementation should be context-sensitive, considering local soil type, land use, and rainfall characteristics to maximize efficiency.

- **Plan Integrated Blue-Green Infrastructure: Linking Water Bodies, Open Spaces, Wetlands, and Tree Corridors for Ecological Health and Climate Resilience**
  Blue-green infrastructure refers to a network of natural and semi-natural areas designed to manage water and support biodiversity. Integrating blue (e.g., rivers, lakes, canals) and green (e.g., parks, green roofs, tree corridors) infrastructure into urban planning allows for ecological connectivity and resilience against climate stressors like extreme rainfall and heat. By linking water bodies with open spaces and vegetated corridors, cities can promote groundwater recharge, control urban flooding, support wildlife movement, and enhance quality of life for residents.

- **Retrofit Existing Built-up Areas with Green Infrastructure to Reduce Runoff and Enhance Infiltration**
  Many urban areas are already heavily built-up with limited permeable surfaces. Retrofitting these areas with green infrastructure—such as green

roofs, permeable pavements, rain gardens, and urban forests—can help reduce runoff and increase rainwater infiltration. These interventions can be gradually introduced into the urban fabric, often through public-private partnerships or municipal schemes, with a focus on improving stormwater management and recharging shallow aquifers that support baseflow in nearby streams and rivers.

- **Integrate Groundwater-Sensitive Zones in Development or Master Plans**
  Groundwater-sensitive zones, which are areas crucial for recharge or vulnerable to contamination, must be identified and formally incorporated into urban Development Plans or Master Plans. Including these zones in land-use planning enables authorities to regulate land use intensity, prevent hazardous activities, and prioritize green infrastructure. This integration ensures long-term water security and prevents over-extraction or pollution of critical groundwater sources.

- **Promote Cluster-Based Recharge Planning for Peri-Urban Areas**
  Peri-urban zones, which lie at the fringe of expanding cities, are often overlooked in urban water management despite being key recharge areas. A cluster-based approach to recharge planning—where several recharge interventions are strategically grouped and distributed—can ensure that water infiltrates effectively across larger areas. Such planning requires coordination among local governance bodies, landowners, and communities to create shared recharge infrastructure that benefits both urban and rural stakeholders.

7. CONCLUSION

Over the past three decades, the Bharathapuzha River system has experienced significant hydrological and environmental changes, driven by urban growth, evolving land-use patterns, and rising pollution levels. A comprehensive scientific analysis, combining hydrological modelling, remote sensing-based land-use assessments, and water quality evaluations, highlights both the challenges confronting the river and the effects of ongoing conservation efforts. Recent data on the river's condition emphasizes the critical need for combining governance-led interventions with evidence-based restoration strategies to ensure its long-term health.

The hydrological analysis indicates a significant decline in the Baseflow Index (BFI), which serves as a key indicator of groundwater contribution to river flow. Between 1993 and 2022, the BFI fell from approximately 0.029453 to 0.027909, reflecting a consistent reduction in groundwater influx due to increasing impervious surfaces, deforestation, and over-extraction for irrigation and domestic purposes. This decline has been accompanied by a trend of extreme seasonal fluctuations, with excessive monsoon-driven peaks followed by prolonged low-flow periods during the dry season. While conservation initiatives, particularly those focusing on wetland restoration and decentralized rainwater harvesting, have demonstrated early signs of success, reflected in a slight recovery of BFI to 0.029532 in 2023, long-term sustainability remains uncertain. Persistent hydrological instability necessitates the adoption of integrated watershed management strategies, including managed aquifer recharge (MAR) and regulated dam releases to maintain ecological flow requirements.

A comprehensive land-use analysis reveals a sharp decline in paddy cultivation, with traditional agricultural lands increasingly replaced by urban infrastructure and commercial cropping systems. This transition has had significant implications for groundwater recharge, as paddy fields traditionally facilitated high infiltration rates. The reduction in percolation has led to increased surface runoff, reducing subsurface water availability and exacerbating dry-season flow deficits. However, targeted wetland restoration programs implemented since 2018 have started reversing some of these adverse effects by enhancing localized water retention, contributing to hydrological stabilization. The findings highlight the urgent need for promoting sustainable agricultural models that integrate agroforestry practices and controlled irrigation to restore the natural water balance.

The assessment of water quality dynamics demonstrates a clear trend of rising contamination levels post-2015, with notable increases in Total Dissolved Solids (TDS), Chromium (Cr), and Chloride (Cl), indicating heightened industrial effluent discharge and urban runoff impacts. Despite a decrease in Biological Oxygen Demand (BOD), suggesting lower organic pollution, variations in pH and Dissolved Oxygen (DO) levels highlight persistent chemical instability within the river system. The diminished capacity of natural filtration mechanisms, as evidenced by declining heavy metal sequestration within the riverbed, further underscores the pressing need for stricter industrial waste regulations and expansion of wastewater treatment infrastructure. While governance-led rejuvenation programs have contributed to reducing some pollution loads, long-term improvement will require the enforcement of regulatory measures targeting both point-source and non-point-source pollution.

Community perceptions align with the scientific findings, with surveyed residents reporting significant environmental degradation, particularly in the form of land-use changes, deforestation, and declining groundwater availability. The concerns raised regarding water scarcity, noise pollution, and the loss of green spaces reflect the increasing socio-environmental pressures on the river system. The widespread recognition of these issues within local communities presents an opportunity to integrate community-driven conservation efforts into policy frameworks. This approach would enhance current governance frameworks while guaranteeing the enduring success of restoration initiatives.

Governance interventions in the last five years have been instrumental in reducing environmental degradation and fostering ecological restoration. The implementation of 154 Green Islands, the restoration of 56 water bodies, and coir-bed riverbank stabilization projects have collectively contributed to improving riparian health and sediment retention. Additionally, rainwater harvesting subsidies introduced in 2020 have yielded preliminary benefits in enhancing groundwater recharge, reinforcing the importance of decentralized water management solutions. However, achieving long-term sustainability will require a shift from fragmented conservation projects to a holistic watershed-based management strategy.

The findings of this study highlight the importance of combining hydrological assessments with governance-driven conservation efforts. The observed patterns of baseflow reduction and partial recovery indicate that while some restoration measures are proving effective, their long-term success depends on sustained efforts that address the root causes of hydrological decline. Strengthening hydrological monitoring through continuous baseflow assessments, groundwater level tracking, and surface water interactions using advanced hydrological models integration will be critical. Sustainable land-use practices that prioritize agroforestry models, controlled irrigation, and urban green infrastructure must be promoted to mitigate further groundwater depletion. Strict enforcement of water quality regulations, alongside the expansion of decentralized wastewater treatment facilities, will be essential in reversing current contamination trends.

Future water resource management strategies must integrate climate resilience measures to cope with the growing variability in hydrological patterns. Climate projections suggest that extreme rainfall events and extended droughts will increase, requiring a flexible approach to river basin management. Incorporating nature-based solutions, such as wetland preservation, afforestation, and bioengineering methods for riverbank stabilization, will be crucial in strengthening the river’s resilience to climate change. Additionally, involving local communities and adopting participatory management practices will be key to ensuring the sustainability of these initiatives over the long term.

The Bharathapuzha River offers a valuable case study for examining the complex challenges faced by urbanizing river systems. The findings emphasize the interconnectedness of hydrological, ecological, and socio-economic factors that influence river health. Tackling these issues necessitates a holistic, science-driven policy framework that integrates advanced hydrological assessments, robust pollution control measures, sustainable land-use strategies, and community-led conservation efforts. Future research should prioritize quantifying climate-induced changes in hydrology, deepening our understanding of groundwater-surface water interactions, and assessing the long-term effectiveness of large-scale nature-based solutions in restoring river ecosystems.

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9. ANNEXURE

9.1 Questionnaire

Bharathapuzha River & Catchment Survey

This survey is for assessing various spatio-temporal , agricultural and irrigation changes that happend in this area for 30 years .

* Indicates required question

1. Age

Mark only one oval.

- ⬭ 18-25
- ⬭ 26-40
- ⬭ 41-60
- ⬭ 61+

2. Gender

Mark only one oval.

- ⬭ Male
- ⬭ Female
- ⬭ Other

3. Occupation

____

4. Years of Residence in this locality

____

5. Type of Land Ownership

Mark only one oval.

- Own
- Rent
- Lease

6. Do you own farm land

Mark only one oval.

- Yes
- No

7. Ha you observed any changes in land use patterns in your locality for the past 30 years

Mark only one oval.

- Yes
- No
- Not sure

8. If yes , specify the changes observed

Check all that apply.

- Increase in residential areas
- Increase in commercial areas
- Increase in Industrial areas
- Increase in agricultural land
- Decrease in agricultural land
- Deforestation / loss of green cover
- Others (please specify)

9. How these land use changes impacted your daily life?

Check all that apply.

- [ ] Increased traffic
- [ ] Noise pollution
- [ ] Water scarcity
- [ ] Loss of green spaces

10. What is your primary source of drinking water

Check all that apply.

- [ ] Bore well
- [ ] Open well
- [ ] River
- [ ] Panchayath / Municipal supply

11. Do you have piped water connection

Mark only one oval.

- ( ) Yes
- ( ) No

12. If yes , how many hours per day?

____

13. Have you experienced water scarcity in the past 30 years? (specify the most experienced year)

____

14. What measures do you take during water shortages?

Mark only one oval.

- Buying water
- Rain water harvesting
- Relying on tankers
- Others

15. Do you practice rainwater harvesting?

Mark only one oval.

- Yes
- No

16. If yes , What type of system

Mark only one oval.

- Rooftop collection
- Ground water recharge

17. What is the total area of your plot (sq. ft./acres)? *

____

18. How much area is available for water seepage in your plot (permeable area)? *

____

19. Have you noticed any changes in groundwater levels in the past 30 years?

Mark only one oval.

- ⬭ Increased
- ⬭ Decreased
- ⬭ No change

20. If you own farmland, what type of crops do you cultivate?

____
____
____
____
____

21. Have you changed crop patterns in the past 30 years? If yes, specify the change

____
____
____
____
____

22. What type of irrigation do you use?

Check all that apply.

- ☐ Bore well
- ☐ Canal
- ☐ River
- ☐ Rain fed
- ☐ Other: ____________________

23. Have you noticed a change in water availability for irrigation over the years?

Mark only one oval.

- Increased
- Decreased
- No change

24. Have you adopted any water saving irrigation technique?

Mark only one oval.

- Drip
- Springler
- Traditional
- Other: ____________

25. Have you noticed any change in the Mangalam River's condition in the last 30 years? if yes , specify the changes

____

26. What are the major issues affecting the river in your opinion? *

Check all that apply.

- Pollution
- Encroachment
- Reduced water flow
- Sand mining
- Other: ____________

27. Have you participated in any river conservation efforts?

Mark only one oval.

- Yes
- No

28. What steps do you think should be taken for river rejuvenation? *

29. Any other suggestions or observations regarding water security, land use, or river health?

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ASSESSING THE INFLUENCE OF LAND COVER CHANGES ON THE BASEFLOW REGIME: A CASE OF BHARATHAPUZHA RIVER

B.PLAN THESIS | SAMUDRA D | 2021BPLN022

"The river is the longest story of all; It is the mother of all knowledge. It teaches patience, persistence, and the ability to flow with the rhythm of life"

01

BACKGROUND

01 Ecological Flow & Governance:
National Water Policy (2012) and Draft Pollcy (2020) emphasize maintaining environmental flows for ecosystem health, while promoting strong riyer governance through integrated planning and strakolder participation.

02 Urban Rivers & Land Cover :
Initiatives like Urban River Management Plans (URMP) and river-centric city planning incorporate sustainable and land cover management to preserve natural drainage, fioodplains, and riparianan zones.

03 Sustainable Management Models
Programs like Namami Gange combine pollution control, ecological restoration, and community involvement- offering a replicable framework for sustainable river basin management in both rural and urban settings.

04 Integrated Water Resource Approach:
The Ministry promotes IWRM to ensure efficient water use across sectors-drinking, Frietion, sanitation- while balancing environmental needs and promomting long-term water security and equity

05 Why Flow matters
Sustaining natural flow regimes supports biodiversity, reduces urban flooding, enhances groundwater recharge, improves public health. and strengthens climate

06 Holistic Approach
A holistic approach and river-sensitive master planning are essential to integrate ecological, hydrological, and socio-economic aspects for sustainable river basin management.

LITERATURE REVIEW

BFI, E-Flows & Rejuvenation
Baseflow supports ecological flows critical for river rejuvenation and sustaining aquatic life. (Acreman et al., 2014; Chinnasamy et al., 2023 – ScienceDirect)

LULC & River Health
Urban expansion and land use changes increase runoff and pollution, degrading river ecosystems. (Das et al., 2022 – Frontiers in Water; Devi et al., 2023 – ScienceDirect)

Small River Rejuvenation
Community-driven restoration of small rivers enhances local water cycles and biodiversity. (Agarwal & Narain, 2019 – CSE India)

Policy, Governance & Sustainability
Integrated policies and river governance frameworks are key for long-term river health. (Narain, 2020 – Down To Earth; India WRIS, 2022)

Groundwater Use & Recharge
Excess extraction lowers baseflow; recharge measures restore flow and support ecosystems. (Kumar et al., 2021 – HESS Journal)

Flow & Self-Purification Power
Continuous flow enhances rivers' natural ability to dilute and break down pollutants. (Sharma et al., 2017 – Environmental Monitoring & Assessment)

SIGNIFICANCE

- Cultural and Spiritual Heritage: Known as Nila, Bharathapuzha holds deep cultural resonance, inspiring literature and art, and hosting sacred sites like Thirunavaya and Chamravattom temples.
- Agricultural Backbone: The river sustains the Palakkad region—Kerala's key rice-producing area—by supporting extensive paddy cultivation across multiple seasons.
- Critical for Irrigation and Livelihoods: Its canal systems are vital for irrigating farmland, ensuring food security and supporting rural livelihoods.
- Ecological Hotspot: The basin harbors rich biodiversity and major protected areas, including Silent Valley, Parambikulam Tiger Reserve, and Karimpuzha Wildlife Sanctuary.

RELEVANT POLICIES & PROGRAMS

- NWCP (1985–86): Supports conservation and wise use of wetlands and rivers through inventories and action plans.
- Kerala Wetland & Paddy Land Act (2008): Legally protects wetlands and paddy fields from conversion, preserving ecological and hydrological functions.
- Wetland Rules (2010 & 2017): Establishes regulatory mechanisms for wetland conservation, applicable to riverine ecosystems.
- Jal Jeevan & Jal Shakti Abhiyan: Promote water security via groundwater recharge, rainwater harvesting, and demand-side management—indirectly aiding river rejuvenation.
- State Initiatives (NavaKerala & Haritha Keralam Missions): Drive river restoration, especially for Bharathapuzha, through integrated ecological and community-based efforts.

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AIM

To explore the possibilities for the sustainable management of Bharathapuzha river.

OBJECTIVES

- To understand core Hydrological concepts and principles of sustainable river management
- To analyze the 30-year trend (1993–2023) of the Baseflow Index (BFI) and groundwater levels in a sub-watershed of the Bharathapuzha River, and water quality improvement.
- To propose Watershed level interventions for the sustainable management of Bharathapuzha River.

SCOPE

- The study focuses on a sub-watershed of the Bharathapuzha River, covering regions in both Kerala and Tamil Nadu.
- Macro-level hydrological analysis spans both states
- A 30-year period (1993–2023) is considered to evaluate long-term trends in hydrology.
- Parameters analyzed include streamflow, baseflow (BFI), precipitation, runoff, and water quality, with data primarily from the Mankara gauging station.

LIMITATION

- Primary data collection and field surveys are restricted to the Kerala portion of the watershed.
- The impact of dam operations on river flow and hydrological alterations is not included in the analysis.
- Temporal and spatial accuracy may be constrained by the availability and resolution of historical data.
- The Tamil Nadu segment is excluded from field level investigation and proposals due to jurisdictional separation from Kerala.

EXPECTED OUTCOME

- The thesis analyzes three decades of baseflow variations in relation to urbanization and land use changes.
- Examines the impact of pollution and reduced self-cleansing on water quality
- Proposes sustainable restoration measures to enhance baseflow and ecological health of the river

RESEARCH GAP

Current river rejuvenation proposals often lack scientifically robust strategies that incorporate Baseflow Index (BFI) calculations to effectively guide and evaluate interventions—especially those aimed at targeted groundwater recharge

NEED FOR THE STUDY

- Declining flows and ecological degradation are evident in the Bharathapuzha sub-watershed, especially in smaller tributaries.
- Unregulated land cover have impacted river health over the past three decades.
- Lack of flow-sensitive strategies, including baseflow and groundwater-linked analysis, limits effective rejuvenation.
- A localized, data-driven approach is needed to support sustainable planning and river-sensitive interventions in Kerala.

View of Bharathapuzha

01 - Parali

02 - Malampuzha

03 - Chittur

ASSESSING THE INFLUENCE OF LAND COVER CHANGES ON THE BASEFLOW REGIME: A CASE OF BHARATHAPUZHA RIVER

B.PLAN THESIS | SAMUDRA D | 2021BPLN022

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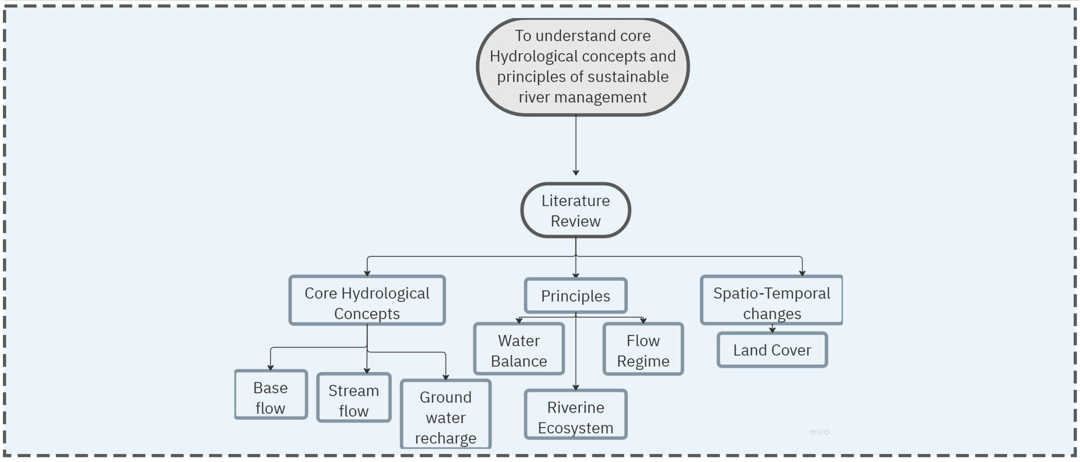
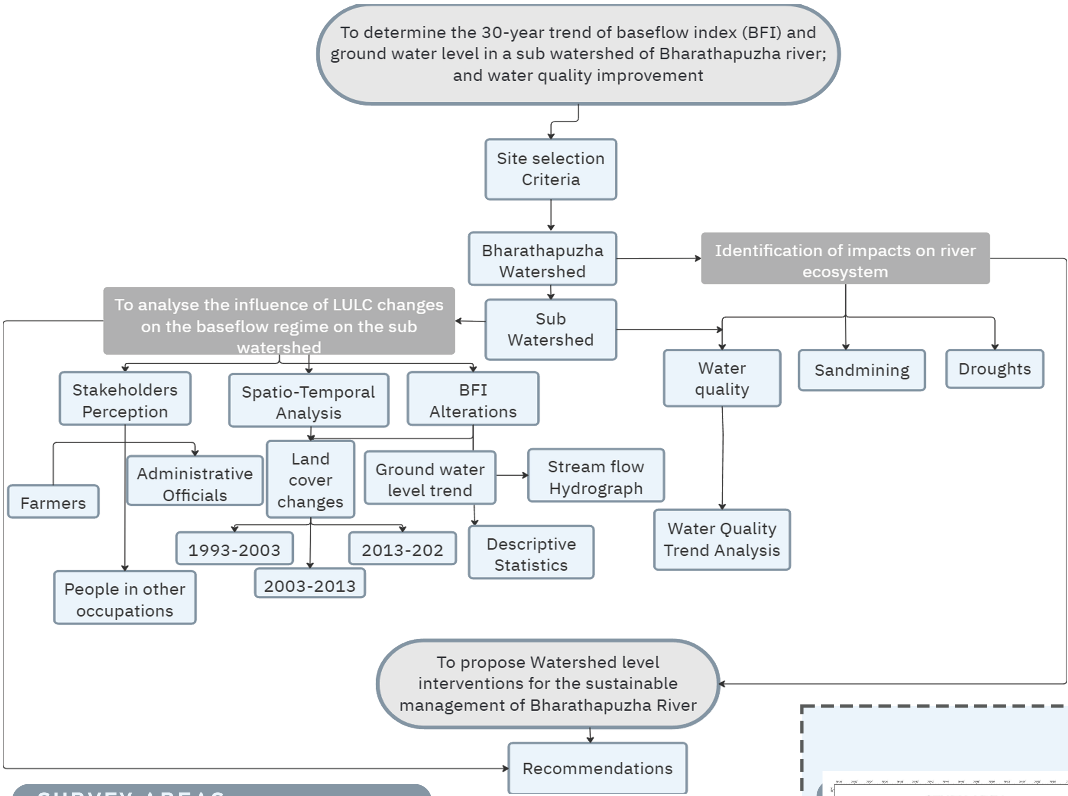
METHODOLOGY

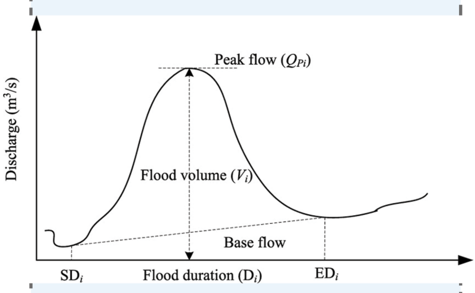




WORKING DEFINITIONS

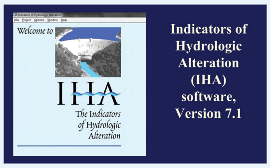
- Runoff: The portion of rainfall that flows over the land surface into streams, often after the soil is saturated.
- Streamflow: The total flow in a river or stream, comprising both surface runoff and subsurface contributions.
- Baseflow: The part of streamflow sustained by groundwater seeping into the river during dry periods.
- Infiltration: The process by which water penetrates the soil surface, contributing to groundwater recharge and reducing surface runoff.
- Base Flow Index (BFI) is the ratio of baseflow to total streamflow, ranging from 0 (runoff-dominated) to 1 (groundwater-dominated).

$$BFI = \frac{\text{Base Flow}}{\text{Total Streamflow}}$$



SOFTWARE SUPPORT

- IHA (Indicators of Hydrologic Alteration) software analyzes river flow patterns to assess hydrologic changes.



SECONDARY DATA LIST

Data	Office	Data Description
Flow Data / Discharge Data	CWC	Daily , Monthly , Weekly, Average Minimum & Maximum
Ground water details	CGWB , SGWD	Data from ground water monitoring wells
Water quality indicators of 30 years	SPCB , Fisheries , Dams	BOD , COD , PH ,TDS,
Existing Rejuvenation analysis	District Panchayath Office Palakkad	Activities till 2022
List of Panchayaths and wards were River being located	District Panchayath Office Palakkad	Done
Satellite Data sets	Bhuvan , USGS	DEM, LISS 3, LANDSAT
Soil Map	Soil department and secondary sources	Permeability , porosity, type geomorphology

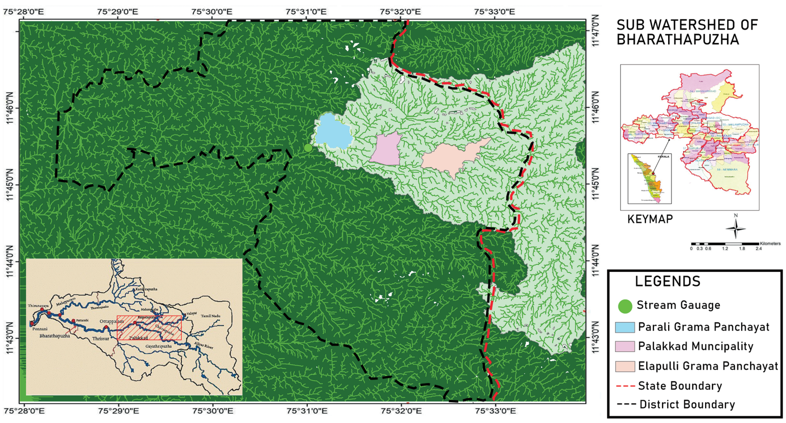
PRIMARY DATA LIST

RECONNAISSE NCE	Bharathapuzha River	Done
✱ Questionnaire- Perception & change in Crop and land use based		Done
Focussed Group Discussion with Authorities and the people		Done

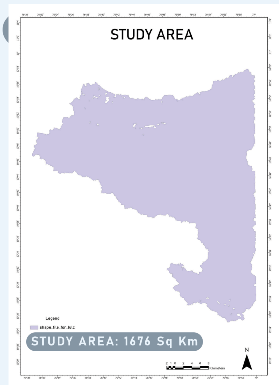
This stream Gauging Station is considered as pour point for the water shed delineation.

✱ Random sampling method used - proportionate to the population

SURVEY AREAS



Location	Key Characteristics	Rationale for Selection
Parali Grama Panchayat	Predominantly rural; located near the Mankara stream gauging station.	Represents a **typical rural catchment**; enables assessment of **natural hydrological conditions**, community **dependency on surface water**, and **local awareness**.
Palakkad Municipality	Highly urbanized with dense population and modified land use patterns.	Selected to examine **urban pressures on hydrology**, shifting **water use patterns**, and **public perceptions and awareness** of river degradation and conservation.
Elapully Grama Panchayat	Rural with **intensive groundwater extraction**; designated as a critical area by state agencies.	Chosen to understand the impacts of **groundwater overuse**, and to capture **community dependency, risk perceptions**, and **attitudes toward conservation initiatives**.



STUDY AREA JUSTIFICATION

Based on the location of CWC Stream Gauging Station on Mankara.

Most drought prone sub watershed of Bharathapuzha River.

Accessibility and language preference.

ASSESSING THE INFLUENCE OF LAND COVER CHANGES ON THE BASEFLOW REGIME: A CASE OF BHARATHAPUZHA RIVER

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03

ANALYSIS

OBJECTIVE 1

To understand core Hydrological concepts and principles of sustainable river management.

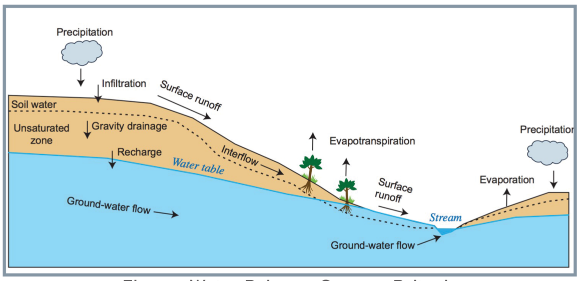


Figure- Water Balance. Source : Britanica

Environmental and Historical Streamflow – Examines flow regimes, seasonal variation, and long-term discharge trends.

Rainfall and Climatic Parameters – Includes spatiotemporal rainfall patterns and temperature influencing hydrological response.

Geomorphology and Watershed Characteristics – Focuses on topography, drainage patterns, and landform influences on flow and recharge.

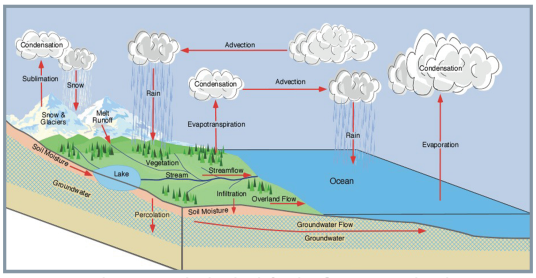


Figure- Hydrological Cycle. Source : Britanica

OBJECTIVE 2

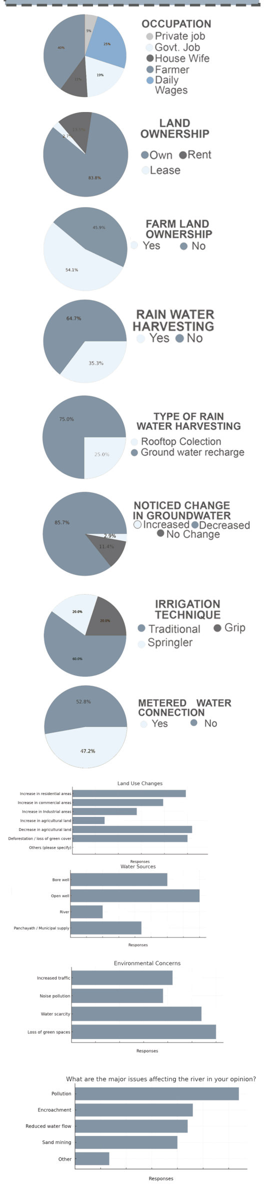
To analyze the 30-year trend (1993–2023) of the Baseflow Index (BFI) and groundwater levels in a sub-watershed of the Bharathapuzha River, and water quality improvement.

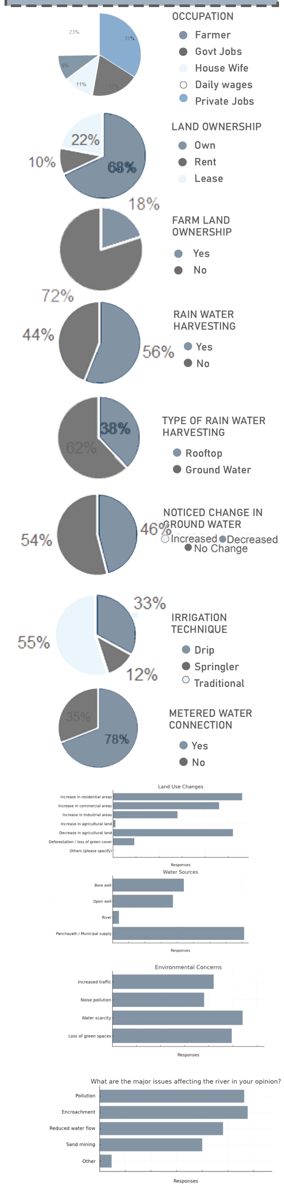
OBJECTIVE 2A

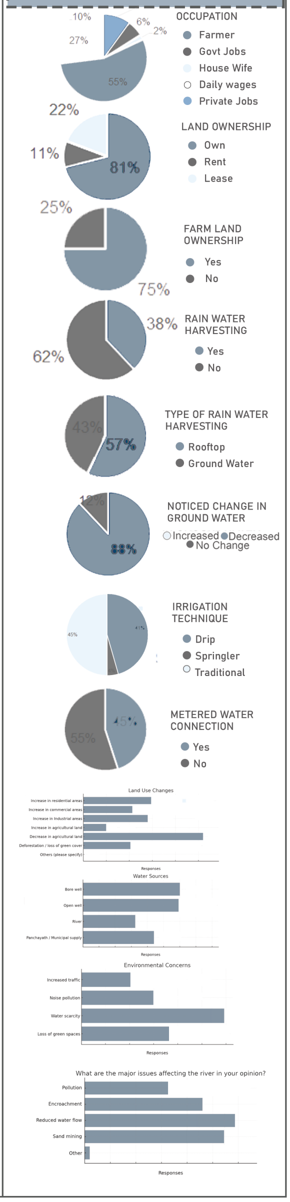
To explore how different people perceive things and to understand what is currently happening.

Perception Survey

QUESTIONNAIRE	PARALI GRAMA PANCHAYATH	PALAKAD MUNICIPALITY	ELAPULLY GRAMA PANCHAYATH
Occupation			
Land Ownership			
Farmland Ownership			
Do you practice Rainwater Harvesting			
Type of Rain Water Harvesting			
Noticed Changes in Ground water			
Any Water Saving irrigation technique			
Metered water Connection			
Change in Land use			
Primary Water Source			
Impact of Land Use Changes in your daily life			
Major Issues affecting the river			







FOCUSED GROUP DISCUSSION

Discussion conducted with river rejuvenation mission district coordinator, ward members and active working group for river conservation.

- Strengthening community awareness and participation
- Expanding conservation measures like bio-fencing, wetland restoration, and check dams
- Ensuring stricter regulation of land use and water management policies
- Encouraging traditional and sustainable agricultural practices
- Promoting rainwater harvesting and ground water recharge project

CURRENT ACTIVITIES

- 154 Green Islands (Pachathuruth) were established under the Haritha Kerala Mission (2017-2022).
- 56 public and private water bodies and wetlands were protected and rejuvenated.
- Riverbanks and water bodies were safeguarded from soil erosion using coir beds.
- Public and private wells are being conserved, with subsidies provided for rainwater harvesting.
- Volunteer groups have been actively working under Grama Panchayats since 2017.

Figure- Coir erosion control mat

Figure- Restored Pond

Figure- Rainwater Harvesting

Figure- Construction of Pond

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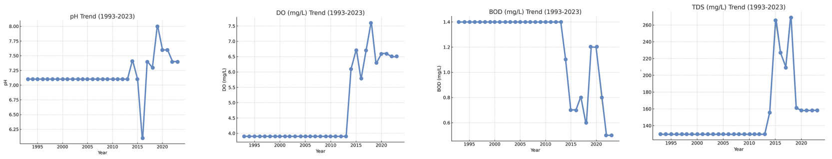
04

ANALYSIS

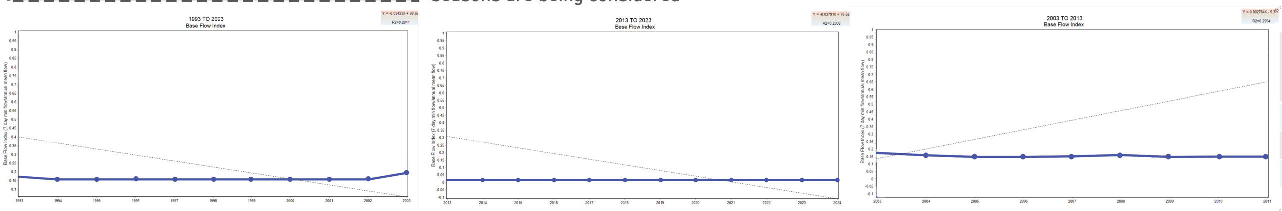
OBJECTIVE 2B

To analyse the influence of Land cover changes on the baseflow regime on the sub watershed



BFI Alterations and Spatio- Temporal Analysis

Base flow of non monsoon seasons are being considered



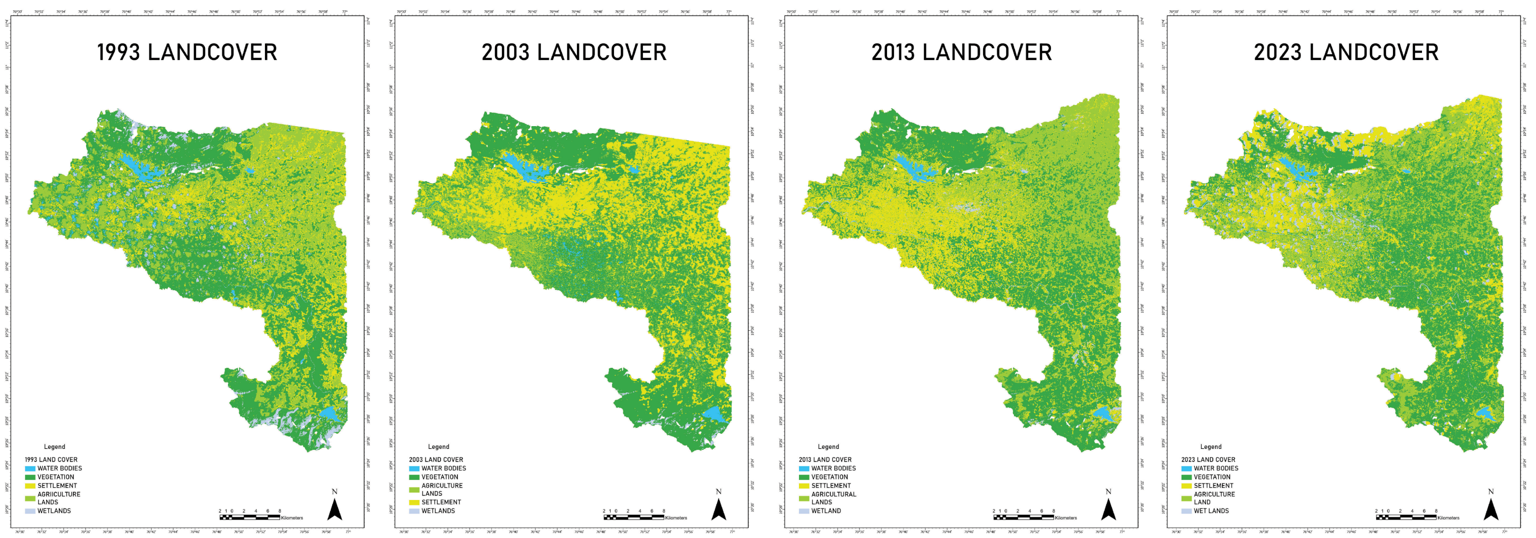
Decade	BFI	Baseflow quantity (m^3/s)
1993-2003	0.21	0.5817
2003-2013	0.052	0.1278
2013-2023	0.058	0.19

Around 20% of the non-monsoon season river flow is sustained by baseflow contributions.

Around 5.2% of the non-monsoon season river flow is sustained by baseflow contributions.

Around 5.8% of the non-monsoon season river flow is sustained by baseflow contributions.

Decadal baseflow quantity

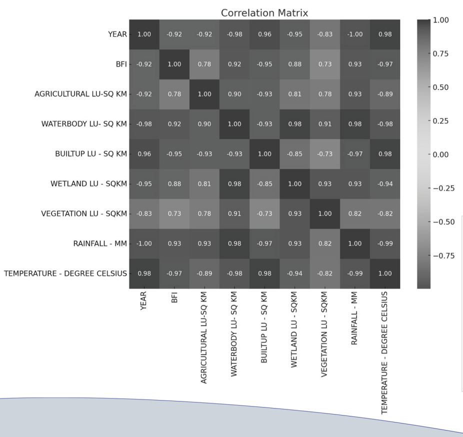


Variations in the Land Use and Land Cover (LULC) area and their respective percentage changes

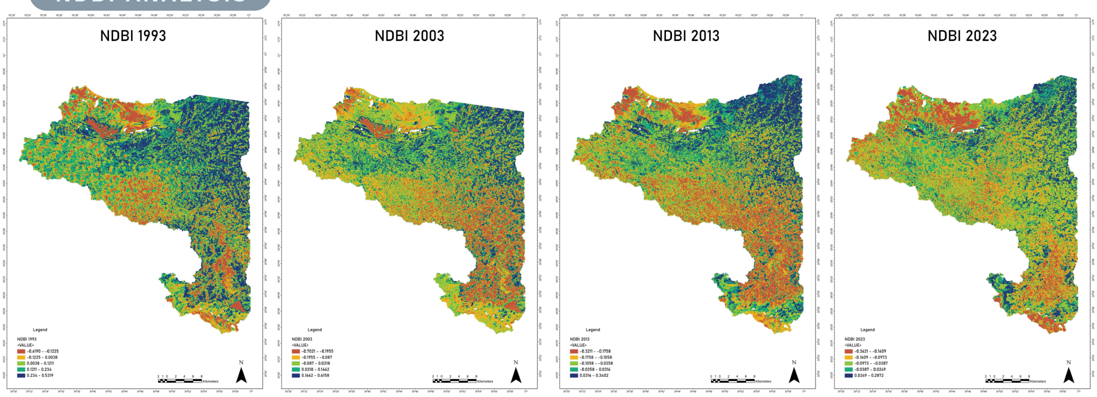
YEAR	BFI	AGRICULTURAL LU-SQ KM	PERCENTAGE	WATERBODY LU- SQ KM	PERCENTAGE	BUILTUP LU - SQ KM	PERCENTAGE	WETLAND LU - SQKM	PERCENTAGE	VEGETATION LU - SQKM	PERCENTAGE	TOTAL
1993	0.2	432.7777487	25.55417494	115.6584321	6.829269332	352.1627499	20.79411093	35.26396163	2.082226841	757.7067485	44.74021795	1693.569641
2003	0.19	415.7604066	25.03551819	106.9263773	6.438701766	361.0879764	21.74335135	28.62516436	1.723699062	748.2823249	45.05872963	1660.68225
2013	0.052	373.3503969	22.23756949	91.54832145	5.452819059	450.8439039	26.85325294	23.56482423	1.403572678	739.6098338	44.05278583	1678.91728
2023	0.058	237.4627393	15.42317971	78.63619547	5.107412548	500.9791369	32.53854176	19.32619509	1.255234319	703.2441313	45.67563167	1539.648398

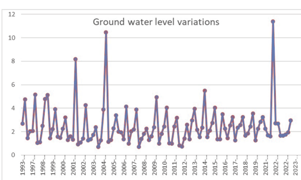
Regression Analysis and Correlation Matrix

Variable	Correlation with BFI	Interpretation
Waterbody_LU_Sq.km	+0.92	Very strong positive effect on BFI
Rainfall_mm	+0.93	Very strong positive effect
Wetland_LU_sq.km	+0.88	Strong positive correlation
Agricultural_LU_sq.km	+0.78	Moderate to strong positive
Open_Green_Cover_sq.km	+0.73	Moderate positive
Buildup_LC_sq.km	−0.95	Very strong negative correlation
Temperature_C	−0.97	Very strong negative correlation



NDBI ANALYSIS





KEY TAKEAWAYS

- Wetlands and waterbodies are most impactful on BFI — their loss reduces BFI significantly.
- Built-up areas also reduce BFI notably, supporting your NDBI findings.
- Vegetation and rainfall contribute positively to BFI but with less impact.
- Temperature and rainfall had the least influence in this regression.
- Urban expansion from 1993 to 2023 is evident through increasing NDBI values, indicating rapid growth in built-up areas.
- Decline in vegetative cover reflects reduced infiltration zones and higher impervious surface dominance.
- Hydrological Stress Intensification: Increased imperviousness has led to reduced groundwater recharge, elevated surface runoff, and a corresponding decline in base flow, exacerbating seasonal water stress.

ASSESSING THE INFLUENCE OF LAND COVER CHANGES ON THE BASEFLOW REGIME: A CASE OF BHARATHAPUZHA RIVER

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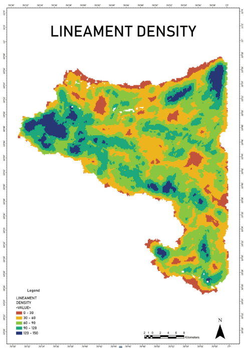
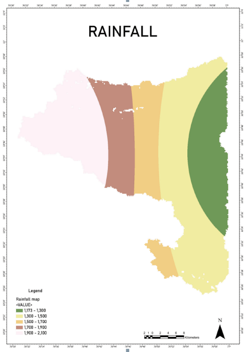
PROPOSALS

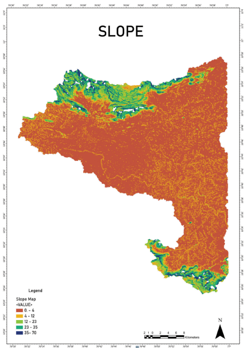
OBJECTIVE 3 — To propose Watershed level interventions for the sustainable management of Bharathapuzha River.

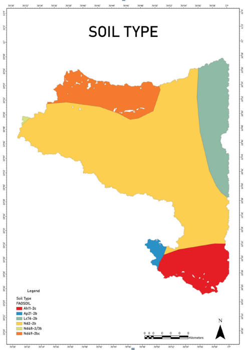
IDENTIFICATION OF GROUND WATER POTENTIAL ZONE

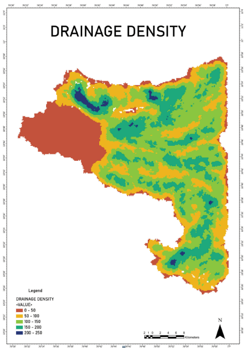
THEMATIC LAYERS

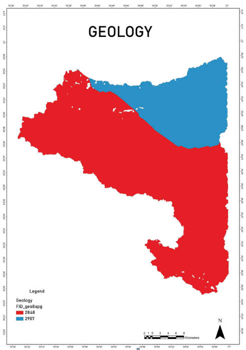




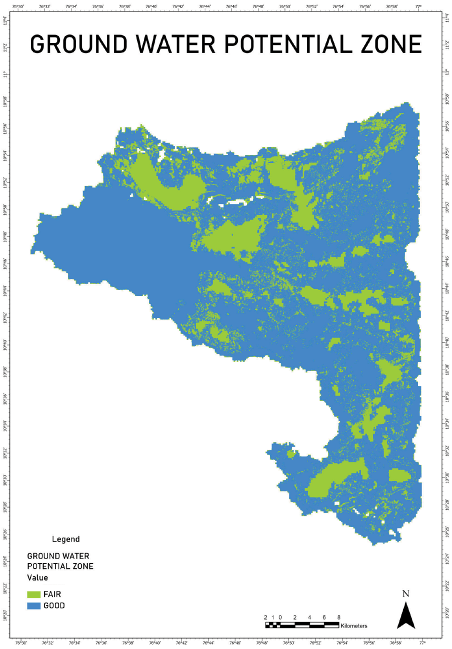


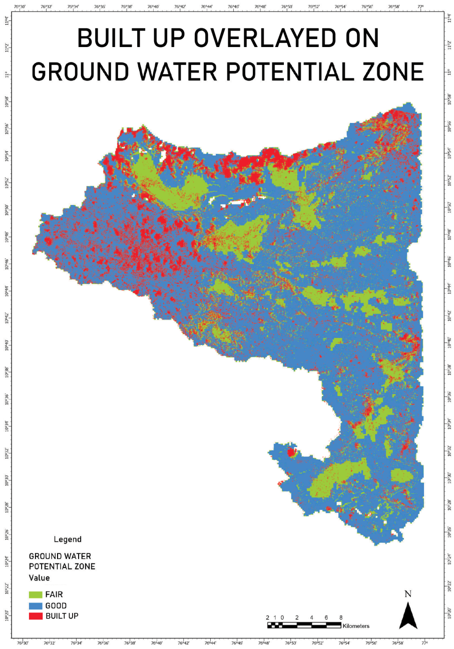






INTERGRATING OF THEMTIC LAYERS AHP PROCESS



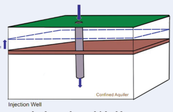


ANALYSIS OF WATER RESOURCE MANAGEMENT POLICIES AND MISSIONS IN KERALA: CHALLENGES AND PROPOSED IMPROVEMENTS

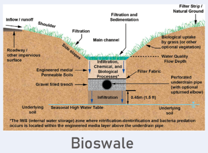
Policy/Mission	Key Features	Challenges	Proposed Improvements
Kerala Groundwater Control Act, 2002	Mandatory well registration, extraction limits	Weak enforcement, low awareness	Strengthen audits, digital monitoring, capacity building
Kerala State Water Policy, 2008	Promotes conjunctive use and sustainability	Lacks focus on recharge and climate impacts	Update with recharge targets and climate resilience
Jalanidhi Mission	Community-based rural water supply, RWH	Implementation and maintenance issues	Standardize practices, enhance capacity building
Atal Bhujal Yojana	Community-led sustainable groundwater management	Limited local adaptation, integration hurdles	Localize programs, enhance technical support
Sajalam 2024–25	Water resource plan for semi-critical blocks	Lacks micro-watershed focus, real-time data	Create micro-watershed plans, local committees
Bharathapuzha Rejuvenation Mission	Desilting, bank stabilization, protect water bodies	Fragmented, unsustainable efforts	Form councils, continuous monitoring, remove encroachments
KMBR Rule	Mandatory rooftop RWH for new constructions	Poor compliance, weak enforcement	Integrate with urban planning, promote green infrastructure
Wetland & Paddy Land Act	Prohibits unauthorized conversion of paddy/wetlands	Exploitable land classification loopholes	Digitize land bank, enforce audits

Aspect	Description
Existing Regulations	
Mandatory RWH	All new buildings >100 m² or plots >200 m² must have RWH systems
Storage Capacity Requirement	Minimum 25 liters per m² of roof area storage or equivalent recharge
Occupancy Compliance	RWH required for completion certificate; enforced by local bodies
Groundwater Regulation	Permission required for extraction in notified areas; recharge encouraged
Urban Local Body Role	Municipalities enforce rules and inspect systems
Recommended Improvements	
Compliance & Enforcement	Stricter post-occupancy checks and penalties for non-functional RWH
Retrofitting Old Buildings	Mandate retrofitting during major renovations of old buildings
Combination Systems	Use both storage and recharge systems for better sustainability
Standardized Designs	Provide approved RWH designs for various soil types and plot sizes
Recharge in Open Spaces	Mandate percolation pits in parks, campuses, and open lands
Public Awareness	Sensitize public through schools, local groups, and campaigns
Incentives	Offer tax rebates or tariff discounts for functional RWH systems
Rain Centers	Establish centers for technical RWH guidance and support

Rain Water Recharging system



Injection Wells



Bioswale

Sub Surface Ground Water Recharging

MONITORING AND EVALUATION OF URBAN RIVER MANAGEMENT PLAN OF NIUA

No.	Desirable Feature	Floodplain Management Points
1	Floodplain boundaries clearly demarcated	4
2	Floodplain boundaries protected through embankments, roads, or other means	1
3	Demarcation of no development zone adjacent to the river in the active floodplain	4
4	Strict enforcement in no development zone	5
5	Updated database of existing land use in floodplain available	1
6	Master Plan has clearly indicated permissible and non-permissible activities in the floodplain/river zone	5
7	All regulations in the Master Plan are enforced (10 points if at least 50% of the regulations are enforced)	6
8	Presence of river friendly landscaping (e.g. constructed wetlands, bioswales, etc.)	10
9	Strict monitoring mechanism in place	3
10	No solid waste dumping on river banks	6
11	Only organic farming practiced in river zone	1
	TOTAL	46

No.	Desirable feature	Eco-friendly riverfront points
1	The riverfront project is a source of revenue for the ULB	5
2	The riverfront project supports commercial activities like shops, stalls, etc	5
3	The riverfront project has a footfall of more than 100 people/day	5
4	The riverfront project is listed as an attraction spot on travel-related websites	10
5	The riverfront project has good waste management facilities	8
6	The riverfront project is made up of predominantly natural material	5
7	The riverfront project has soft landscaping elements	8
8	The riverfront project does not block the natural path of the river	8
	Total Points	**54**

No.	Desirable feature	Citizen sensitization points
1	Dedicated Information, Education and Communication (IEC) program for the river-related aspects	15
2	River related sensitization is part of existing citizen awareness raising program	12
3	Presence of a dedicated website for river-related aspects	4
4	Use of traditional sensitization media (e.g. hoardings, murals, competitions, radio)	10
5	Use of social media for river-related sensitization	8
6	A dedicated river day for the city	2
7	Earmarked budget for citizen sensitization	2
8	Sensitization of school children through special events	8
	Total Points	**61**

$$NET\ URM_{INDEX} = \frac{I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7}{7} = 24/7 = 3.43$$

INDICATORS	SCORE
Floodplain management	2
Net DO score	4
Water Body Revival Score	5
Riparian Buffer Factor	3
Eco Friendly River front points	3
River economy score	2
Calculation of Citizen Sensitization points	5
OVERALL URM SCORE	3.43

2.6-3.5: Average level of urban river management - The city has a satisfactory urban river management system. However, some dimensions of urban river management are still a cause of concern.

✱ NOTE - THIS IS BASED FROM THE ANALYSIS ON PALAKKAD MUNCI-PALITY

ASSESSING THE INFLUENCE OF LAND COVER CHANGES ON THE BASEFLOW REGIME: A CASE OF BHARATHAPUZHA RIVER

06

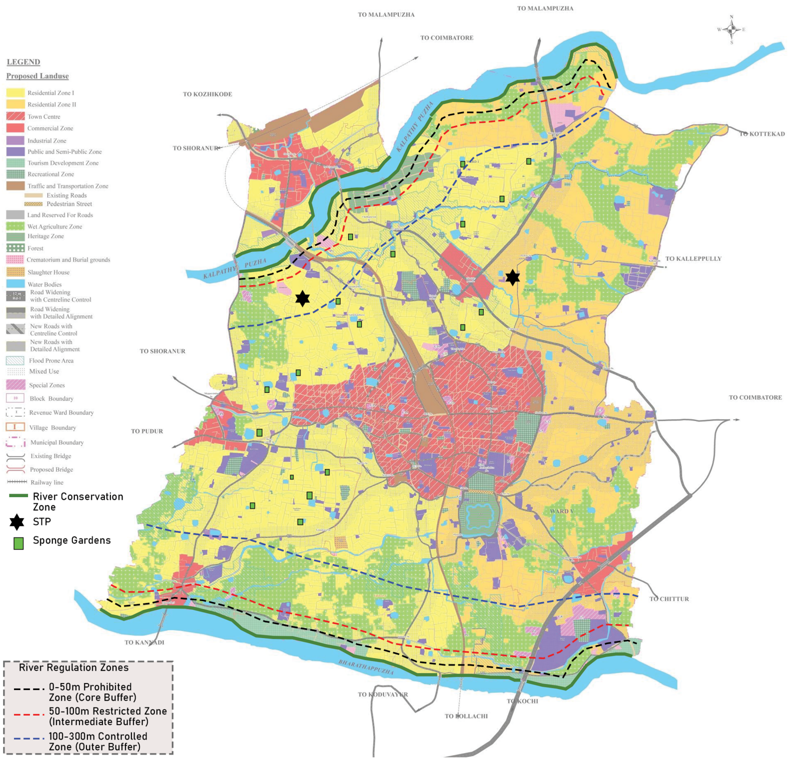
B.PLAN THESIS | SAMUDRA D | 2021BPLN022

"The river is the longest story of all; It is the mother of all knowledge. It teaches patience, persistence, and the ability to flow with the rhythm of life"

PROPOSALS

Effective Regulations of Activities

Modified Landuse Plan of Palakkad Muncipality



Introducing zonning category River conservation zone. (RCZ)

1. 15m of Riparian green buffer
2. Demarcation of active flood plain and regulation zones.
3. Ecological redesign of river fronts.
4. Implementation of Green Corridors


Amphi theatre


Paved Walkways


Transformation of stream banks into recreational spaces

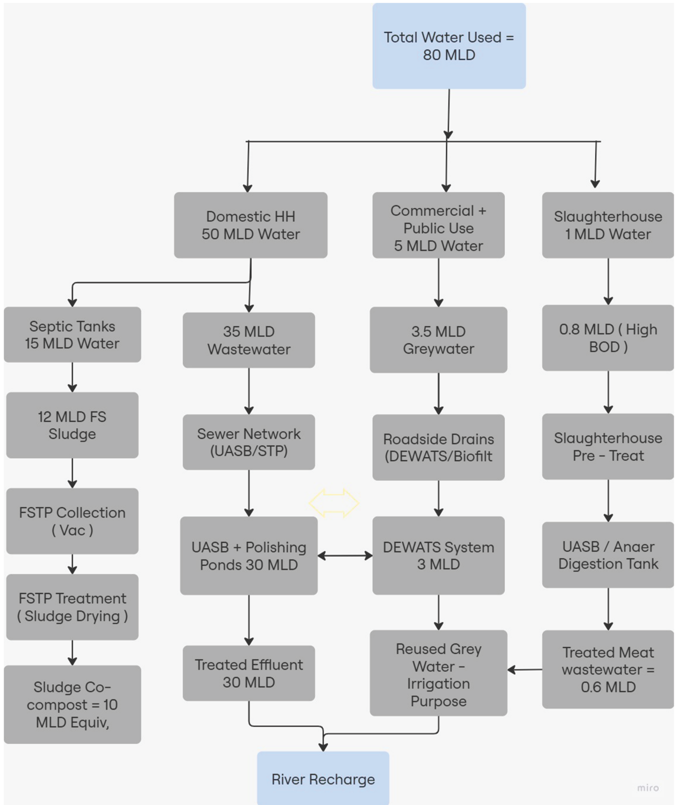

Bank protection

5. Proposals for practising sponge city concept.
   5.1 Paddy field Dam
   5.2 Community Farms on vacant lands with the integration of urban green cover.
   5.3 Riparian Conservation

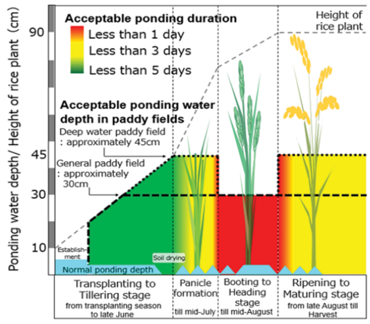
6. Proposals for culverts and water balancing canals to prevent excess water ac-cumulation and to easing out excess runoff.

To Ensure Good Quality Return Flow

Return Flow Interventions and Water Reuse Strategy



System	Purpose	Suitable Areas	Key Components	Advantages	Limitations
STP (Sewage Treatment Plant)	Treats centralized sewerage (blackwater & greywater)	High-density urban zones with sewer networks	Primary, secondary, tertiary treatment units	High treatment efficiency, handles large volumes	High cost, land requirement, needs sewer network
FSTP (Faecal Sludge Treatment Plant)	Treats septage from on-site sanitation systems (OSS)	Areas with septic tanks, no sewerage	Sludge drying beds, anaerobic digesters, dewatering	Decentralized, cost-effective, quick setup	Periodic desludging needed, varied input quality
DEWATS (Decentralized Wastewater Treatment System)	Localized treatment of domestic wastewater	Peri-urban or cluster-based areas	Settler, anaerobic baffled reactor, planted gravel filter	Low maintenance, low energy	Needs regular monitoring, space for modules
Constructed Wetlands	Nature-based wastewater treatment	Low-density or peri-urban zones	Vegetated beds, settling tanks	Eco-friendly, low operational cost	Larger land area needed, seasonal performance
UASB (Upflow Anaerobic Sludge Blanket Reactor)	Anaerobic treatment of sewage	Medium- to large-scale STPs	Reactor tank, gas collection dome	Energy recovery (biogas), compact	Less effective for high-strength or toxic waste



Ponding duration for paddy field dams. Source: NARO 2020

----- / .... } Maximum ponding water depth in paddy fields

- This chart illustrates reference to make use of paddy field as a countermeasure to unusual heavy rain events and flood damages.
- It shows the maximum ponding water depth (same height as the levee) and the colors show the strength of rice in each growth stage to the submergence.

Relatively strong ⟷ weak

- Appropriate utilization of paddy field within the condition shown in the chart is expected to mitigate flood damages after heavy rains.

SUSTAINABLE WATERSHED MANAGEMENT STRATEGIES

Promote low impact development (LID) and sustainable land use safegaurds floodplains, wetlands and recharge zones.
Restrict clusters of impervious developments in critical reserve areas.
Plan and implementation of urban recharge structures: recharge wells, percolation pits, infiltration parks, bioswales etc.
Plan integrated blue - green infrastructure : linking water bodies, open spaces, wetlands, and tree corriors for ecological health and climate resilence.
Retrofit existing built up areas with green infrastructure to reduce runoff and en-hance infiltration.
Intergrate groundwater sensitive zones in the Development plans or Master plans.
Promote cluster based recharge planning for peri urban area.