Assessing the Influence of Land Cover Changes on the Baseflow Regime: A Case Study of the Bharathapuzha River, Kerala.

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Abstract

This research investigates the influence of multi-decadal land use and land cover (LULC) changes on the baseflow regime of the Bharathapuzha River, Kerala, India. A combination of hydrological analysis, remote sensing, and stakeholder engagement was employed to assess trends in the Base Flow Index (BFI) and groundwater contributions, and to relate these to shifts in land cover. Daily river discharge data from 1993 to 2023 were analysed using a digital filtering technique (via the Indicators of Hydrologic Alteration software) to separate baseflow from stormflow. Decadal Landsat satellite imagery was classified to map land cover transitions, including forest, agricultural, and built-up categories. Additionally, structured questionnaires and focus group discussions were conducted in three representative sub-watersheds to gather community perspectives on water availability and watershed management. The Bharathapuzha basin (approximately 6,186 km^2) was selected as the study area due to significant vegetation loss and increasing hydrological stress. The results indicate a consistent decline in baseflow volumes over the study period, closely associated with the reduction in natural vegetation and an increase in built-up land. For instance, baseflow volume declined from approximately 2.49×10^6 m^3 in 1993 to 1.54×10^6 m^3 in 2013, before showing signs of partial recovery. During the same period, urban areas expanded considerably. Community responses indicated a strong perception of declining water availability and broad support for watershed interventions. The study concludes that conserving and restoring natural vegetation is essential for maintaining sustainable baseflows. These findings highlight the need for integrated watershed management approaches that combine land use planning, ecological restoration, and community-based water conservation strategies to mitigate the impacts of land cover changes on river hydrology.

Keywords: Land cover, Base flow index, Ground water potential, Baseflow.

Introduction

Urban rivers across India are under increasing stress due to rapid land cover transitions, driven largely by unplanned urbanization, infrastructure expansion, and ecological degradation. These transformations have altered the hydrological behaviour of catchments, affecting the baseflow—a critical component sustained by groundwater during non-rainy periods. Declining baseflows threaten urban water security, ecological stability, and the cultural lifelines of many Indian cities. This study situates the Bharathapuzha River Basin[1], particularly its urbanizing sub-watershed in Palakkad, Kerala, as a representative case of this broader national challenge. The river's hydrological health, measured through the Base Flow Index (BFI), has shown marked decline in relation to land cover changes between 1993 and 2023. Using remote sensing, hydrological modelling, and stakeholder engagement, this research aims to assess these linkages and offer a planning-oriented framework to address baseflow decline. The results have implications for urban river rejuvenation, integrated watershed management, and adaptive urban planning, in alignment with national programs like the Urban River Management Plan (URMP) and AMRUT 2.0.

Globally, rivers form the lifeline of ecological systems and human societies, delivering freshwater across diverse landscapes and sustaining agricultural, industrial, and domestic demands. However, over recent decades, increasing anthropogenic pressures—including land cover transformations, urbanization, and deforestation—have significantly altered the hydrological functioning of river basins (Scanlon et al., 2007; FAO, 2021). These changes have a profound impact on streamflow dynamics, particularly the baseflow, which represents the groundwater-fed component of river discharge and plays a crucial role in maintaining perennial flow during non-rainy periods (Smakhtin, 2001).

Hydrologically, river flow is typically decomposed into multiple components: surface runoff, interflow, and baseflow. Among these, baseflow—defined as the sustained, delayed contribution of groundwater to streamflow—is of critical importance, especially in regions with pronounced dry seasons or where monsoon patterns dominate precipitation (Huang et al., 2016). Baseflow supports ecological integrity, sustains aquatic biodiversity, and ensures the availability of water for human use during hydrological stress periods (Gordon et al., 2004). As a slow and relatively stable contributor to stream discharge, baseflow also serves as a natural buffer against hydrological extremes such as droughts.

The Base Flow Index (BFI), which quantifies the ratio of baseflow to total streamflow, is commonly used to assess groundwater-surface water interactions and the overall resilience of catchment systems (Tallaksen and van Lanen, 2004). A declining BFI typically indicates reduced groundwater contribution, often symptomatic of unsustainable land and water management practices. BFI trends, therefore, offer insights into long-term changes in catchment hydrology and can inform water resource planning and ecosystem conservation.

Multiple global studies have documented the strong sensitivity of baseflow to Land Use and Land Cover (LULC) changes. In regions like the Amazon (Costa et al., 2003), the Yangtze

[1] Bharathappuzha ("River of Bhārata"), also known as Nila, spans approximately 209 km, making it the second-longest river in Kerala. Its basin covers about 6,186 km², of which roughly 4,400 km² lie within Kerala and the rest in Tamil Nadu

(Zhang et al., 2014), and parts of North America (Price, 2011), deforestation and rapid urban expansion have been linked to decreased infiltration, altered evapotranspiration patterns, and diminished groundwater recharge. These transformations disrupt the subsurface hydrological balance, leading to altered streamflow regimes characterized by reduced low flows and intensified peak flows. Research by Gunduz and Arain (2011) and Chen and Teegavarapu (2021) corroborate the global concern that human-induced land transitions can significantly affect the magnitude and timing of baseflow, thus influencing water availability and ecological stability.

India, home to a complex and diverse hydrological landscape, is no exception. Rivers such as the Ganga, Narmada, and Krishna have shown signs of declining baseflow, attributed to a combination of land cover changes, groundwater extraction, and shifting rainfall patterns (Mukherjee et al., 2018; Jain and Kumar, 2012). In Kerala, which lies along the biodiverse and geomorphologically unique Western Ghats, recent decades have witnessed rapid transformations in land cover driven by urban growth, infrastructure development, and changing agricultural practices (George et al., 2020). These shifts are particularly relevant in the context of smaller yet ecologically and culturally significant river systems such as the Bharathapuzha River.

Baseflow, defined as the portion of streamflow sustained by groundwater discharge in the absence of direct precipitation or surface runoff, plays a vital role in maintaining river flow during dry periods (dry weather flow), regulating ecosystem health, and supporting water security (Smakhtin, 2001; Huang et al., 2016). It reflects the integrative functioning of catchment-scale hydrological processes and the resilience of a watershed in the face of hydroclimatic variability.

The Base Flow Index (BFI) is a common way to measure how much groundwater contributes to overall streamflow. It is usually shown as the ratio of baseflow to total streamflow over a certain time period (Gustard et al., 1992). A higher BFI usually means that there is more groundwater and a more stable flow regime. On the other hand, a lower BFI means that the system is more runoff-dominated or disturbed, which means it has less hydrological buffering. Because of this, BFI has become an important way to tell how healthy a catchment is. It is used to look at how groundwater and surface water interact, how a watershed works, and how land and water use practices affect it (Price, 2011; Eckhardt, 2005).

Scientific studies have established that land use and land cover (LULC) changes—such as deforestation, wetland loss, agricultural intensification, and urban sprawl—can substantially alter baseflow dynamics (Gunduz & Arain, 2011; Zhang et al., 2014). These changes influence infiltration capacity, soil moisture regimes, and groundwater recharge potential. For instance, impervious surfaces associated with urbanization reduce infiltration and promote quick runoff, resulting in reduced baseflow and flashier stream responses. Similarly, monoculture plantations or altered cropping cycles can modify evapotranspiration (ET) rates and subsurface water availability, indirectly affecting baseflow regimes. Climatic drivers such as altered precipitation patterns, temperature rise, and drought frequency further complicate baseflow behavior. Increased ET under warming conditions can lead to higher soil moisture deficits, reducing recharge and lowering baseflow, especially in tropical monsoon systems (Taylor et al., 2013). However, the hydrological response to climatic factors is often modulated by the land cover context—highlighting the need to examine land-climate interactions in tandem (Sterling et al., 2013).

Furthermore, anthropogenic pressures such as groundwater abstraction, sand mining from riverbeds, and floodplain encroachments can directly degrade baseflow. (Beck, H. J., & Van der Velde, Y. (2014)). Studies in Indian river systems, including the Ganga and Krishna basins, have shown significant BFI declines over recent decades, primarily driven by land transformation and groundwater stress (Mukherjee et al., 2018; Jain & Kumar, 2012). These shifts underscore the importance of BFI not just as a hydrological parameter, but as a sentinel indicator for sustainable river basin management.(Acreman & Dunbar, 2004)

Study Area Profile

The Bharathapuzha River, locally known as "Nila," is the second-longest river in Kerala and one of the most culturally and hydrologically significant west-flowing rivers in South India. It originates from the eastern slopes of the Western Ghats and flows approximately 209 km westward before emptying into the Arabian Sea at Ponnani. The river basin spans an area of about 6,186 km², distributed across Kerala (~4,400 km²) and Tamil Nadu, encompassing diverse physiographic and climatic conditions.(Nikhil Raj & Azeez, 2012)

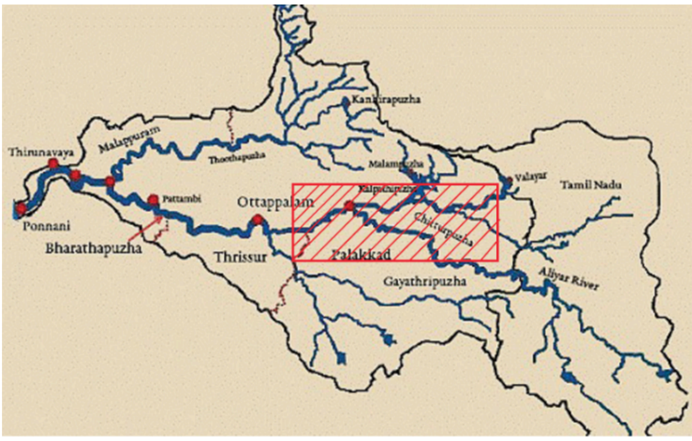

Figure SEQ Figure * ARABIC 1 Tributaries of Bharathapuzha River.

Source: PSC Arivukal.com, modified by Author

The river is fed by four major tributaries—Kalpathipuzha, Gayathripuzha, Thoothapuzha, and Chitturpuzha—each contributing to the basin's complex hydrology. The terrain is varied, ranging from coastal plains to midlands and highlands, with elevations from near sea level to over 1,100 meters. The Kerala portion falls under a humid tropical climate, while the upper basin in Tamil Nadu lies in a semi-arid rain-shadow region. This climatic contrast is reflected in the land cover: dense agriculture and plantations in the lower basin, and more sparsely vegetated, fallow land in the upper basin.

As of 2018, land cover analysis reveals that plantations, primarily rubber and arecanut, dominate 45% of the basin. Natural forests comprise 20%, with the rest covered by agriculture and expanding built-up areas. The basin lies within the Western Ghats biodiversity hotspot, and groundwater recharge from upland regions is vital for sustaining baseflow during dry seasons. Annual average rainfall is approximately 2,042 mm, with nearly 75% received during the southwest monsoon (June–September). However, recent trends show declining rainfall and increasing climate variability. Soils, mainly sandy clay loams and clay loams, influence infiltration and runoff behaviour.

Over four million people depend on the river for agriculture, water supply, and livelihoods. Major irrigation infrastructure—such as the Malampuzha, Walayar, and Pothundi reservoirs[2]—regulates flow. However, rapid land use change since the 1970s, including deforestation, wetland loss, and urbanization, has disrupted groundwater recharge and baseflow continuity, raising concerns about long-term water sustainability in the basin.(Logan, 1996)

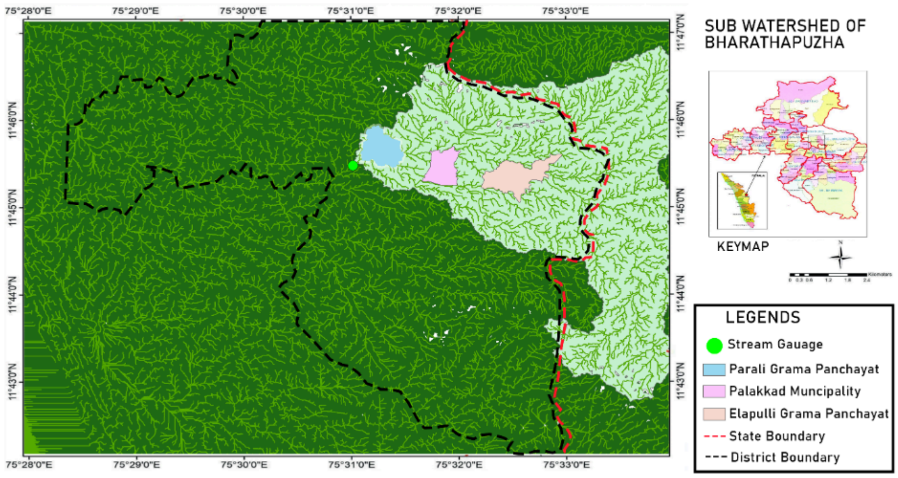

Figure SEQ Figure * ARABIC 2 Site Selected, Light green patch is the study area

Source: Author

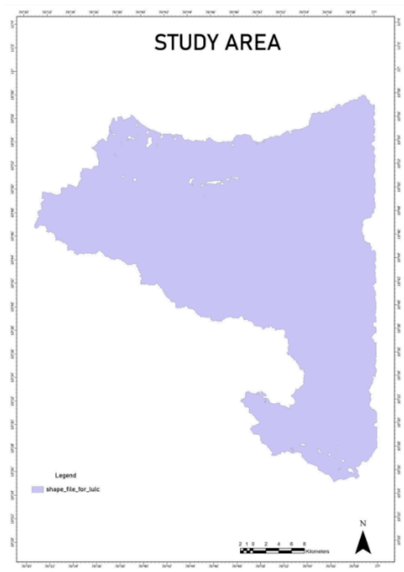

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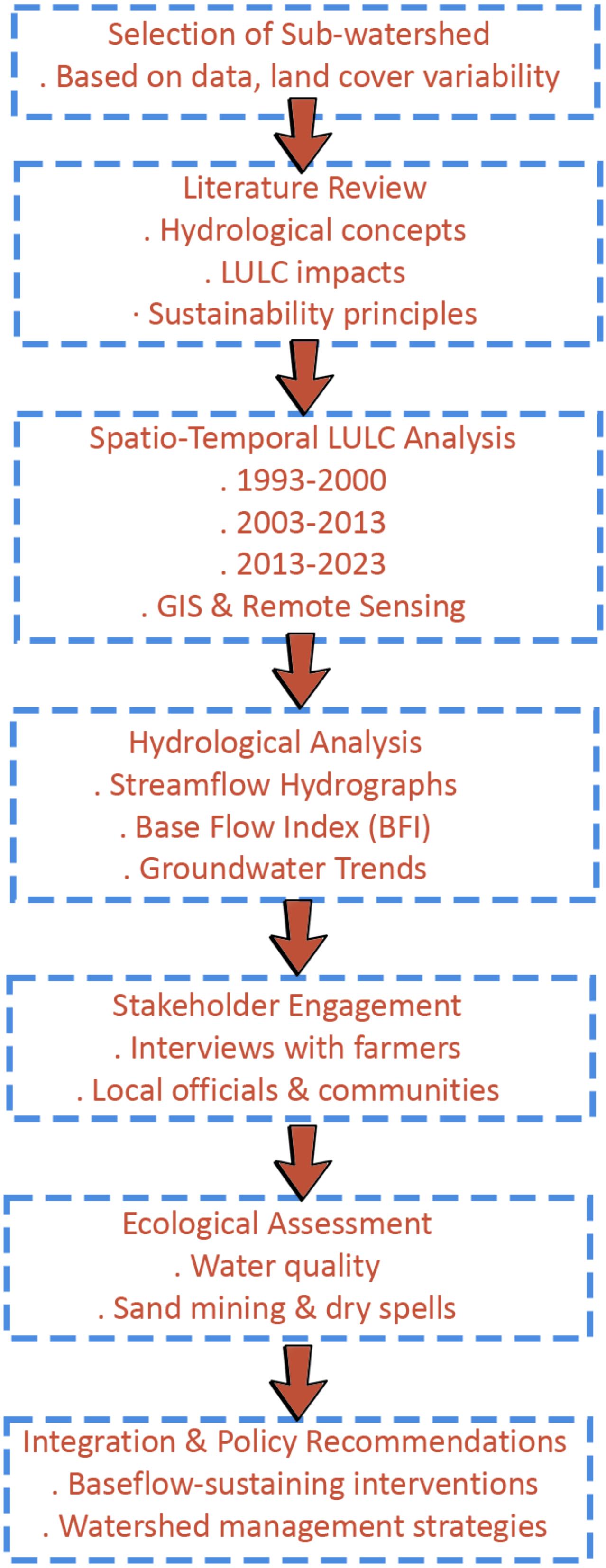
Figure SEQ Figure * ARABIC 3 Study area Demarcation

[2] These are located in the tributaries of Bharathapuzha River

Research Methodology



The study adopted a multidisciplinary approach combining remote sensing, hydrological modelling, and stakeholder perception analysis. The analyses conducted and the tools used were as follows:

Methods and Tools

<u>Baseflow Index Calculation</u>

- BFI was calculated using the HYSEP and IHA (Indicators of Hydrologic Alteration) tools.
- Streamflow data (1993–2023) from CWC's Mankara station was used.
- BFI = Baseflow / Total Streamflow; a declining BFI indicates reduced groundwater contribution. Groundwater Potential Mapping:
- Multi-Criteria Evaluation (MCE) in ArcGIS using layers: slope, soil type, geology, drainage density, and rainfall.

<u>Remote Sensing and GIS:</u>

- Landsat TM/ETM+/OLI imagery (1993, 2003, 2013, 2023) was processed using QGIS.
- Supervised classification (Maximum Likelihood Classifier) was used for LULC mapping.
- Change detection analysis was conducted to assess transitions in land categories.

<u>Stakeholder Engagement:</u>

- Focused group discussions with farmers, municipal staff, and residents.
- Surveys and participatory mapping to identify stress zones and community-prioritized issues.

<u>Tools Used:</u>

- QGIS, ArcGIS, MS Excel, IHA software, HEC RAAS, Google Earth Engine.

Analysis and Discussion

This study investigates the long-term dynamics of baseflow index (BFI)[3], groundwater levels, and land cover changes in a sub-watershed of the Bharathapuzha River over a 30-year period (1993–2023), with a focus on hydrological sustainability and ecological resilience.

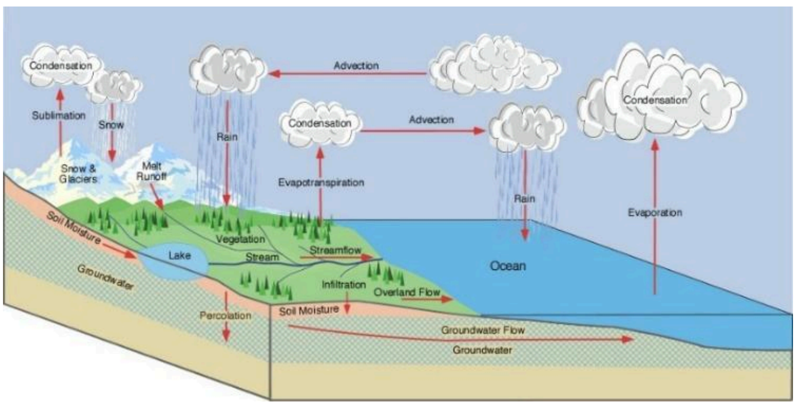


Figure 4 Hydrological Cycle

Source: PhysicalGeography.net

[3]The Base Flow Index (BFI) is a hydrological indicator that quantifies the proportion of total river or streamflow that is sustained by groundwater discharge (baseflow) over a specific time period.

Land Cover Transitions and Hydrological Implications

The spatio -temporal change analysis reveals significant transformations in land cover across the study area. Most prominently**,** agricultural land experienced a substantial and continuous decline—by 22% in 2003, 41% in 2013, and 54% in 2023 compared to 1993 levels. This reduction aligns with a decrease in paddy cultivation, traditionally the dominant agricultural practice. Factors contributing to this trend include land conversion for non-agricultural uses, urban expansion, and market-driven shifts in crop selection.(Waiyasusri, 2021)

In parallel, built-up areas increased dramatically—by 43% in 2003, 56% in 2013, and 61% by 2023—reflecting widespread urbanization and infrastructural development. This rapid urban expansion, confirmed by increasing Normalized Difference Built-up Index (NDBI) values, indicates the proliferation of impervious surfaces, which disrupts the natural hydrological regime by reducing infiltration and augmenting surface runoff.

Wetlands and forest areas showed a cumulative 38% decline by 2023. This has direct implications on ecosystem services provisioning, especially concerning carbon sequestration, microclimatic regulation, and groundwater recharge. Meanwhile, a marginal increase in barren land and a slight decline in river/water body area suggest localized degradation and possible hydrological stress, exacerbated by altered flow regimes and anthropogenic pressures.

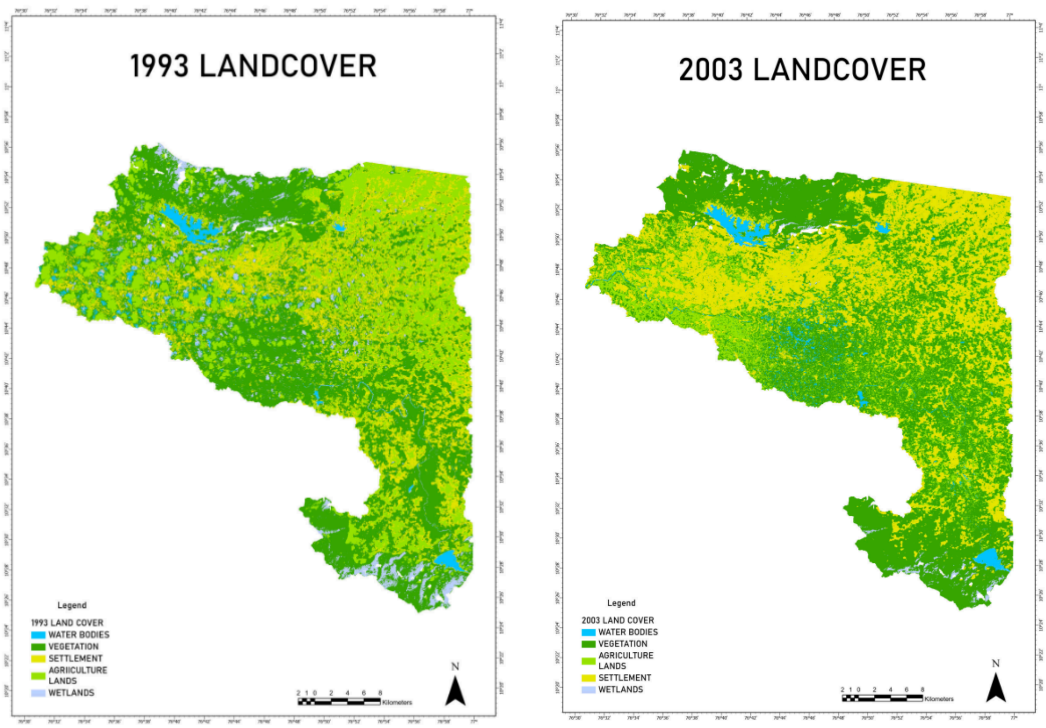


Figure SEQ Figure * ARABIC 5
Landcover of 1993 and 2003
Source: Author

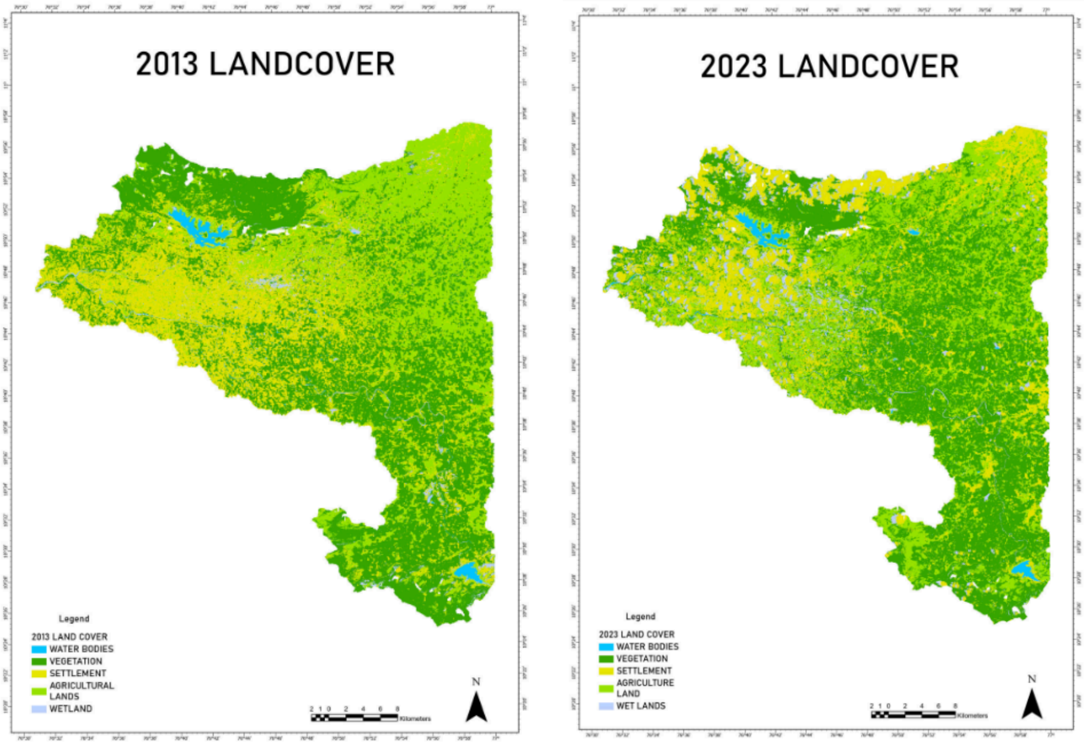


Figure SEQ Figure * ARABIC 6 Landcover of 2013 and 2023.

Source: Author

Table 1 Change in landcover from 1993 to 2003, Source: Author

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	432.77	25.55	115.65	6.82	352.16	20.79	35.26	2.08	757.70	44.74	1693.56
2003	0.19	415.76	25.03	106.92	6.43	361.08	21.74	28.62	1.72	748.28	45.05	1660.68
2013	0.052	373.35	22.23	91.54	5.45	450.84	26.85	23.56	1.40	739.60	44.05	1678.91
2023	0.058	237.46	15.42	78.63	5.10	500.97	32.53	19.32	1.25	703.24	45.67	1539.64

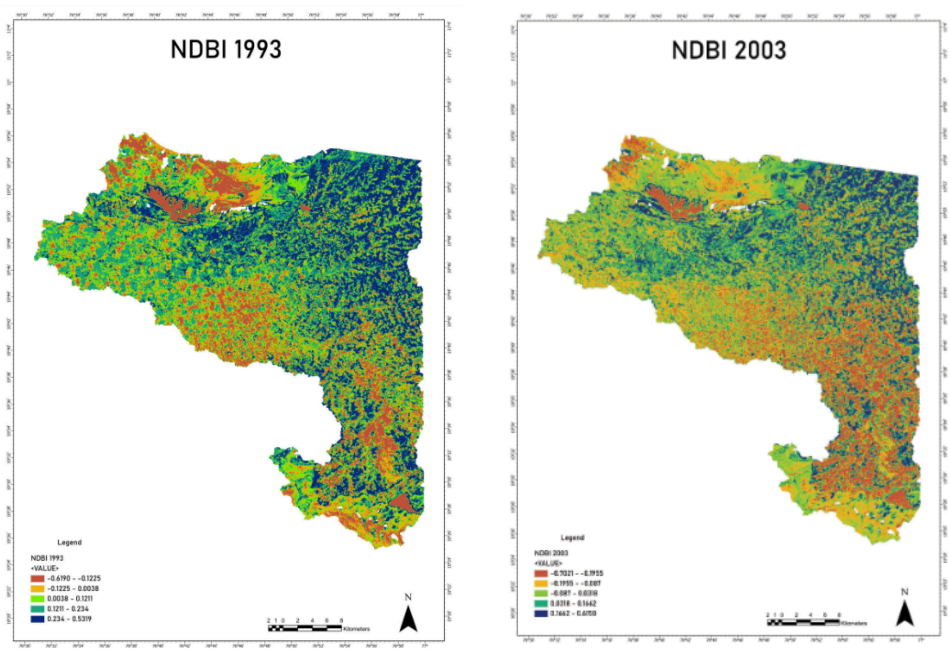


Figure SEQ Figure * ARABIC 7 NDBI analysis of 1993 and 2003

Source: Author

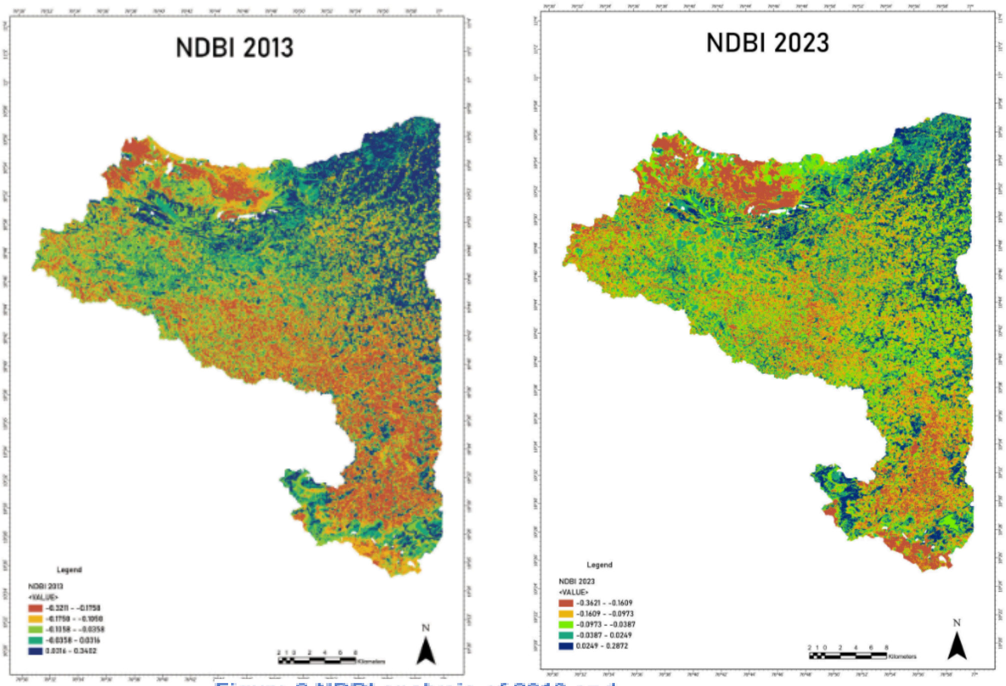


Figure 8 NDBI analysis of 2013 and 2023

Source: Author

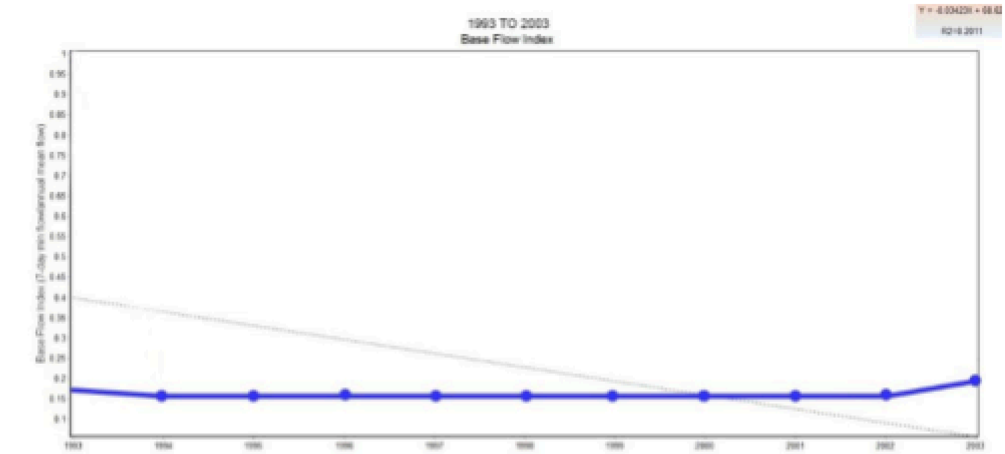
Baseflow and Groundwater Dynamics: Implications for Hydrological Sustainability (1993–2023)

The regression analysis links LULC changes with declining baseflow index (BFI) values, underscoring a negative correlation between urban expansion and baseflow contribution. The degradation of wetlands and reduction in surface water bodies emerged as the most critical factors affecting BFI, highlighting the sensitivity of groundwater-sustained flows to surface hydrology and land use. Built-up areas significantly reduced BFI due to decreased infiltration capacity and loss of natural recharge zones. Conversely, vegetative cover and wetland presence positively influenced BFI, though their effects were less dominant relative to built-up expansion. Rainfall and temperature exhibited minimal influence in the multivariate regression model, indicating that anthropogenic land use changes have become the primary driver of baseflow variability in the region.(Walsh et al., 2005)

This pattern is consistent with the observed groundwater level decline, attributed to reduced percolation zones, increased abstraction, and declining recharge from both direct rainfall and adjacent surface water systems. The long-term reduction in BFI indicates a shift from baseflow-dominated to stormflow-dominated regimes, increasing hydrological flashiness and reducing stream permanence.

Decadal analysis of the Baseflow Index (BFI) and baseflow quantity reveals a marked deterioration in groundwater contributions to streamflow within the Bharathapuzha sub-basin. Between 1993 and 2003, BFI averaged 0.21, with a baseflow volume of 0.5817 m^3/s. However, from 2003 to 2013, BFI plummeted to 0.052, alongside a sharp decline in baseflow volume to 0.1278 m^3/s. Although a marginal recovery was observed in 2013–2023 (BFI: 0.058; baseflow: 0.19 m^3/s), values remain significantly lower than in the baseline decade, reflecting sustained anthropogenic and climatic pressures. (Tan et al., 2020)

This BFI reduction indicates a transition toward flashier hydrological regimes—characterized by diminished groundwater support and increased stormflow dominance. The correlation between declining BFI and land cover transformation[4]—particularly the expansion of impervious built-up areas—suggests reduced infiltration and aquifer recharge. Concurrently, the decline in wetland extent and riparian vegetation further diminishes the basin's capacity to sustain baseflow during dry periods, weakening river resilience and seasonal flow continuity. Long-term groundwater level monitoring corroborates this trend. Seasonal post-monsoon recharge peaks have progressively declined since the early 2000s, with critical lows recorded in 2022 (~11.4 meters). This signals an increasing recharge-extraction imbalance, driven by intensive water abstraction, reduced percolation zones, and erratic monsoonal patterns. The loss of shallow groundwater storage directly translates into weakened baseflow discharge, particularly during the non-monsoon period when river systems rely heavily on subsurface flow.(Hellwig et al., 2021)



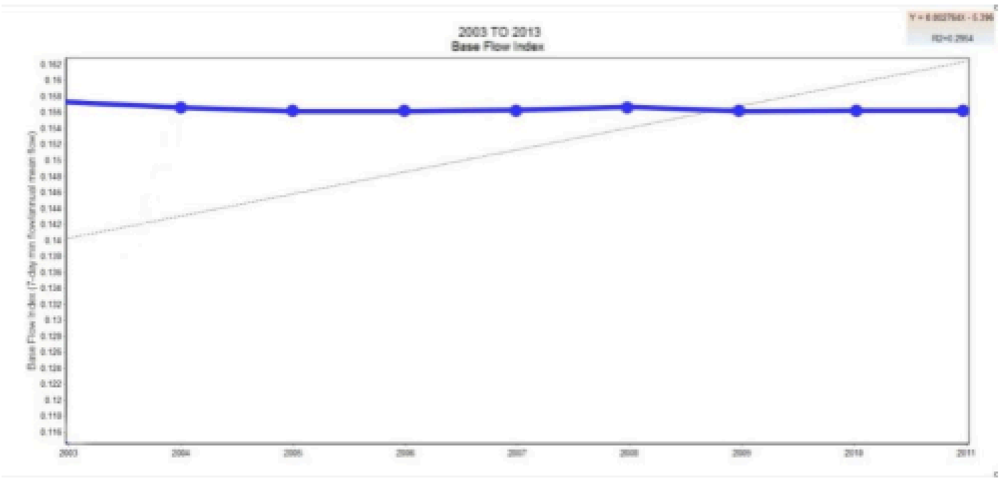
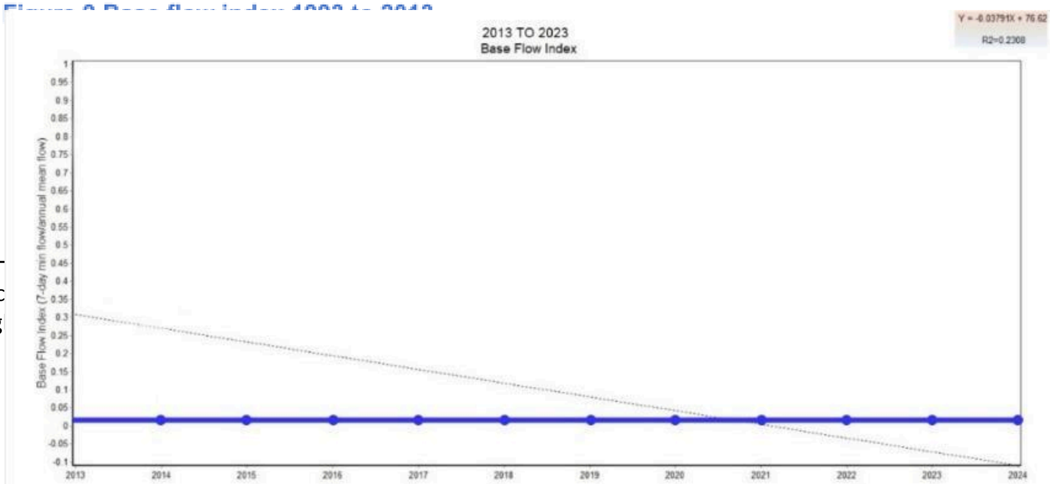


Figure 9 Base flow index 1993 to 2013



[4] A dec [illegible] runoff, highlig [illegible]

Figure 10 Base flow index 2013 to 2023

Source: Author

Water quality trends since 2015 provide additional insight into watershed stress. Rising concentrations of Chromium, Chloride, and Total Dissolved Solids (TDS) reflect increasing pollution from urban and industrial sources. Though Dissolved Oxygen (DO) levels have improved, fluctuating pH and persistent chemical loading suggest an evolving contamination profile.

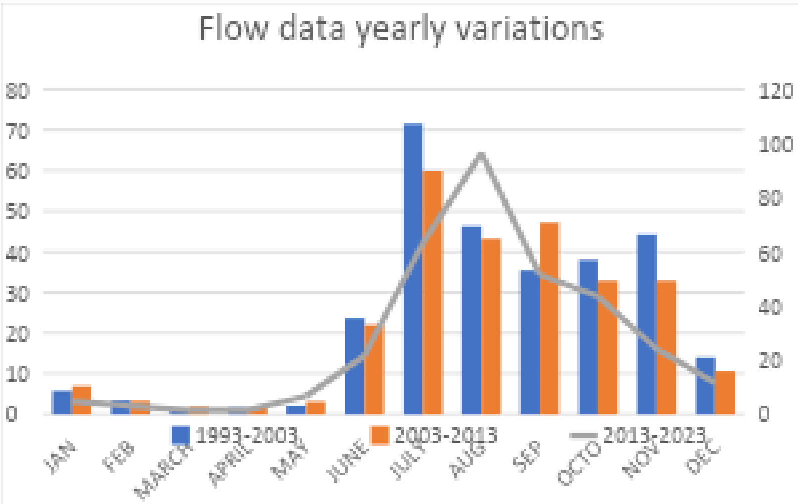
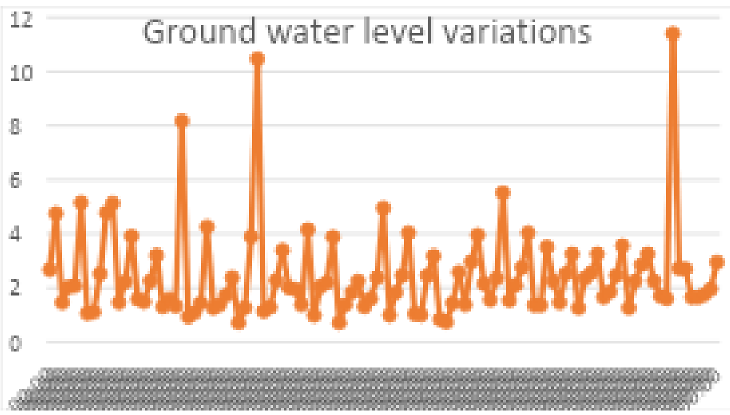


Figure 11 Flow Data yearly variation, Source: Author



Groundwater recharge potential in the Bharathapuzha Basin, particularly in the Palakkad region, is governed by a complex interplay of geological, geomorphological, climatic, and anthropogenic factors. Identifying Groundwater Potential Zones (GWPZs) is essential for sustainable water resource planning, aquifer recharge strategies, and maintaining baseflow in rivers like the Chitturpuzha and Kalpathy Puzha, especially during dry periods. (Kumar et al., 2022)

The region's geology is dominated by charnockites and gneisses, where groundwater occurs mainly in weathered and fractured zones. Lateritic formations in uplands contribute to storage where permeability is high, while valley fills and floodplains act as key recharge zones, particularly in the Palakkad plains. Soil variation influences infiltration: alluvial soils near rivers allow high recharge, red loamy soils offer moderate permeability, and lateritic soils, though porous in places, often compact and limit infiltration in upland areas.

Drainage density, defined as the total length of streams and rivers per basin area, reflects how surface water is distributed and responds to rainfall. Low drainage density areas typically have higher infiltration rates and reduced surface runoff, promoting groundwater recharge. Slope is equally critical—gentle slopes allow longer water residence and greater infiltration, while steep slopes, such as those near the Western Ghats, drive rapid runoff and limit recharge. Together, slope and drainage density determine groundwater potential: low drainage density and gentle slopes favour recharge, whereas steep, high-density areas promote runoff and restrict infiltration.

Lineament density, indicating the presence of subsurface fractures and faults, is particularly important in hard rock terrains like Palakkad. Areas with high lineament density, especially where lineaments intersect, are zones of enhanced secondary porosity and high recharge potential. Rainfall, mainly from the southwest monsoon (2000–2500 mm annually), is the primary recharge source. However, recharge efficacy depends on rainfall intensity and distribution. Sustained, moderate rainfall supports percolation, while high-intensity events lead to runoff, especially in areas with poor land cover or compacted soils.

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Land use plays a crucial role in groundwater recharge, with forests and agricultural land aiding infiltration, while urban areas with impervious surfaces hinder it and increase runoff. Rapid urbanization in Palakkad is altering these recharge dynamics. Using Remote Sensing (RS) and GIS, integrating layers like geology, soil, slope, rainfall, and land use, groundwater potential maps can be created. These maps classify zones from very high to very low recharge potential, helping plan artificial recharge structures and irrigation strategies. Such mapping is vital for conserving groundwater, easing aquifer stress, and enhancing water security in the Bharathapuzha Basin.

Recommendations

1. Integrate BFI indicators into river basin planning frameworks.

Integrating the Baseflow Index (BFI) into river basin planning helps quantify groundwater contributions to streamflow, offering insight into baseflow dynamics. Using BFI enables targeted interventions, better water budgeting, and strategies to sustain ecological flows during dry periods.

- The objectives of the URMP Framework followed - 3. To rejuvenate waterbodies and wetlands in the city

2. Protect recharge zones through zoning regulations and enforcement against encroachments.

Safeguarding groundwater recharge zones through strict zoning and enforcement helps maintain aquifer replenishment and sustain baseflow. Controlling harmful development in these areas also reduces runoff and enhances flood management. (Sophocleous, 2002)

- The objectives of the URMP Framework followed - 1. To ensure effective regulation of activities in the floodplain.

3. Promote afforestation and riparian buffer restoration in degraded areas.

Afforestation and riparian buffer restoration enhance soil permeability, improve groundwater recharge, and stabilize riverbanks. These nature-based solutions also filter pollutants, boost biodiversity, and strengthen the river basin's resilience to climate and land use pressures.

- The objectives of the URMP Framework followed - 4. To enhance the riparian buffer along river banks.

Figure 13 Riparian Edge, Source: Author

Figure 14 Riparian Edge Section, Source: Author

4. Install managed aquifer recharge systems, such as injection wells and check dams.

Installing managed aquifer recharge (MAR) systems, such as injection wells, check dams, and percolation tanks, can significantly enhance groundwater replenishment. These systems are designed to capture excess surface water—often during monsoons or peak flow periods—and channel it into the subsurface aquifers. Injection wells directly recharge deep aquifers, while check dams slow down river flow, allowing water to percolate into shallow groundwater reserves. By strategically locating these MAR structures in high recharge potential zones, we can mitigate groundwater depletion and sustain baseflow levels throughout the year.

- The objectives of the URMP Framework followed - 3. To rejuvenate waterbodies and wetlands in the city.

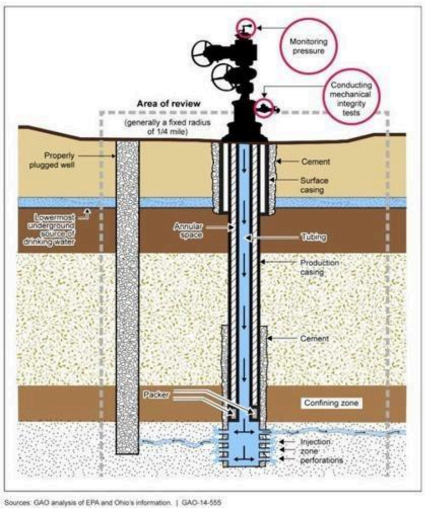


Figure 15 Functioning of a Injection well, Source: GAO analysis of EPA and Ohio Information

5. Adopt urban planning strategies that incorporate bioswales, permeable pavements, and green roofs.

Sustainable urban planning strategies like bioswales, permeable pavements, and green roofs help mimic natural hydrological processes by enhancing infiltration and reducing runoff.

These green infrastructure solutions mitigate flooding, improve water quality, and strengthen city resilience to climate extremes.(Bosch & Hewlett, 1982). Green roofs transform unused rooftops into vegetated areas that absorb rain, slow stormwater, and reduce runoff, with intensive systems retaining more water than extensive ones. They also mitigate floods, improve water quality, cool urban areas, and boost ecological resilience in cities.(Barnhart et al., 2021)

- The objectives of the URMP Framework followed - 6. To ensure maximum good quality return flow from the city into the river

Figure 16 Sponge Garden, Source: Author

Afforestation and urban greening boost infiltration, stabilize soil, and enhance evapotranspiration while adding shade and biodiversity. When combined with other green infrastructure, they strengthen urban resilience and support sustainable groundwater recharge.(Farley et al., 2005)

- The objectives of the URMP Framework followed - 3. To rejuvenate waterbodies and

wetlands in the city

6. Expand decentralized water quality monitoring through citizen science initiatives.

To ensure data-driven water management, it's crucial to expand decentralized water quality monitoring using citizen science initiatives. Local residents, trained with simple testing kits and mobile tools, can collect valuable data on parameters such as pH, turbidity, and contamination levels. This democratization of monitoring not only fills data gaps in underrepresented regions but also fosters a sense of ownership and awareness among communities, making water conservation a shared responsibility.

- The objectives of the URMP Framework followed - 5. To adopt increased reuse of treated wastewater and 9. To inculcate river-sensitive behavior among citizens

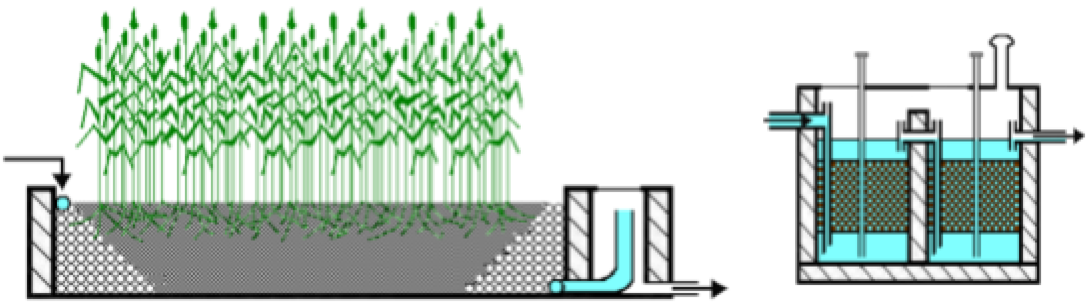


Figure 18 Horizontal planted gravel filter (HPGF) and Two-chamber anaerobic filter (AF)

Source: Praxis-oriented Training Manual, DHAN Foundation, Centre for urban water resources

Anaerobic Filters (AF) use media like gravel or plastic for bacteria to break down dissolved and non-settleable solids, requiring periodic cleaning to prevent clogging. Horizontal Planted Gravel Filters (HPGF), a low-maintenance subsurface wetland system, provide an effective and sustainable option for decentralized wastewater treatment when properly designed.(*Praxis-Oriented Training Manual*, n.d.)

7. Pollution control measures

Pollution control measures in the study area included promoting sodium hypochlorite-based low-cost filters to reduce bacterial contamination and improve disinfection. Activated charcoal submersible filters for rooftop rainwater harvesting were also installed with rainwater units, enhancing water quality and long-term sustainability.

- The objectives of the URMP Framework followed - 2. To keep the river free from pollution, 5. To adopt increased reuse of treated wastewater and 9. To inculcate river-sensitive behavior among citizens.

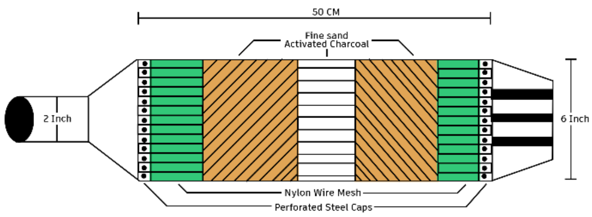


Figure 19 Schematic Diagram of Submersible Filter

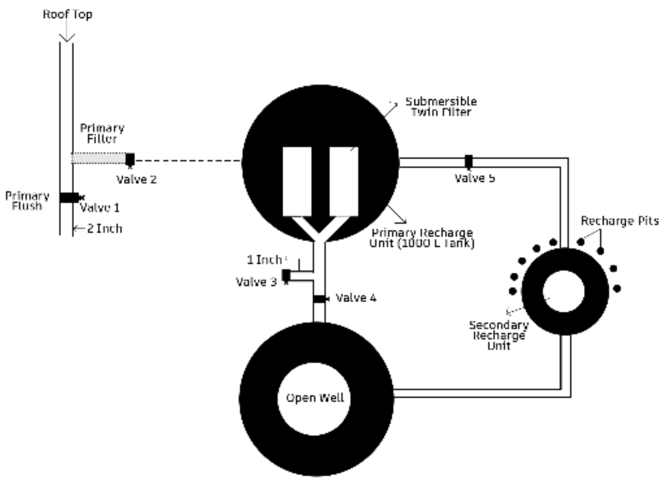


Figure 20 Open Well recharge unit with Submersible filters

Source: Vasudevan Pillai K, 2008, Studies On Water Management Strategies In elavancherry Grama Panchayat With A View To develop A Pollution Abatement Water conservation Model For Rural Development, Mahatma Gandhi University, Kottayam, Kerala

8. Communal Rainwater System

The water treatment facility uses sand filtration, UV sterilization, and chlorination to supply treated water to a 20 kL balance tank for household and community distribution, with a bore providing backup during shortages. CDM's 200 kL storage tanks are kept at least half full for fire safety, and the entire system is managed by a trained operator under the body corporate. (Cook et al., 2012)

- The objectives of the URMP Framework followed - 5. To adopt increased reuse of treated wastewater and 9. To inculcate river-sensitive behavior among citizens

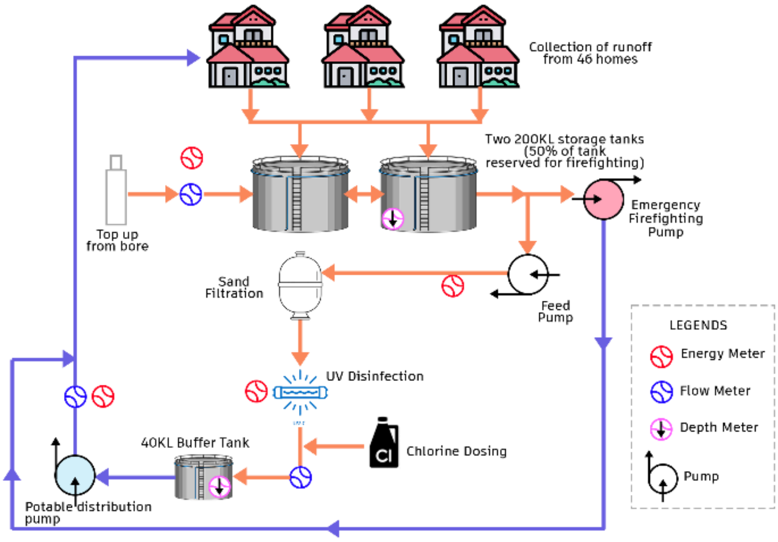


Figure 21 Flow chart showing portable water hydraulic circuit

Source: Cook, S., Sharma, A., Gurung, T. R., Chong, M. N., Umapathi, S., Gardner, T., Carlin, G., & Palmer, A. (2012). Performance of Cluster Scale Rainwater Harvesting Systems: Analysis of Residential and Commercial Development Case Studies

9. Paddy Fields as Water Banks

Paddy fields function as natural "water banks" by holding water for long periods, allowing gradual infiltration that replenishes aquifers. Their bunded design, soil traits, and irrigation practices enhance groundwater recharge, supporting both agriculture and long-term water availability.(Hama et al., 2020)

- The objectives of the URMP Framework followed - 3. To rejuvenate waterbodies and wetlands in the city and 6. To ensure maximum good quality return flow from the city into the river.

Figure SEQ Figure * ARABIC 22 Inclusion of Paddy fields

Source: Author

7. Strengthen inter-state coordination between Kerala and Tamil Nadu for unified watershed management.

Improved coordination between Kerala and Tamil Nadu is crucial for managing shared river basins like Bharathapuzha and Periyar. A joint, basin-wide approach with shared data, planning, and policies can prevent conflicts and promote sustainable water use across state borders.

- The objectives of the URMP Framework followed - 7. To develop ecofriendly riverfront projects 8. To leverage on the economic potential of the river 9. To inculcate river-sensitive behavior among citizens 10. To engage citizens in river management activities.

8. Include local communities in water governance through participatory planning and education campaigns.

Engaging local communities in water governance through participatory planning and education makes rejuvenation efforts more effective and context-driven. Initiatives like awareness campaigns and village water committees foster long-term stewardship and lasting behavioural change.

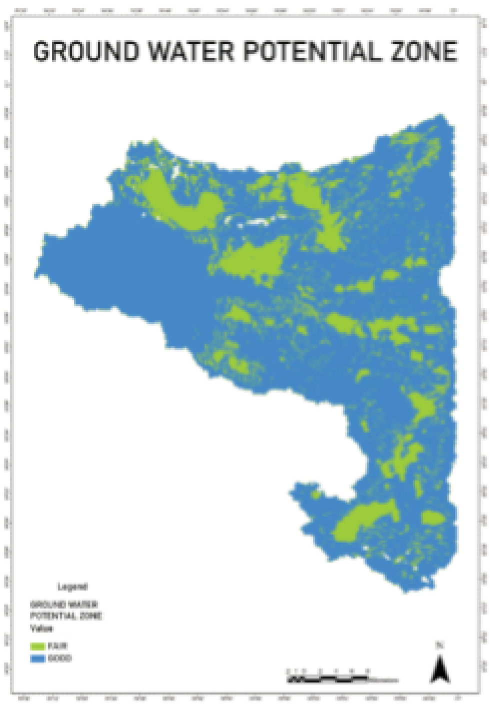
The objectives of the URMP Framework followed - 9. To inculcate river-sensitive behaviour among citizens 10. To engage citizens in river management activities.

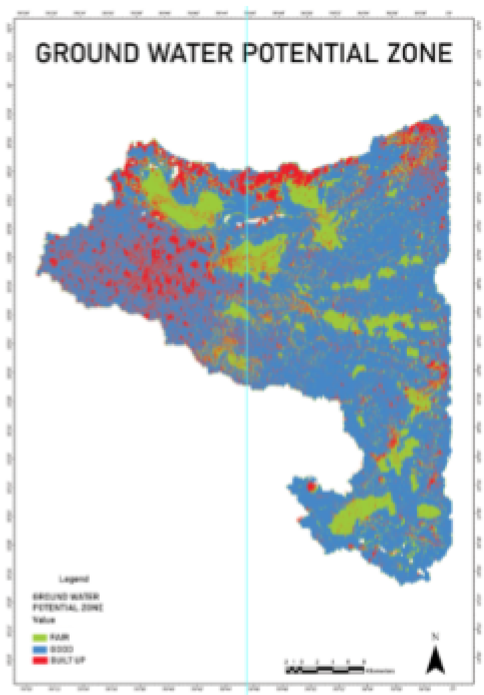
Conclusion

The analysis reveals a marked transformation in land use over the 30-year study period. Vegetation cover decreased by 18%, while built-up areas increased by 25%. This transition directly correlates with a drop in the BFI from 0.61 in 1993 to 0.39 in 2023, indicating a weakened baseflow regime.

Groundwater level data from the Mankara gauging station highlights a 3–5-meter decline in aquifer depth. GIS-based groundwater potential mapping showed critical recharge zones being encroached upon by urban development. Additionally, annual streamflow records showed increasing variability, especially during non-monsoon months, reflecting reduced aquifer contributions.

Despite the Kerala Conservation of Paddy Land and Wetland Act (2008), paddy fields and wetlands continue to decline due to weak enforcement, competing land uses, and limited community involvement. This loss, coupled with rapid urbanization, has degraded ecosystems and reduced baseflow in the Bharathapuzha sub-basin. The combined impacts of wetland decline, vegetation loss, and expanding built-up areas have created hydrological stress and weakened basin resilience. Addressing these issues requires stronger wetland policies, integrated land-water management, and the use of BFI and LULC metrics in planning for water security and ecological stability. (Government of Kerala. (2008). *Kerala Conservation of Paddy Land and Wetland Act, 2008 (Act No. 28 of 2008)*. Kerala: State Legislature.)





Water quality analysis indicated higher BOD and lower DO in high-built-up sub-watersheds. Community surveys confirmed perceived reductions in river flow during dry periods and rising dependency on borewells.

The study reaffirms that rapid land cover changes—particularly urban expansion and vegetation loss—have critically altered the baseflow regime of the Bharathapuzha River. The declining Base Flow Index (BFI) signals reduced groundwater contributions and increasing hydrological flashiness, endangering the river's ecological and cultural vitality. These findings underscore the need to integrate baseflow assessments into urban planning and water governance. A resilient future for urban rivers like Bharathapuzha lies in adopting nature-based solutions, enforcing recharge zone protections, and designing context-specific interventions.

Way Forward:

1. Policy Integration: Embed BFI and land cover metrics into watershed-level urban planning policies.

2. Nature-Based Solutions: Promote riparian restoration, afforestation, and wetland revival.
3. Infrastructure Interventions: Deploy managed aquifer recharge systems and urban green infrastructure like bioswales.

4. Community Engagement: Foster participatory governance, citizen science, and local water stewardship.

5. Inter-State Coordination: Facilitate integrated basin-scale collaboration between Kerala and Tamil Nadu.

These steps, if adopted through scalable policy instruments, can serve as a model for urban river restoration across India.

The results affirm the hypothesis that land cover changes—particularly deforestation and urbanization—have adversely affected baseflow in the Bharathapuzha River. A lower BFI not only signifies reduced groundwater contributions but also reveals a shift towards a more ephemeral, rain-fed system. Hydrological degradation poses threats to biodiversity, agricultural reliability, and cultural practices dependent on riverine stability. Declining groundwater recharge increases irrigation costs and vulnerability to drought, especially in agriculturally intensive areas like Palakkad.

In conclusion, without proactive intervention, Bharathapuzha may face further hydrological stress. Sustainable land and water management, backed by community participation and scientific modelling, is essential to restore its baseflow and ecological integrity

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