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Total word count: 5813

Number of tables: 5

Number of figures: 6

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Evaluating the Impacts of River Pollution on Ecosystem Services: A Case of Periyar River, Kerala

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***Abstract*— River ecosystems have, since the advent of human civilization, served as key areas for human settlements, production, and infrastructure. With ever-increasing intensification of land use coupled with other radical changes in recent years, there has been a shift in the functions and services available in riverine ecosystems. This underscores the need for understanding ecosystems at the level of the services they provide. Ecosystem services can primarily be defined as the 'various benefits humans derive from ecosystems in the form of goods and services.' Evaluation of ecosystem services has also been growing as a popular method to create an important argument towards improving their visibility in decision-making processes, apart from significantly validating the need for ecosystem conservation. The study aims to evaluate the impacts of one of these drivers of change – pollution – on the major ecosystem services provided by a river and analyze the temporal changes to understand the extent of pollution impacts. The chosen river of study, Periyar River flows through the districts of Ernakulam and Idukki in Kerala, providing various essential services to the towns on its banks as well as the rest of the state. In recent years, the river has been steadily undergoing eco-degradation, primarily owing to the industrial pollution from the units set up along its banks. The study has been carried out along four objectives: i) identifying the key parameters of pollution, ii) identifying and examining the key ecosystem services provided by the river, iii) mapping and analyzing the temporal changes in the ecosystem and its services as a result of pollution, and further iv) suggesting suitable strategies to address the associated problems. The key ecosystem services studied were provisioning services of fisheries production and water supply, and cultural services of recreational value. A rapid participatory appraisal method was undertaken to study local perceptions of river value and degradation as well. The land use land cover change was estimated using Landsat images of 1988 and 2023 and the changes in ecosystem service value were subsequently calculated, establishing the losses incurred by the ecosystem. Various policy interventions for averting the impacts of pollution have been explored by making use of global case studies and best practices. Levying pollution taxes on industries, incorporating real-time monitoring of pollution through newer technologies are some recommendations proposed out of the study.**

Keywords: *ecosystem services; valuation; Periyar river; drivers of change; river pollution*

INTRODUCTION

A. Contextual Background

River ecosystems have served as areas for settlements, production, and infrastructure over the years. With changing and increasing intensification of land use along with other radical changes like damming in recent years, there has been a shift of the functions and related services available in river ecosystems (Böck et al., 2018). Valuation and assessment of ecosystem services thus play a significant role in highlighting their importance- essential for proper decision-making related to these ecosystems. The Millenium Ecosystem Assessment (MA) developed under the United Nations has defined ecosystems as "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit, with humans forming an integral part of them" (MEA, 2005).

The numerous benefits derived by people from ecosystems have been identified as ecosystem services (ES). Under the MEA, these ecosystem services have been classified into provisioning services like food, freshwater, and fiber; regulating services like climate regulation and water purification; cultural services like aesthetic, educational and religious values; and supporting services which include soil formation and nutrient cycling (MEA, 2005). Aquatic ecosystems, including rivers, are crucial as they support the delivery of ecosystem services like fish provision, climate regulation, water provisioning and regulation. However, the rivers in India are in dire states, with 46 per cent of the country's 603 rivers classified as polluted, as per a 2022 report released by the Central Pollution Control Board (CPCB, 2022). These aggravations, coupled with other human interventions, have adversely affected the delivery of ecosystem services (Datry et al., 2018; Stewardson et al., 2017).

The chosen area for evaluation is the Periyar, the longest river flowing through the state of Kerala and is also often called the 'Lifeline of Kerala,' owing to the various benefits derived from the river. The river provides drinking water to several major towns in the state, including Kochi and is also important from an economic perspective- generating a considerable proportion of Kerala's hydroelectric power apart from supporting various industries along its banks, fisheries and providing water for irrigation and other domestic purposes. The river runs a length of 244 km in Kerala and flows through the districts of Idukki and Ernakulam before joining the Arabian Sea. Over the years, the river has experienced a gradual degradation of its ecosystem, primarily attributed to anthropogenic factors such as encroachments, widespread deforestation, and notably, industrial pollution (Eleyadath & Madhu, 2014; The Hindu, 2023). There have been multiple reports of discoloration of the river water, dying fishes over the years especially in this industry concentrated region (AP, 2023; TOI, 2015).


Edayar industrial unit responsible for discoloration in Periyar River, finds Kerala State Pollution Control Board

September 15, 2023 05:35 pm | Updated 05:35 pm IST - KOCHI

Warming water and pollution amplify fish mortality in Kerala during summer

by Reema Abraham on 15 May 2023

25 years on, forum against Periyar pollution continues its relentless fight

November 17, 2023 09:03 pm | Updated 09:03 pm IST - KOCHI

Figure 1- Newspaper Articles talking about the issue of pollution plaguing the Periyar

The evaluation of ecosystem services helps create an important argument towards improving their visibility and the improvement of the consideration of ecosystem services in political and economic decision-making processes (Böck et al., 2018), apart from significantly validating the need for ecosystem conservation. Changes in the ecosystem and subsequently, in ecosystem services and human well-being are effected by various factors, acting both directly and indirectly. Comprehending these factors becomes essential for devising interventions that amplify positive effects while mitigating negative ones (MEA, 2005b).

B. Research Framework

The research paper aims to assess the impacts of pollution of the Periyar river and related drivers of change on the river ecosystem and its ecosystem services. For achieving the aim of the study, the following objectives have been identified and will be undertaken:

1) To identify the key parameters of pollution associated with the river under consideration.
2) To identify and examine the key ecosystem services provided by the river.
3) To map and analyze the temporal changes in the ecosystem and its services as a result of pollution.
4) To suggest suitable interventions to address the problems associated with river pollution.

The methodology undertaken for the study is derived from various frameworks involving the classification and assessment of ecosystem services and economic valuation methods. As per the Millenium Ecosystem Assessment, 'Inland Water' form a category of ecosystem which is defined as 'permanent water bodies inland from the coastal zone and can include rivers, lakes, floodplains, reservoirs and wetlands' (MEA, 2005). A background study was conducted prior to identification of aims, objectives and other parameters within the research framework. Further, the macro study area was delineated as the Periyar river basin to facilitate a holistic understanding of the issues in the region.

Further, the ecosystem services derived from the river are identified from a combination of primary and secondary sources. A rapid participatory appraisal method has also been undertaken for the purpose of understanding the local perceptions of ecosystem service value and level of degradation in the river basin. The Rapid Ecosystem Services Participatory Appraisal (RESPA) is a method proposed by Rey-Valette et al. (2017) that can be used to identify and prioritize ecosystem services of actual local value and use. Subsequently, the spatio-temporal changes in the river ecosystem are studied in terms of the land use land cover change observed in the basin in a 25-year time period (Sharma et al., 2020). Costanza's (1997) global value coefficients of ecosystem biomes as well as ecosystem services are made use of for evaluating the changes to the ecosystem services due to land use change from an economic perspective. The losses incurred to the ecosystem due to drivers of change like pollution will thus be established from a monetary perspective. Moving forward, the obtained results will be used to justify the need for better monitoring of effluent dumping and other issues. Strategies have further been formulated for the judicious utilization of ecosystem services as well as their conservation, with policy interventions and community-based approaches.

LITERATURE REVIEW

A major assessment of the human impact on the environment undertaken in recent years is the Millenium Ecosystem Assessment (MA) undertaken by the United Nations. The framework has defined ecosystems as,
"a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit, with humans forming an integral part of them" (MEA, 2005b).

The rationale to define ecosystem services came about from the increased exploitation of ecosystems, their functions and essentially their "services" and further necessitating a study of the complex trade-offs involved in the use of these ecosystem services (Daily, 1997). Daily (1997) defines ecosystem services as “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life.” The MEA further builds on these definitions and classifies ecosystem services into four categories along functional lines.

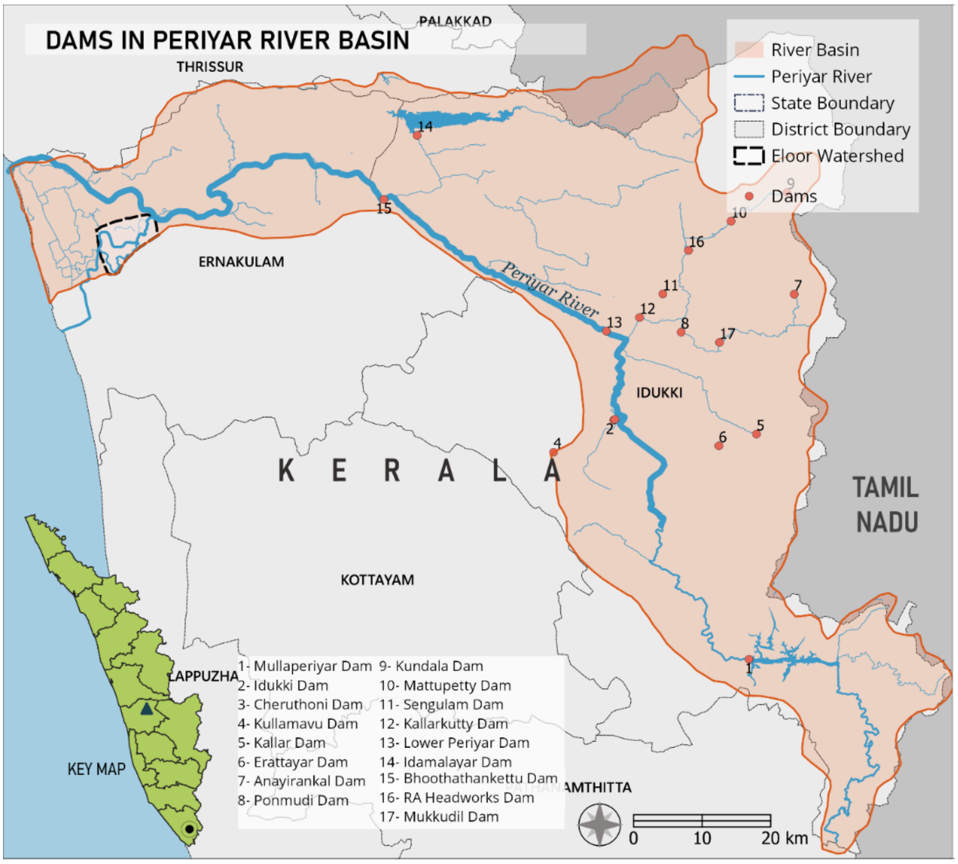
Mostly exacerbated by anthropogenic activities, recent years have seen global biodiversity and ecosystems being affected by various drivers of change. The Millenium Ecosystem Assessment (2005) defines a driver of change as ‘any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.’ They have been further classified as direct and indirect drivers and among the drivers of change affecting biodiversity and ecosystems, the direct drivers primarily include land-use change, climate change, overexploitation, invasive alien species and pollution. On the other hand, the indirect drivers are broadly categorized as demographic, sociopolitical, economic, scientific and technological, and cultural and religious.

Ecosystem services assessments are primarily done with the aim of informing environmental management and sustainable planning by making use of multiple appropriate indicators (economic, ecological, socio-cultural) (MEA, 2005a; TEEB, 2010). Research on the economic evaluation of ecosystem services gained more attention after the publication of Robert Costanza’s study in 1997, after which there has been a steady growth in the articles and methods introduced for the monetary valuation of ecosystem services. The MAES (Mapping and Assessment of Ecosystems and their Services) framework notes that an ecosystem assessment should include both an analysis of the state of biodiversity and ecosystems and an evaluation of the level of provision of ecosystem services to people (MAES, 2013). The framework outlines four steps within the assessment of ecosystem: baseline mapping and assessment of (i) ecosystem, (ii) defined ecosystem services, (iii) assessment of ecosystem services with scenarios of future changes and (iv) valuation of ecosystem services for baseline and contrasting scenarios.

ABOUT THE STUDY AREA

A. Area Profile

The longest river flowing through the state of Kerala, the Periyar River is also often called as the ‘Lifeline of Kerala’, providing drinking water to several major towns in the state, including Kochi and is also important from an economic perspective- generating a considerable proportion of Kerala’s hydroelectric power apart from supporting various industries along its banks, fisheries and providing water for irrigation and other domestic purposes. The river originates from the Sivagiri Hills (part of the Western Ghats) in the district of Idukki and runs a length of 244 kilometers through the districts of Idukki and Ernakulam in Kerala. Moreover, the river has been instrumental in enhancing Kerala's economic outlook. Apart from helping in power generation, the river has also been crucial in domestic water supply to the towns along its banks, supporting tourism, fisheries, industrial production, as well as being a deposit of various inorganic resources. There are 58 pumping stations on the river that supply around 290 million liters of water per day to the surrounding region (Kerala Irrigation Department, n.d.). The river basin covers major towns and cities including Kalamassery, Aluva, Kattappana, as well as the industrial towns of Eloor and Edayar and part of the Kochi Municipal Corporation. There are a total of 7 municipalities and 94 Grama panchayats in the basin, that is essentially seventy-five percent of the region is rural.



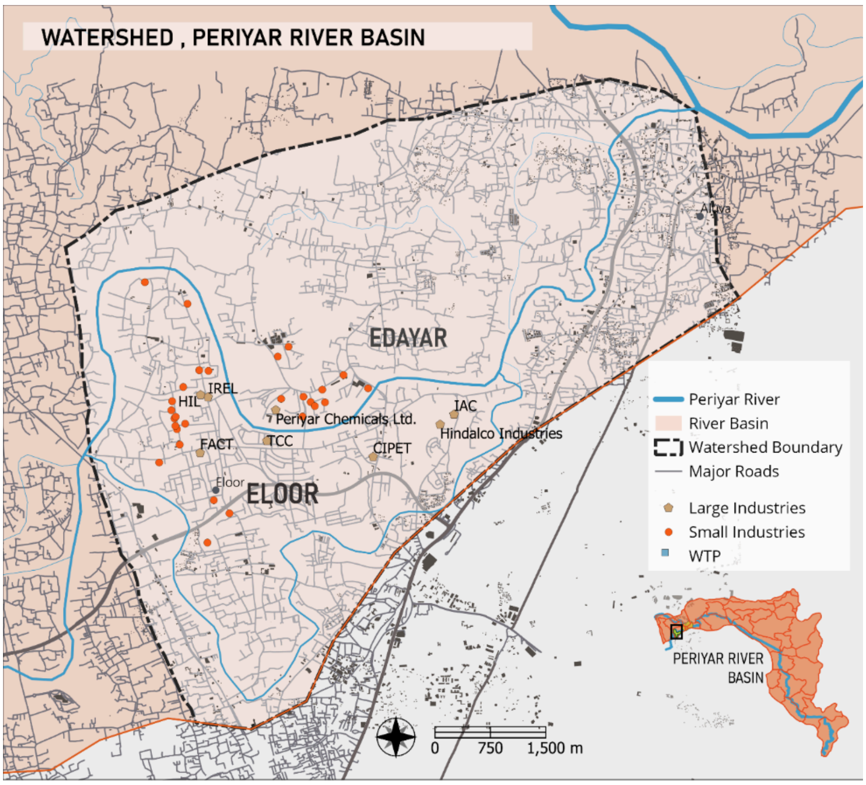
For the purpose of the study, the river basin was looked at in terms of the higher, middle, and the lower reaches of the river and the various sub-basins present in each. A comparative study can significantly show how the lower reaches have been more susceptible to river pollution and the subsequent degradation and impacts. Anthropogenic activities and industrialization have been among the primary factors contributing to the river's degradation.

Table I River Stretch Comparison
(Source: Joseph, M.L..; Kerala Irrigation Department, n.d.; compiled by the author)

River Stretch	**Prominent Land Uses**	**Key Ecosystem Services Derived**	**Pollution Vulnerability Level**
Idukki Stretch (Higher Reaches)	Evergreen Forest, Agricultural Plantations, Grassland, Settlements with treecrop	Water for consumptive & non-consumptive use, aquatic organisms, flood & erosion control; recreational, spiritual & aesthetic values, role in nutrient cycling, water purification	BOD (mg/L) Range: 0.7- 5.4 Coliform (Cfu/100 ml) Range: 1400- 15000
Perumbavoor Stretch (Middle Reaches)	Natural Forest, Evergreen Forest, Agricultural plantations	Water for consumptive & non-consumptive use, flood & erosion control; aesthetic values, role in nutrient cycling, water purification, habitat maintenance	BOD (mg/L) Range: 3- 6.1 Coliform (Cfu/100 ml) Range: 1- 14
Ernakulam Stretch (Lower Reaches)	Agricultural Plantations, Settlement with treecrop, Built-up	Water for consumptive & non-consumptive use, flood & erosion control; aesthetic & spiritual values, role in nutrient cycling, water purification	BOD (mg/L) Range: 0.3- 44.5 Coliform (Cfu/100 ml) Range: 350- 800000
Eloor Stretch (Lower Reaches)	Settlement with treecrop, Built-up, Cropland	Water for consumptive & non-consumptive use, flood & erosion control; aesthetic & spiritual values, role in nutrient cycling, water purification, waste treatment	BOD (mg/L) Range: 0.9- 640 Coliform (Cfu/100 ml) Range: 900- 21000

B. Data Collection Process

The micro-study area consists of 2 municipalities and parts of 3 Gramapanchayats including Eloor and Aluva Municipalities, with the boundaries as shown in Figure. The average number of households in the region was identified through a combination of Census 2011 and primary survey. This was undertaken for the rapid participatory appraisal method. The respondents included residents, industry owners and workers, fisherfolk, as well as other river users. The effectiveness of the appraisal method largely hinges on the diversity of respondents involved (Rey-Valette et al., 2017). It is assumed that a diverse range of respondents can provide a more comprehensive understanding of the full spectrum of critical services relevant to the geographical area under study. Simultaneously, office visits were also conducted for both obtaining secondary datasets and for



getting expert opinions on the issues surrounding the river ecosystem. A discussion was held with the Eloor Municipal Commissioner on details including the current status of the river pollution as well as schemes being undertaken by the municipality to improve the conditions or compensate the affected population.

DATA ANALYSIS

The major brunt of the river pollution is borne by the lower reaches of the Periyar river, especially in the Eloor and Edayar regions. This region also has the maximum concentration of industries, housing nearly twenty-five percent of Kerala's industries. The industries include chemical industries producing petrochemical products, rare-earth elements, pesticides, fertilizers, zinc or chrome products, rubber processing chemicals, as well as leather products. Many of these industries are over 50 years old, hence often the technologies employed have the most potential to cause pollution. Only five industries have the Government permission to discharge treated effluent into the river, but it should be noted that most of these industries take in freshwater from the river in huge amounts and subsequently, release concentrated effluents back into Periyar with nominal treatment (Eleyadath & Madhu, 2014).

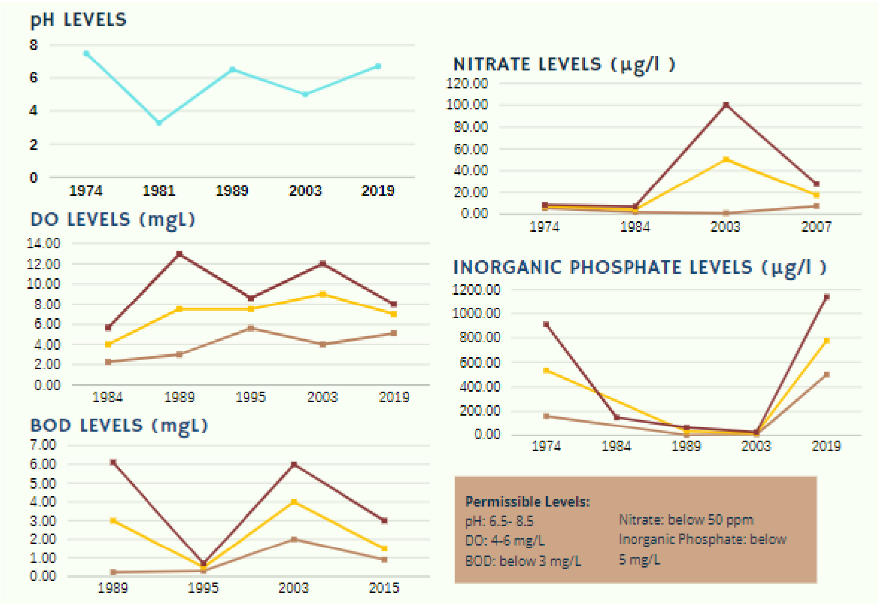


Figure 4- Pollutant Levels in the Eloor Region through the Years
(Source: Joseph et.al., 1984)

Furthermore, the deleterious consequences of industrial pollution extend beyond physical and chemical alterations to the Periyar River ecosystem, profoundly impacting its biodiversity and fish populations. Alarmingly, nearly 16 fish species have been reported to have disappeared from the region, indicative of the severe ecological disturbances wrought by pollution. Various literature and reports on the river basin, the pollution in the river were studied; along with deriving inferences from consultations with stakeholders like environmentalists and activists, local residents, fisherfolk. The set of services to be evaluated were thus scoped down, in terms of their vulnerability to pollution and the constraints involved in assessment and valuation of these services. A rapid participatory appraisal method was also undertaken for the purpose of understanding the local perceptions of ecosystem service value and level of degradation in the river basin.

Due to the complexity of the ecosystem and the scope of the study, it has been necessary to focus on a select number of key ecosystem services, potentially overlooking other important aspects. From the four categories of ecosystem services under MEA, supporting services were thus eliminated from the assessment owing to the close interlinkages between supporting and the other three categories of services which creates a potential for double counting. The provisioning of clean water for drinking and agriculture is severely impacted, leading to shortages and heightened reliance on alternative sources. Moreover, the cultural and recreational values associated with the Periyar River, including its aesthetic appeal and spiritual significance, are diminished as pollution diminishes its natural beauty and sanctity.

The Rapid Ecosystem Services Participatory Appraisal (RESPA), as proposed by Rey-Valette et al. (2017), is a method designed to actively engage local communities, direct ecosystem users, and relevant stakeholders in the identification and prioritization of ecosystem services that hold significant value and utility within a given area. To begin the study, researchers compile a comprehensive reference list of ecosystem services provided by the selected area. Local inhabitants, direct users of the ecosystem (such as fishermen or farmers), and other stakeholders are asked to review the reference list and select a limited subset of ecosystem services (typically 5-10) that they perceive as most important and valuable for the area. This step allows for the identification of key ecosystem services that resonate with the local community and are essential for their well-being and livelihoods.

The spatio-temporal changes in the river ecosystem are studied in terms of the land use land cover change observed in the basin in a 25-year time period. Costanza's (1997) global value coefficients of ecosystem biomes as well as ecosystem services are made use of for evaluating the changes to the ecosystem services due to land use change from an economic perspective. An integrated assessment framework is also formulated to link the drivers of change, the pressures on the ecosystem, ecosystem status, and the impact on ecosystem services provisioned by the ecosystem. The linkages were identified based on the aforementioned review of relevant literature as well as from stakeholder consultations.

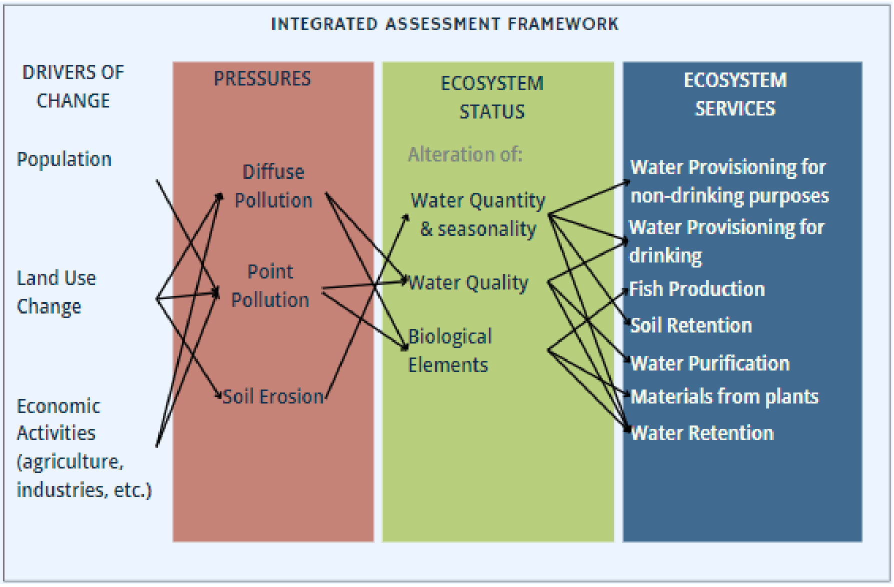


Figure 5- Integrated Assessment Framework of ES in the Basin

The Costanza method of economic valuation has been adopted for evaluating the ecosystem services provided by the Periyar basin. For this method, the coefficient values of the biomes were calculated using meta-regression by screening around 350 publications. More than 1350 data points from 300 different case study locations were collected and stored in the Ecosystem Services Value Database (ESVD) and around 665 of these data points were used to calculate the value of ecosystem services derived from the different biomes (Costanza et al., 2014). The land use land cover (LULC) maps were prepared for the Periyar basin for the years 1998 and 2023. The satellite images used are obtained from Landsat-5 (1998) and Landsat-9 (2023) and a maximum likelihood supervised classification was done in ArcGIS on the respective bands. The different LULC classes have been aggregated into the following land use types: Built-up, Waterbody, Barren, Forest, and Agriculture/ Plantation.

The valuation coefficients (VC) given in Costanza's study are limited to the 10 biomes as mentioned in Table, hence the equivalent proxy biomes are identified for each of the LULC classes of the study area and are mentioned in the table below, along with their respective value coefficients.

Table II LULC classes, their corresponding biomes and value coefficients [Source: Costanza et.al., 1997]

LULC classes	Equivalent Biome	Value Coefficient (US$ ha^{-1} $year^{-1}$)
Agriculture/ Plantation	Grasslands	232
Forest	Forest	969
Barren	Grasslands	232
Waterbody	Rivers/lakes/ponds	8498
Built-up	Urban	0

Table III VCs for ecosystem functions of different LULC classes. (Source: Costanza et.al., 1997)

Categories	Ecosystem Services/ Functions	WB	BU	AG	BR	FO
Provisioning	Food production	41	0	67	67	43
	Raw material	-	0	-	-	138
Regulating	Gas regulation	-	0	7	7	-

Supporting	Climate regulation	-	0	-	-	141
	Disturbance regulation	-	0	-	-	2
	Water regulation	5445	0	3	3	2
	Water supply	2117	0	-	-	3
	Waste treatment	665	0	87	87	87
	Soil formation	-	0	1	1	10
	Nutrient cycling	-	0	-	-	361
	Erosion control	-	0	29	29	96
	Pollination	-	0	25	25	-
	Biological control	-	0	23	23	2
	Genetic resources	-	0	-	-	16
Cultural	Recreation	230	0	2	2	68
	Cultural	-	0	-	-	2
Total		**8498**	**0**	**232**	**232**	**969**

WB- Waterbody; BU- Built-up; AG- Agriculture; BR- Barren; FO- Forest

The following figures depict the LULC maps of the years 1998 and 2023. The ESVs were then estimated using Costanza's value coefficients taken of the equivalent proxy biomes from the LULC classes categorized in the river basin. The estimated ESV for each LULC type within the basin and the ecosystem service values for specific services within the waterbody biome of the river basin are mentioned in the tables below.

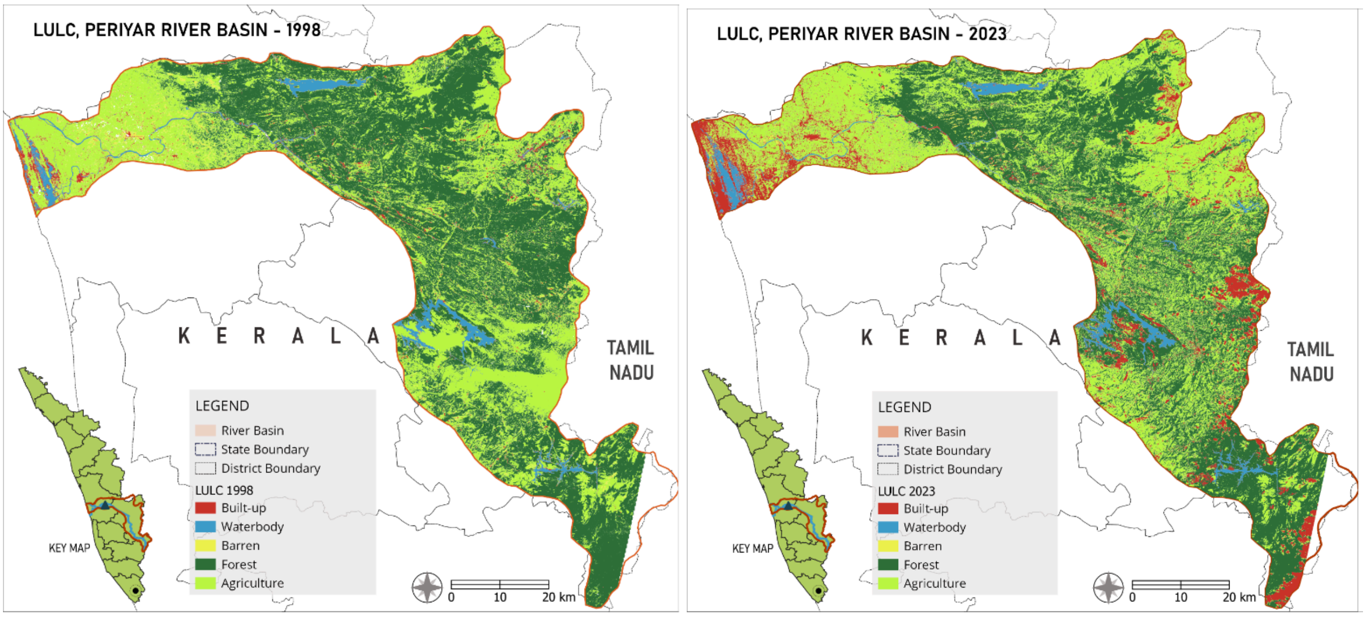


Figure 6- LULC Maps of River Basin in years 1998, and 2023

Table IV Estimated ESV of each LULC type and change observed (1988-2023) [Source: Author]

LULC Class	Change in area (Ha) (1988-2023)	VC (US$/ha/ year) of proxy biomes	Estimated ESV (US$ million /ha/yr)		Change in ESV (US$ million /ha/yr)
			1988	**2023**	
Agriculture	+42823.61	232	44.19	54.13	+9.94
Barren	-2659.21	232	2.15	1.53	-0.62
Built-up	+44979.01	0	0	0	0
Forest	-27927.77	969	133.50	106.44	-27.06
Waterbody	-2382.02	8498	31.74	11.50	-20.24

Total	-	-	202.45	173.60	-37.99

Table V Estimated ESV service-wise for the waterbody biome and changes in ESV (1988-2023) [Source: Author]

Category	Ecosystem Service	VC (US$/ha/ year) of Waterbody LULC	Estimated ESV (US$ million /ha/yr.)		Change IN ESV (US$ million /ha/yr.)
			1988	2023	
Provisioning	Food (fisheries) production	41	0.15	0.06	-0.10
Regulating	Water regulation	5445	20.34	7.37	-12.97
	Water supply	2117	7.91	2.87	-5.04
	Waste treatment	665	2.48	0.90	-1.58
Cultural	Recreational/ aesthetic values	230	0.86	0.31	-0.55
Total	**-**	**-**	**31.74**	**11.50**	**-20.24**

The estimates of the ecosystem service values (ESV) derived from the tables signify the losses incurred to the ecosystem as a result of land use land cover change. The overall ESV change in the river basin signify a negative change of -37.79 million USD per hectare per year. The ecosystem services/ functions valued include fisheries production, water regulation, water supply, waste treatment, and recreational/ aesthetic values. In the 25-year period, a negative change in the ecosystem functions of the basin has thus been registered as well, a reduction of USD 20.24 million per hectare per year. This sums up to a decrease percentage of 63.7 per cent in the 25-year period. The calculated loss serves as a poignant reminder of the intricate relationship between human activities and ecosystem health. Incorporating these findings into decision-making processes is crucial for informing strategies that prioritize the conservation and restoration of ecosystem services.

RECOMMENDATIONS

A. Proper Sewage Management

To address the pressing issue of pollution in the river, it is imperative to implement effective legislation aimed at eliminating the discharge of sewage into its waters. This legislation should be comprehensive and enforceable, with stringent penalties for non-compliance to deter violators. Additionally, there is a need to prioritize the adoption of newer technologies designed to reduce the levels of physicochemical parameters in the river to permissible levels in a cost-effective manner. These technologies may include advanced wastewater treatment systems, innovative pollution control measures, and sustainable practices in industrial and urban sectors. By combining regulatory measures with technological innovations, it is possible to mitigate the impacts of pollution on the river ecosystem and safeguard public health and environmental integrity for present and future generations.

B. Improving Industrial Practices

Industrial practices can be improved through a two-pronged approach: improving the management of industrial effluents and providing industries with incentives to improve their practices and activities. A database should be created containing information regarding industrial and waste generation, having real-time monitoring. It should be made transparent and publicly available to facilitate better community monitoring, in a region which is already proactive in its approach towards fighting for the river. Training programs should be conducted to improves business practices as well.

The industrial area also urgently requires a Common Effluent Treatment Plant (CETP) to serve the small-scale industries in the region. To incorporate the treatment of effluents within their manufacturing processes is economically not feasible in most cases of small-scale industries. Hence, a CETP is an ideal solution for the same; a 2 MLD CETP had been proposed in the Edayar industrial area in 2021 but it is yet to come out of the design stage. Neutralized wastes from various industries can be collected through pipes and transported to the CETP and the subsequent operational and maintenance expenses can be borne by the industries in proportion to the pollution load sent.

Further, industries can be incentivized to adopt cleaner production methods, eco-friendly technologies to minimize waste generation and pollution, as well as recycling initiatives. Payment for Ecosystem Services (PES) is a scheme that can be utilized to incentivize industries to improve discharge quality and prioritize the river ecosystem.

Payment for Ecosystem Services (PES) is a concept and mechanism through which individuals or entities who benefit from ecosystem services compensate those who provide or maintain them. It aims to incentivize conservation and sustainable management practices by assigning a financial value to ecosystem services such as clean water provision, carbon sequestration, and biodiversity conservation. PES schemes can involve direct payments, subsidies, or other forms of compensation to landowners or communities in exchange for implementing practices that enhance or protect ecosystem services. This approach helps internalize the value of nature's benefits into economic decision-making and promotes the long-term sustainability of ecosystems.

C. Pollution Taxation

In the Netherlands, businesses and households are subject to a pollution tax levied based on the volume of pollutants directly discharged into rivers (Vollebergh & Dijk, n.d.). This taxation system is designed to discourage harmful practices and incentivize pollution reduction efforts. The tax rate varies depending on the quantity of pollution emitted, with higher fees imposed for larger discharges. This approach not only generates revenue for environmental conservation efforts but also serves as a regulatory tool to hold polluters accountable for their actions.

Meanwhile, in China, a 'Pay for Permit' policy mandates that firms acquire a permit from local authorities for each unit of anticipated emissions. Companies are required to purchase these permits, which effectively serve as a form of pollution quota, from the government (Biggs et al., n.d.). Additionally, stringent penalties are imposed on violators who exceed their permitted emission levels. This policy framework aims to regulate industrial emissions, limit environmental degradation, and encourage businesses to adopt cleaner production methods. Both the Netherlands' pollution tax and China's 'Pay for Permit' policy demonstrate innovative approaches to environmental governance.

Similar schemes should be adopted in the Periyar basin, which make it mandatory for industries to monetarily compensate the amount of pollution discharged into the river. These methods can go a long way in discouraging industries from directly dumping into the river and in encouraging them to adopt better effluent treatment methods.

D. Community-based Approaches

Community-based approaches offer a promising avenue for revitalizing the river and empowering local stakeholders to take ownership of its management. By establishing a database, as discussed earlier, community members can access crucial information about the river's health and pollution levels. This database serves as a valuable tool for facilitating community engagement and participation in monitoring and managing the river. Empowering locals with the knowledge and resources needed to monitor water quality and pollution enables them to play an active role in identifying problems and implementing solutions. Community members can conduct regular monitoring activities, report pollution incidents, and collaborate with authorities to address environmental concerns effectively.

Furthermore, community-based approaches foster a sense of stewardship and collective responsibility for the river among local residents. By working together to protect and restore the river ecosystem, communities can promote environmental sustainability and enhance the quality of life for everyone who depends on the river for water, livelihoods, and recreation.

Incorporating community-based approaches into river revitalization efforts not only strengthens local capacity for environmental management but also fosters a sense of ownership and connection to the river among residents. By harnessing the collective efforts of communities, we can achieve meaningful and lasting improvements in the health and resilience of the river ecosystem.

E. A Single Management Body for the River/ Basin

The river basin currently does not have a consolidated river management authority, which is absolutely essential for the streamlined management and revitalization of the river. However, it should also be noted that under the National River Conservation Plan, a river basin authority was proposed for the Periyar river in 2024, which is a move in the positive direction for the improvement of the river basin.

WAY FORWARD

Moving forward, it is essential to translate the insights gained from this study into concrete actions that address the pressing challenges facing river ecosystems, especially those vulnerable to factors like pollution. This entails implementing a comprehensive approach that combines regulatory measures, technological innovations, community engagement, and adaptive management strategies. Strengthening legislation to regulate pollution sources and enforce environmental standards is a significant strategy, along with promoting the adoption of cost-effective technologies for pollution reduction. Furthermore, engaging stakeholders through participatory processes and encouraging monitoring and evaluation efforts are needed. By taking decisive and collaborative action, it can be possible to move towards revitalizing river ecosystems, safeguarding their health, and promoting the well-being of both people and nature.

ACKNOWLEDGEMENT

The completion of this work would not have been possible without the support and guidance of many individuals. Foremost I'd like to thank the Almighty for making me who I am today. I am very grateful to my guides Dr. Natraj Kranthi for his help and Nikita Madan ma'am (NIUA) for her invaluable insights. Immense appreciation to the people and officials at Eloor and other locales who assisted me in my study. Lastly, lots of love and gratitude to my parents, family and friends for their encouragement.

FUNDING STATEMENT

This statement is to note that the thesis was completed with the support of the National Institute of Urban Affairs (NIUA) and the National Mission of Clean Ganga (NMCG) as part of the 'Sponsored Student Thesis Competition (STC)- Season 4' on 'Re-imagining Urban Rivers' (2023-24).

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