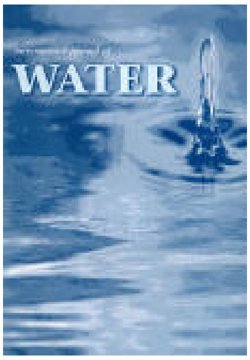

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A study on the assessment of pollution and strategies for rejuvenation of Bharathapuzha river in Kerala, India

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A study on the assessment of pollution and strategies for rejuvenation of Bharathapuzha river in Kerala, India

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Abstract: Human civilisation has historically thrived along riverbanks; however, anthropogenic interventions in rivers, especially in developing nations like India, have negatively impacted its environment, economy and society. This calls for studies on assessing river pollution and formulating strategies to conserve and rejuvenate the polluted rivers. The present study focuses on assessing the state of pollution in the Bharathapuzha river, the second longest river in Kerala, India. It is inferred from the study that the disposal of domestic sewage and untreated wastewater are major factors for river pollution. In the light of these findings, the authors propose: i) sustainable measures to control the domestic pollution existing in the vicinity of the river; and ii) establishing sewage treatment plants to abate the river pollution. The current study also highlights the significance of stakeholder involvement in river conservation and delineates various social strategies oriented towards river rejuvenation.

Keywords: Bharathapuzha river; water quality; pollution assessment; physico-chemico-biological water characteristics; domestic pollution; rejuvenation strategies; sewage treatment plant; stakeholder engagement; asset pentagon lens; sustainable management.

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Kerala, situated near Bharathapuzha river. Her study investigates the potential role of railway stations and passengers in the pollution of Bharathapuzha.

1 Introduction

The human civilisation originated, developed, and flourished along river banks. However, various anthropogenic interventions have led to the deterioration of the rivers, especially in developing and underdeveloped nations. Ariffin and Sulaiman (2015) revealed a critical decline in Malaysia's rivers, primarily due to sewage pollution, citing insufficient legal enforcement, outdated wastewater treatments, and low public awareness as key contributors. In Dhaka, one of the world's most polluted cities, Yin et al. (2021) reported rivers with dark, foul waters, burdened by untreated sewage and industrial waste. They suggested enhancing sewer systems, planning industrial locations strategically, and establishing robust management for river restoration. Similarly, Awoke et al. (2016) observed a marked degradation in the water quality of four Ethiopian river basins, recommending policy revisions and increased stakeholder engagement and awareness to address the pollution. Groundwater and surface water studies in Samail, Oman, by Shaik et al. (2021), found bacterial contamination and high hardness levels in most samples. This scenario mirrors the situation in India, Sharma et al. (2022) examined pollution levels in the Ganges, Beas, and Sutlej rivers between 2012 and 2016. Their study identified the Ganges as the most polluted among these, primarily due to the discharge of household and industrial waste. This degradation of rivers has significantly impacted India's environmental, social, economic, and cultural development, a common plight faced by many countries in similar circumstances (Goel, 2006; Sinha et al., 2013).

Over the past few years, extensive studies have been carried out to evaluate the level of pollution in major rivers of India, and based on the insights from these studies appropriate strategies for river restoration and river basin management, such as the Ganga Action Plan, Yamuna Action Plan, Krishna River Conservation Plan have been initiated by the government of India (Gopal and Sah, 1993; Boon and Raven, 2012; Gupta et al., 2020; Simon and Joshi, 2022). Moreover, India's commitment towards achieving Goal 6, 'Clean Water and Sanitation' one among the seventeen sustainable development goals framed by the United Nations in 2015, has led to a multifaceted approach in addressing the issues associated with river pollution across the country. Recently, the National Green Tribunal of India has ordered for rejuvenation of critically polluted rivers in Kerala, a southern state of India. The Bharathapuzha river, the second longest river in the state is reported to be highly polluted due to the disposal of untreated sewage and solid waste, discharge of industrial and agricultural effluents, sand mining, deforestation and human encroachments on account of urbanisation (Priya and Lakshmi, 2020). Studies on the Bharathapuzha river basin pertaining to the morphological characteristics (Magesh et al., 2013), changes in land use and land cover pattern (John et al., 2019; Raj and Azeez, 2010), existence of potential groundwater zones (Ali et al., 2015), variation in rainfall patterns and climatic variables (George and Athira, 2020; Raj and Azeez, 2012) and drought and flood hazard assessment (Sasidevan and Santha, 2018; Jacob et al., 2020) are available in the literature. However, determination and upkeep of water quality is crucial as both banks of this river are densely populated, and people depend mainly on it to meet their domestic, agricultural, and industrial needs. It is observed from the existing literature that only limited studies are available on the spatio-temporal variation in the physico-chemico-biological characteristics of the Bharathapuzha river (Kannan and Joseph, 2022; Raj and Azeez, 2009).

The design and implementation of appropriate strategies to conserve the river and mitigate the pollution can only be executed when the factors and sources polluting the river are clearly identified (Jyothi et al., 2021). Moreover, the absence of adequate data that depicts the existing condition of Bharathapuzha river pose a challenge to the river conservation activities. Under these circumstances, the authors believe that a scientific study on identification of the different sources of pollution along the course of Bharathapuzha river and quantifying the variation in the physico-bio-chemical characteristics of the river water would be insightful in recommending strategies for river rejuvenation. River rejuvenation studies are largely focussed on proposing engineering/ technical practices and often the emphasis on social aspects that is crucial for effective implementation of river restoration programs is neglected. In the present study attempts are made to recommend the engineering and social strategies, the two sides of the same coin oriented towards restoring the pristine nature of Bharthapuzha river.

2 Study area

The Bharathapuzha river, is an interstate river, which originates in Tamil Nadu and flows through Kerala into the Arabian sea. It is the second longest river in the state of Kerala. The river is the lifeline of the state as it supplies water for domestic, agricultural and industrial uses to a significant area. Salient features of the Bharathapuzha river are presented in Table 1.

A preliminary survey was initially carried out along the study area that stretched from Mayyannur in the upstream side to V K Kadavu in the downstream side of the Bharathapuzha river. Subsequently, a total of six sampling points (refer Table 2) was identified, keeping in mind the accessibility, high population density and proximity to sources of pollution that existed on either side of the study area. The study area and sampling locations are depicted in Figure 1. It is observed during the preliminary survey that there existed certain point sources of pollution (namely, railway station, hospitals, institutions, marketplaces etc.) which discharged some quantities of effluents generated at these sources into the nearby storm water drains which eventually drained into the river. With this in view, samples from two drains (designated as drain 1 and drain 2) located on either side of Shornur railway station, which is considered to be a major point source of pollution along the Bharathapuzha river were also selected. The drains collect wastewater discharged from railway platforms and toilets and flows into the river. The drain 2 flows through an agricultural field on its way to join the river (refer Figure 2).

Table 1 Salient details of Bharathapuzha river

Latitude	11°12'25''N to 10°26'24''N
Longitude	75°54'32''E to 77°12'32''E
Basin area, km^2	6186
Basin area in Kerala state, km^2	4400
Basin area in Tamil Nadu state, km^2	1786
Origin of river	Annamalai Hills (Elevation 1964 m above mean sea level)
Length of main stream, km	209
Navigational length of river, km	40
Main tributaries	Gayathripuzha, Chitturpuzha, Kalpathipuzha, Thuthapuzha[a]
Average annual rainfall in the river basin, mm	2300
Average annual stream flow, Mm^3	5082.9
Average water requirement for wetland for three crops, Mm^3/ year	4458
Average water requirement for garden land, Mm^3/ year	226
Average water requirement for domestic use, Mm^3/ year	338
Average water requirement for industrial use, Mm^3/ year	450

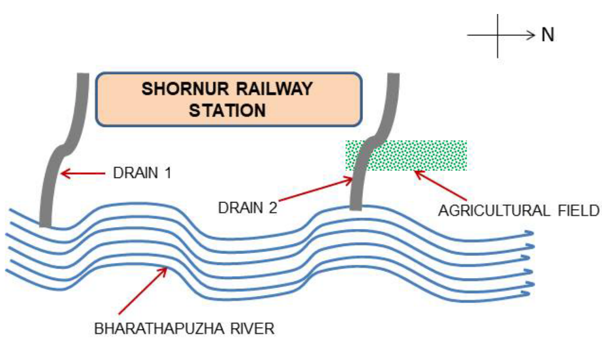
[a]Puzha in the local vernacular, Malayalam, means river.

Table 2 Details of sampling points along the Bharathapuzha river

S. no.	*Location*	*Municipality/ Panchayath corresponding to sampling location*	*Sampling Location ID*	*Distance from Mayannur* (km)	*Latitude*	*Longitude*
1	Mayyannur	Ottappalam	S1	–	10.76949	76.3832
2	Mananoor		S2	14	10.74794	76.32207
3	Shornur Railway Station	Shornur	S3	28	10.75636	76.27824
4	Kizhayoor Nambram		S4	44	10.7838	76.18669
5	Pattambi Bridge	Pattambi	S5	48	10.8004	76.17882
6	V.K Kadavu	Thrithala	S6	56	10.8006	76.16773

Figure 1 Location map depicting the sampling points along the course of the Bharathapuzha river (see online version for colours)

Figure 2 Pictorial representation of the two storm water drains located on either sides of Shornur railway station (see online version for colours)



3 Methodology and materials

The methodology adopted in the present study is summarised in the following steps:

i A pollution inventory was prepared, based on participatory data gathered on sources of pollution along the Bharathapuzha river.

ii A total of 56 (7 samples from 8 sampling locations) water samples were collected and tested to determine its physical and bio-chemical characteristics.

iii Qualitative and quantitative assessment of the pollution level of the river was based on the guidelines formulated by Central Pollution Control Board (CPCB) of India. (Designated Best Use Water Quality Criteria, 2019)

iv Appropriate strategies required for the abatement of the pollution in the river, incorporating the engineering and social aspects are proposed.

A door-to-door survey in 690 homes, 5 hospitals, and 428 other organisations located on either side of Bharathapuzha river was carried out to identify the potential point and non-point sources of pollution. The information collected in this process was utilised to develop a pollution inventory and is summarised in Table 3. The water sampling was carried for nineteen weeks during December 2020 to April 2021 and the samples from each designated sampling point were collected in duplicates in pre-washed, dried and sterilised sampling bottles of 2000 ml and 300 ml capacity. The bottles were transported to the laboratory and, the tests to determine the chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved oxygen (DO) content and bacteriological count were carried out immediately. The water samples were preserved by keeping in refrigerator maintained at 4^{o}C until other physico-chemical analysis was performed. The samples were tested for various parameters, namely pH, total dissolved solids (TDS), turbidity, total hardness (TH), total alkalinity (TA), concentration of iron, nitrate, fluoride, chloride and sulphate. The equipment and methods used to determine the water quality parameters are

i pH and TDS using a water quality analyser (Systronics 361)

ii turbidity using a turbidimeter (Systronics 135)

iii volumetric analysis for total alkalinity and total hardness

iv DO using Wrinkler's method

v COD by dichromate method

vi BOD by dilution method

vii concentration of iron, nitrate, fluoride, chloride and sulphate using colorimetric analysis in a Spectrophotometer (Systronics UV-Vis 117).

The tests were performed as per the standard procedures mentioned by Walter (1961). The total coliform bacteria in the water samples were determined as per the procedure outlined in IS 1622:1981 and the result were reported as most probable number (MPN) per 100 ml of water sample. Also, based on the values of these water quality parameters and the CPCB criteria for the designated best use of water the class of river water was identified. In the light of the social survey conducted among the local populace, and interactions held with social reformers and local governance, appropriate strategies to abate the river pollution are proposed under two verticals, namely the engineering and social components. It is observed from the existing literature that no studies carried out on Bharathapuzha river have focused on the social aspects of river rejuvenation and under these circumstances the authors believe that a holistic techno-social approach could find a more acceptable answer to ameliorate problems and threats faced by the river and its stakeholders.

4 Results and discussions

As mentioned previously, identification of sources of pollution along the river course is inevitable to propose suitable solutions to abate the pollution. In this context, the activities/processes and communities residing/established in and around the vicinity of the study area that is likely to cause pollution of the river water was analysed (refer Table 3). It can be summarised from Table 3 that the sources of pollution can be bifurcated as direct and indirect sources, the former refers to such places from where contaminant(s) flow into the river and the latter refers to the activities that eventually contribute to the deterioration of river water quality. The direct sources of pollution are largely non-point sources, comprising of urban centres, industrial and agricultural zones. Aggressive sand mining carried out in the past decades, deforestation in the upper portions of the river basin and clearing of riparian forest covers on account of rapid urbanisation and industrialisation, and construction of temporary structures across the river course for various irrigation projects and domestic water supply schemes have indirectly deteriorated the river quality in the long run.

Table 3 Pollution inventory for Mayyannur to V K Kadavu stretch along Bharathapuzha river

Direct source of pollution	*Type of source*	*Causes for pollution*
Houses located within 700 m from the river banks	Non-point source	• Disposal of grey water directly into river through open drains • Discharge of black water and silt from improperly built soak pits and septic tanks • Unscientific disposal of municipal solid waste
Municipalities adjacent to the river	Non-point source	• Absence of facilities for scientific and efficient disposal and management of solid and liquid waste released from establishments/institutions located within the municipal limits
Industries located on the upstream side of the river stretch, under the study	Non-point source	• Disposal of partially treated effluents • Surface runoff mixed with oil, grease and other chemicals released from industrial units
Agricultural land adjacent to the river	Non-point source	• Pesticides and fertilisers leaching out of agricultural fields interacts with the surface runoff which drains into the river
Shornur railway station	Point source	• Untreated sewage released from the toilets in the railway platforms • Use of soap water for cleaning the railway coaches

Table 3 Pollution inventory for Mayyannur to V K Kadavu stretch along Bharathapuzha river (continued)

Indirect source of pollution	*Type of source*	*Causes for pollution*
Sand mining	n.a.	• Aggressive rate of removal of sand from river bed • In and out movement of mining vehicles
Construction of temporary structures across the river	n.a.	• Construction activity of temporarily installed bunds or dikes
Changes in land use pattern and adherence to mono-cropping	n.a.	• Reduction in vegetative cover has expedited drying of river • Lead to water stress

*n.a.: not applicable.

The impact of various sources of pollution on the physico-chemico-biological characteristics of the river water was studied by analysing 14 water quality parameters of water samples collected from the six sampling points along the study area. The spatial variation in the physical characteristics (viz., pH, TDS, turbidity), chemical characteristics (viz., TH, TA, DO, BOD, COD) and concentration of different chemical components (chloride, fluoride, nitrate, sulphate and iron) present in the river water is represented in Figures 3–5, respectively.

It can be seen from Figures 3(a) and (b), 4(a) and (b), 5(a)–(d) that the values of pH, TDS, total hardness, total alkalinity, concentration of chloride, fluoride, nitrate and sulphate respectively, of the river water meet desirable limits for drinking water as per guidelines imposed by World Health Organization (2011) and Indian Standards 10500:2012 along the entire stretch of study area. Hence, with respect to the afore-mentioned parameters the river water is suitable to serve as a source of potable water. It is noted from Figure 5(e) that although the concentration of iron at certain instances along the river stretch are above the permissible limits prescribed by WHO (2011) and IS 10500:2012. Nevertheless, the mean value is below the permissible drinking water standard limits. Furthermore, on comparing with the studies conducted by researchers Raj and Azeez (2009), its concentration has increased in the last few years. The researchers reported that the concentration of iron in most of the sampling locations along the river is zero since iron in the flowing water was easily oxidised and settled down. Currently, the presence of iron in the river water (mean value in the range of 0.13–0.17 mg/L) demonstrates a decrease in the self-purification capacity of the river. It is observed from Figure 3(c) that the average values of turbidity have been found to be slightly beyond the desirable limit prescribed by Indian Standards for drinking water applications. Moreover, the average value of turbidity increases as the river flows downstream. A similar trend can be found for values of BOD and COD in Figure 4(d) and (e), respectively. The parameters BOD and COD are very pertinent in assessing the level of pollution in a river and these values increase as the river flows from upstream to downstream. This is contradictory to the fact that as the river flows down, the level of organic contamination in the rivers should have decreased owing to the self-purification capacity of the river. However, the river in this stretch flows through three major municipalities, namely Ottappalam, Shornur and Pattambi where both the banks of the river are densely populated and there exists a significant inflow of domestic sewage into the river. This inflow must have led to the increase in values of BOD and COD. Also, a sudden spike in the value of BOD (7.1 mg/L) and COD (38 mg/L) is reported at a specific instance (week 9 of sampling) at sampling point S6 which is the located in the downstream of the river. It is understood from interacting with the local populace during the social survey that there are instances when considerable quantities of septic tank sewage are illegally dumped in the river. Hence, the authors believe that the sudden spike in the value of BOD could be due to the disposal of septic waste into the river a few days prior to the sampling date. The values of DO were maintained above 4 mg/L, which is the minimum required limit for sustaining aquatic life (Figure 4(c)). However, a decrease in its average value is seen from S1 to S6, corroborating the presence of higher levels of organic contamination in the downstream side of the river. Furthermore, the total coliform bacteria in the water samples

Figure 3 The spatial variation in the physical characteristics of Bharathapuzha river water samples (see online version for colours)

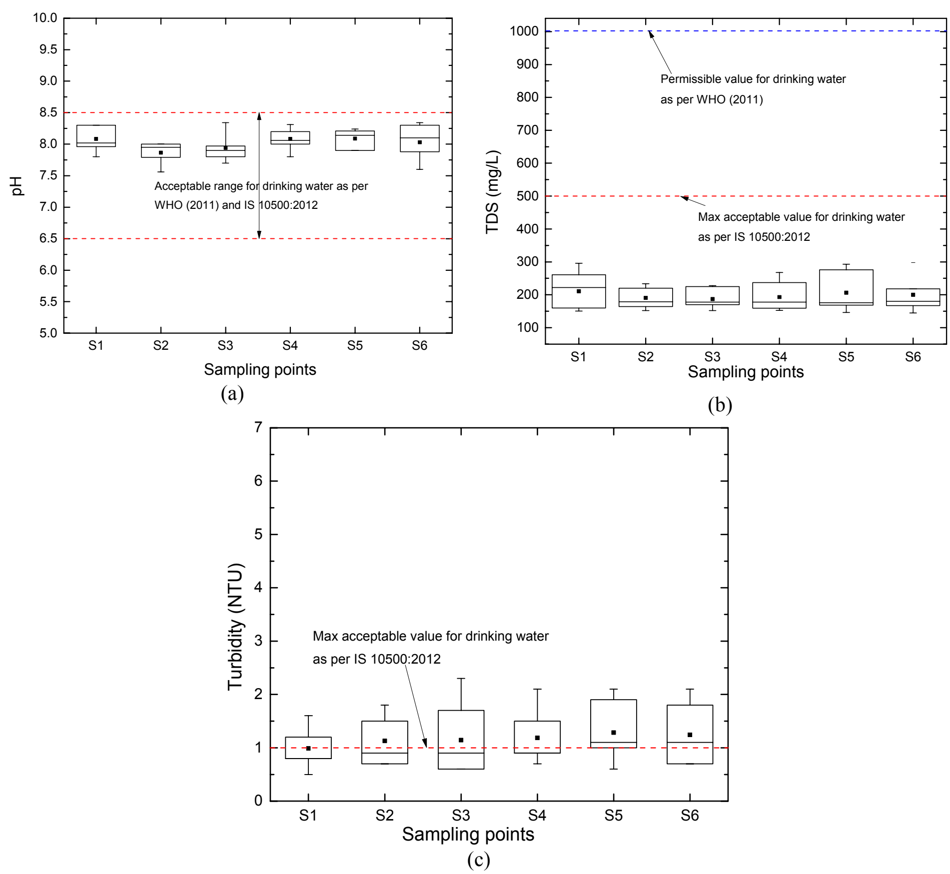


Figure 4 The spatial variation in the chemical characteristics of Bharathapuzha river water samples (see online version for colours)

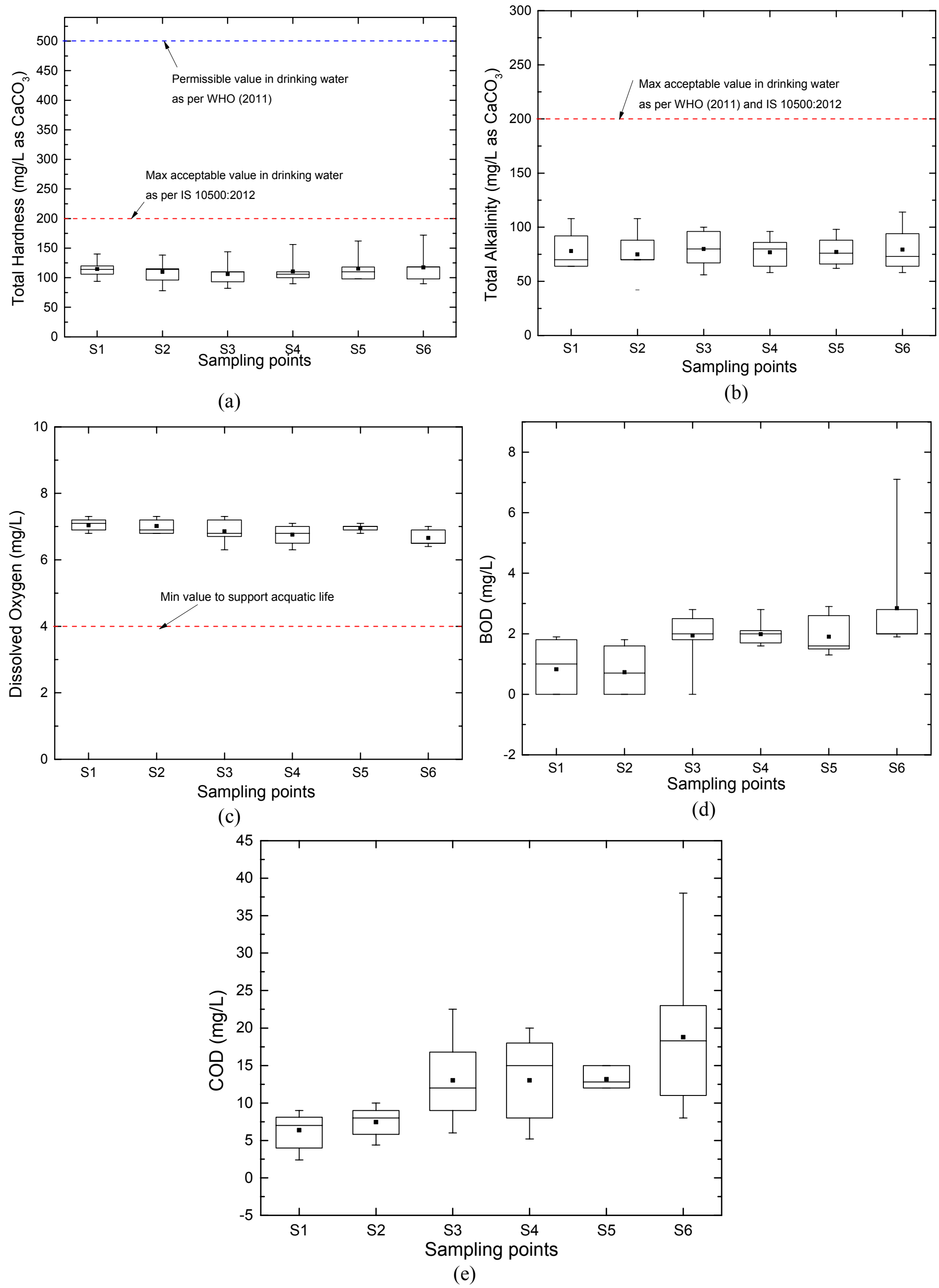
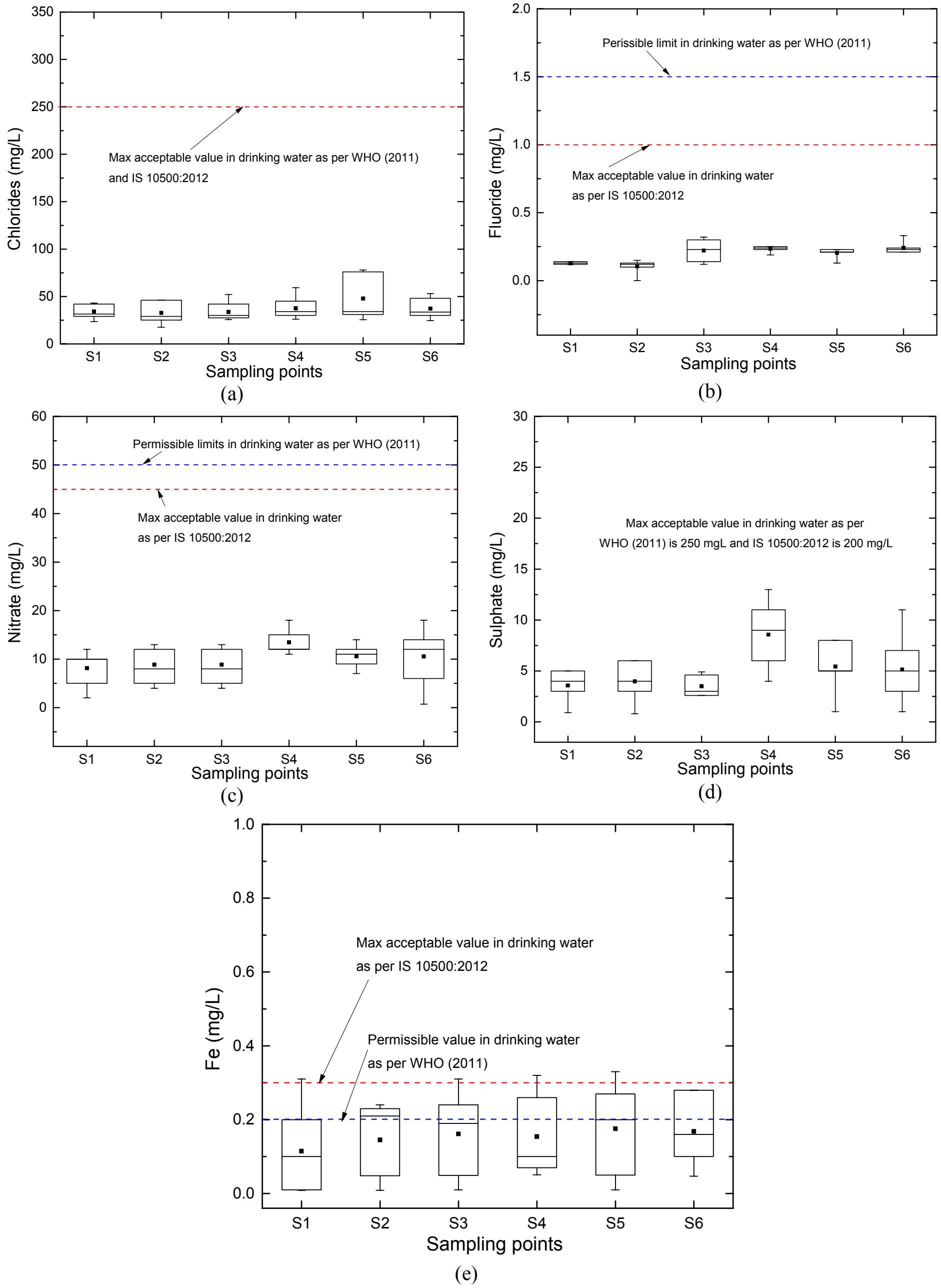


Figure 5 The spatial variation in the concentration of chemical species present in Bharathapuzha river water samples (see online version for colours)



In addition to spatial variation, the temporal variation in the physical characteristics (viz., pH, TDS, turbidity), chemical characteristics (viz., TH, TA, DO, BOD, COD) and concentration of different chemical species (chloride, fluoride, nitrate, sulphate and iron) present in the river water was also studied and is represented in Figures 6–8, respectively.

It is observed that the variations in the values of the physico-chemical properties of the river water did not exhibit a specific trend with respect to time. The variation in the values of pH, TDS, TH, TA and, concentration of chlorides, fluorides, nitrate and sulphate as represented in Figures 6(a) and (b), 7(a) and (b), 8(a)–(d), respectively, all throughout the duration of study was within the desired limits for drinking water as specified in WHO (2011) and IS 10500:2012. The values of turbidity at all six sampling locations corresponding to weeks 4, 14 and 19 exceeded the permissible limits as per IS 10500:2012 (Figure 6(c)). It can be inferred from Figure 8(e) that the concentration of iron except for sampling locations S1, S3, S4 and S5 during the week 19 was within the permissible limits as mentioned by Indian Standards. However, as per WHO (2011) the concentration of iron escalated the permissible limits at all the sampling locations corresponding to week 19 and at certain locations corresponding to week 1, 4 and 9. This could be due to certain variations in the inter flow and baseflow the river. It is seen that the value of DO exhibit a linear variation with respect to time (Figure 7(c)). The values of BOD and COD varied randomly with respect to time as shown in Figure 7(d) and (e), respectively. This could be due to some unanticipated anthropogenic interventions similar to disposal of sewage from septic tanks mentioned earlier, and variations in the characteristics of the river inflow and outflow. Nevertheless, the points corresponding to high values of BOD also have high values of COD.

Figure 6 The temporal variation in the physical characteristics of Bharathapuzha river water samples (see online version for colours)

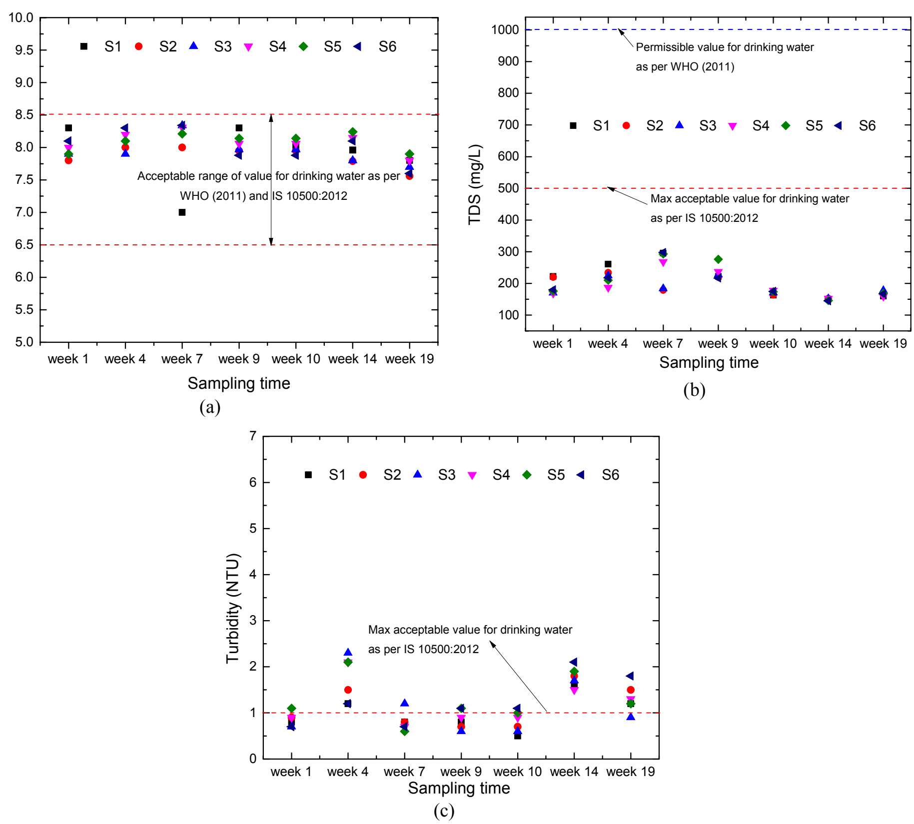
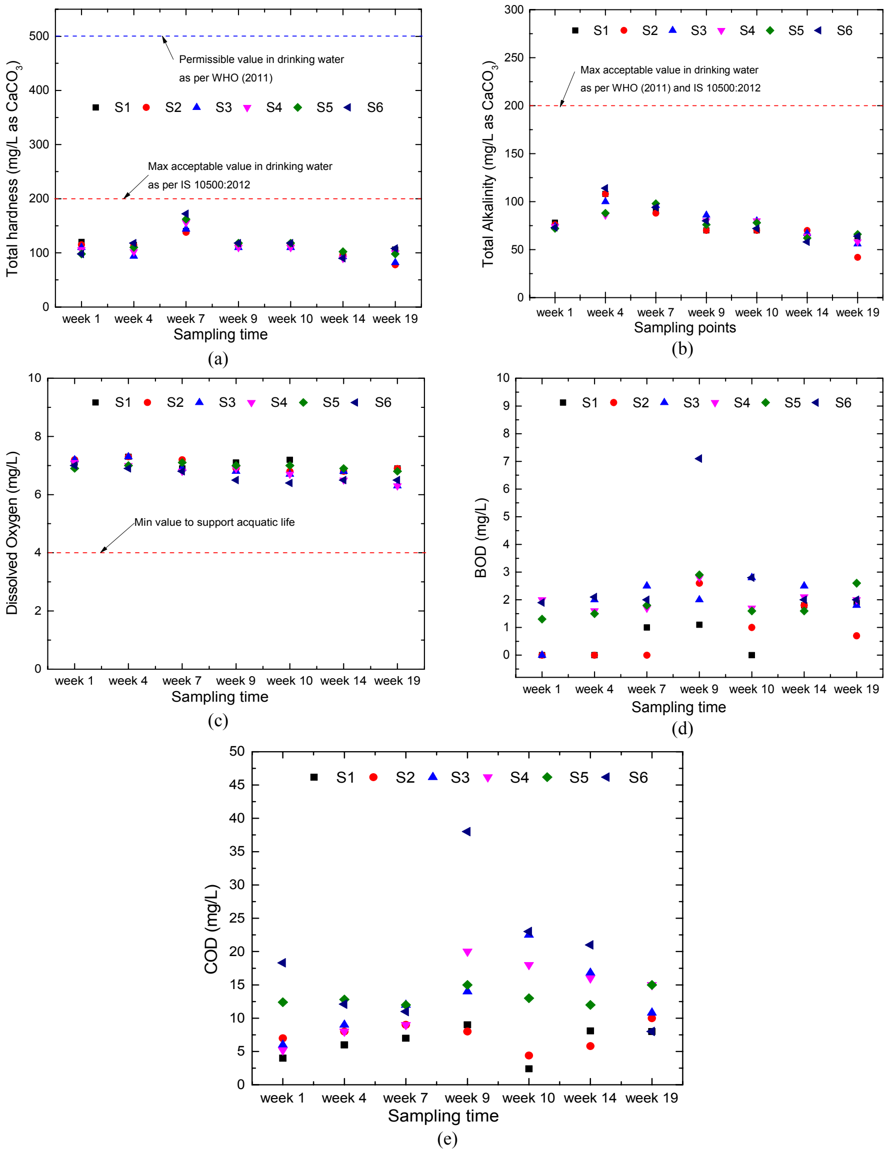


Figure 7 The temporal variation in the chemical characteristics of Bharathapuzha river water samples (see online version for colours)



According to the report submitted to National Green Tribunal by Pollution Control Board (2021), the Shornur railway station uses 22.35 lakh litres of water and discharges around 10 lakh litres of wastewater directly into the river daily as currently there is no facility to treat the wastewater. It is reported that the average value of BOD and COD of the sewage generated from the railway station is 250 mg/L and 400 mg/L, respectively. In the present study, the physico-chemical characteristics of the water flowing in the municipal storm water drains that carries a portion of the wastewater discharged from the Shornur railway station is determined. The obtained values were then compared with the properties of the river water sampled very close to the railway station (sample ID S3) and are graphically depicted in Figures 9–11.

Figure 8 The temporal variation in the concentration of chemical species present in Bharathapuzha river water samples (see online version for colours)

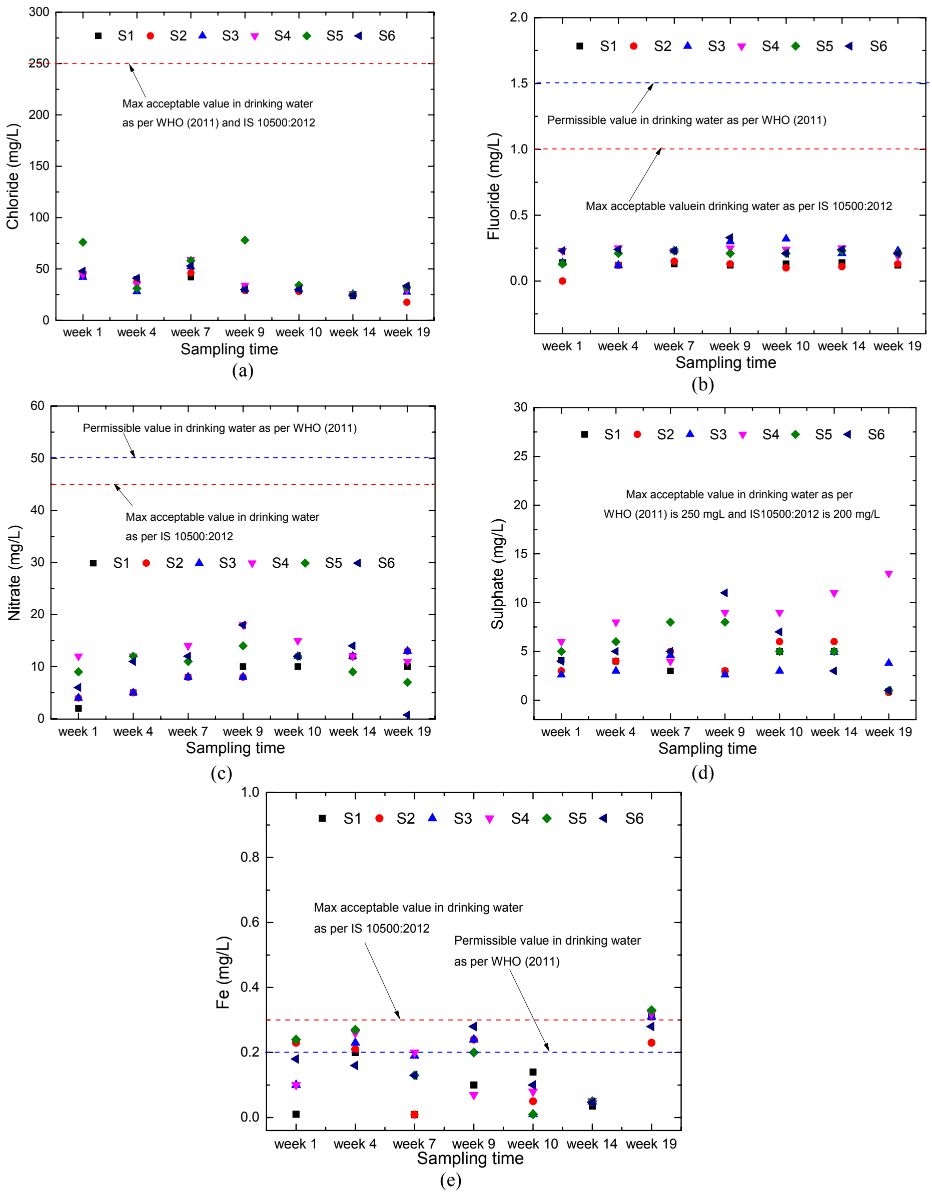
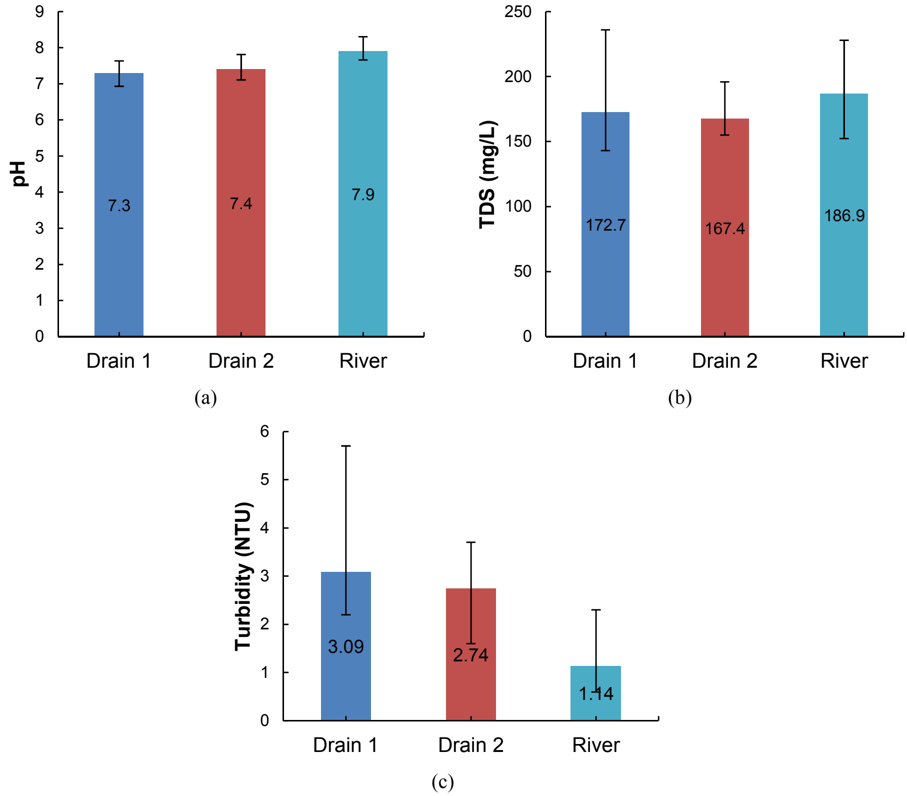


Figure 9 The spatial variation in the physical characteristics of water samples collected from drains adjacent to Shornur railway station (see online version for colours)



From Figure 9(a) it is seen that the average value of pH is slightly higher for river water than the water in drains, this could be because the pH of grey water entering the drains can be as low as 5 (Rakesh et al., 2020). Also, the intensified bacterial actions in the drains on account of an increase in organic matter produce carbon dioxide and thereby lower the pH value of the drain water. The TDS is less and turbidity is more for drain water compared to river water as shown in Figure 9(b) and (c), respectively. Since the TDS of water in drains is less, the total hardness recorded (Figure 10(a)) for drain water is also less compared to river water. However, the values of alkalinity reported for river water was less than drain 1 and more than drain 2 (Figure 10(b)). The variation in the values of DO, BOD and COD as represented in Figure 10(c)–(e), respectively confirms the presence of organic contamination in the effluent released from Shornur railway station to the drains. The higher values of chlorides, fluorides, nitrates, sulphates and iron in drain water as seen in Figure 11(a)–(e), respectively, substantiates the presence of inorganic contaminants at higher levels in drain water compared to river water. This demonstrates the fact that the effluent discharged from Shornur railway station contributes to the pollution of the drain water which eventually gets diluted upon joining the river. Also, it is seen from the graphs that the values of COD, BOD, concentration of sulphate, nitrate and fluoride is more and DO is less for the wastewater in drain 2 compared to drain 1. This implies that the wastewater in drain 2 is comparatively more polluted than drain 1. This could be attributed to the fact that drain 2 flows through an agricultural field before draining into the river, the fertilisers and agro-supplements that are rich in nitrates, sulphates and fluoride content, applied in the field may have entered the water in drain 2.

Figure 10 The spatial variation in the chemical characteristics of water samples collected from drains adjacent to Shornur railway station (see online version for colours)

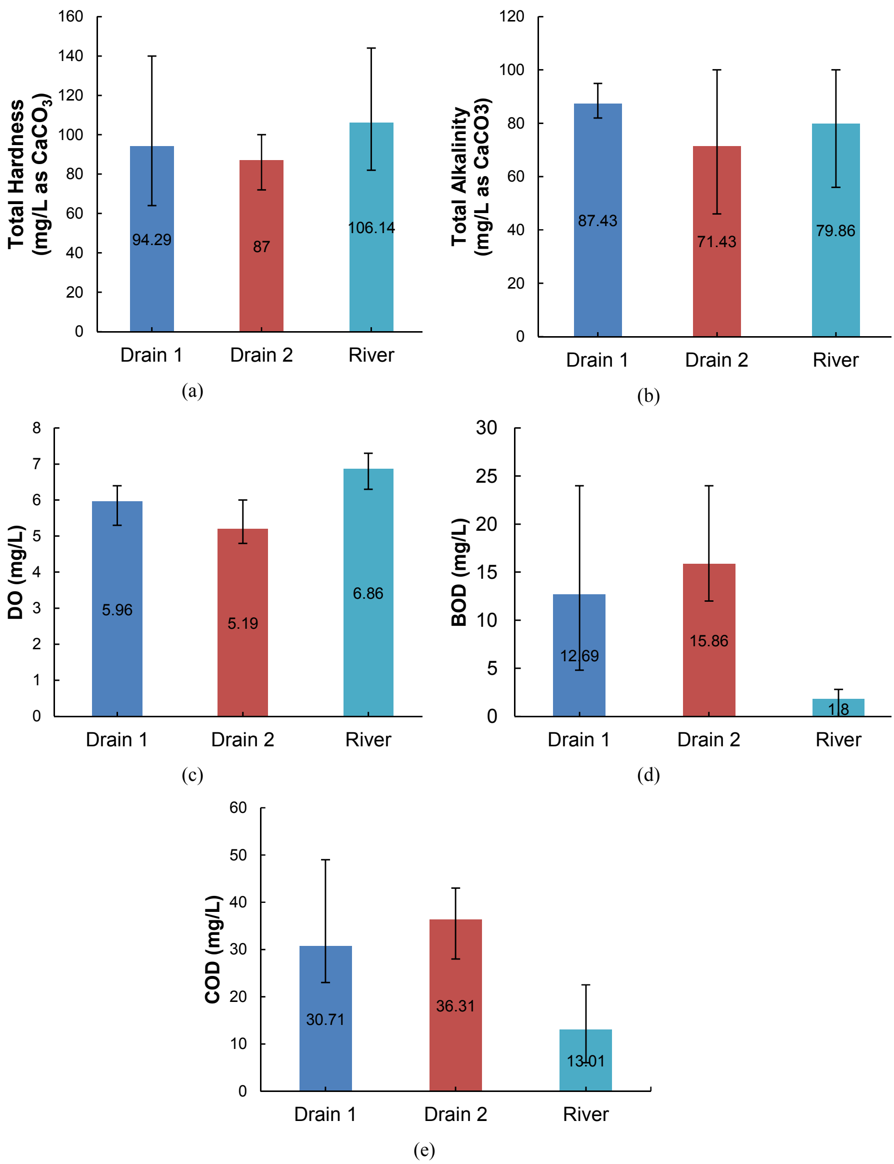
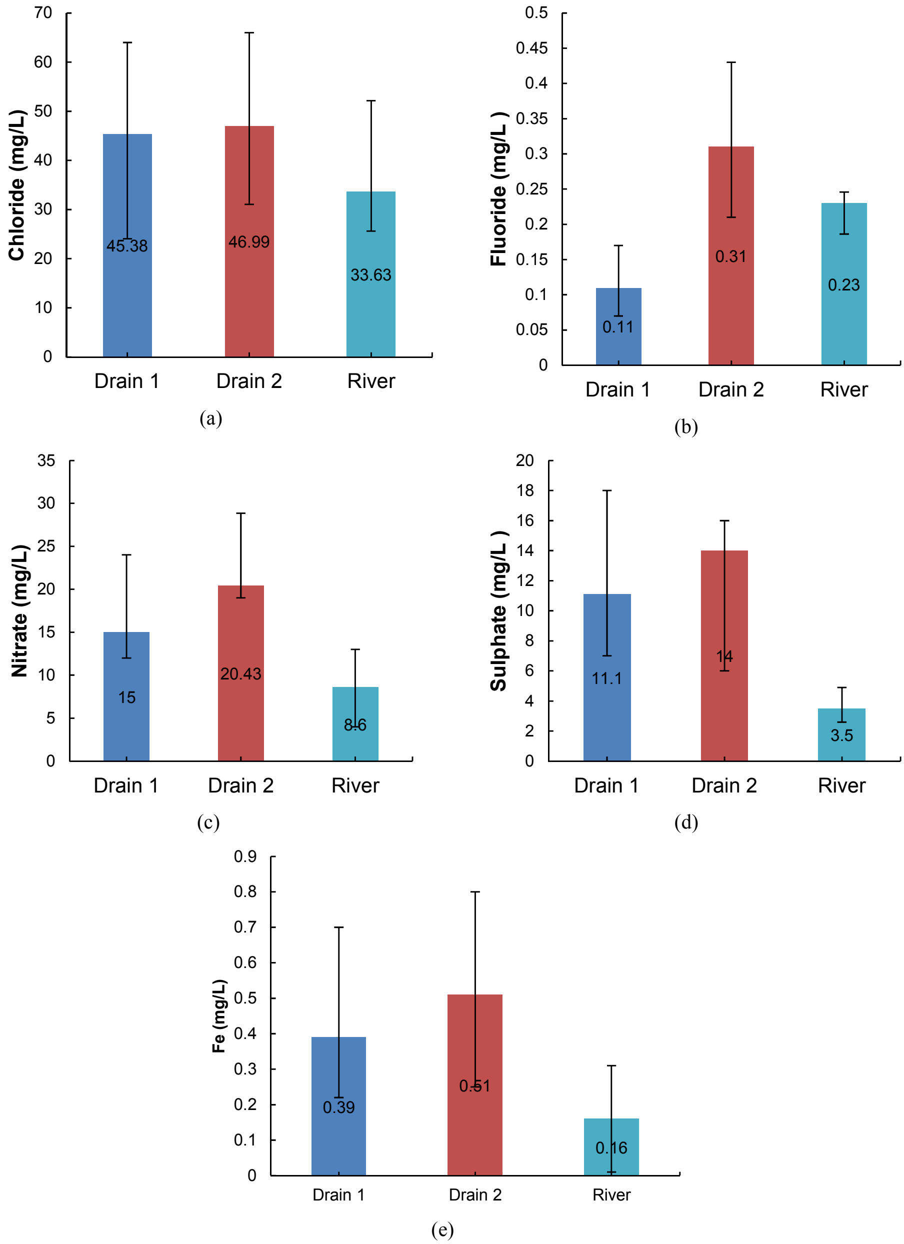


Figure 11 The spatial variation in the concentration of chemical species present in water samples collected from drains adjacent to Shornur railway station (see online version for colours)



The authors have also attempted to carry out a comparative study on certain water quality parameters of Bharathapuzha river available in the literature for pre-monsoon period (refer Table 4).

Table 4 A comparative study on the water quality parameters of the Bharathapuzha river

Water quality parameter	*Unit*	*Study by Kannan and Joseph (2022)*			*Present study*		
		Year of study: 2006			*Year of study: 2019–2020*		
		Min value	*Max value*	*Mean value*	*Min value*	*Max value*	*Mean value*
pH	–	7.5	8.6	7.9	7.5	8.3	8
DO	(mg/L)	6.5	11	8.5	6.3	7.3	6.9
TDS		129	533	302	145	298	197.8
TH		80	344	198	78	172	112.3
TA		88	336	204	42	114	77.7
Cl^-		33	105	57	17.5	78	37.2
NO_3^-		0	0.21	0.07	0.73	18	10.01

It is inferred from Table 4 that although the value of DO is above the minimum required limit for the sustenance of aquatic life, the value has shown a declination which signifies the increase in the level of pollution over the years. The value of TDS, TH, TA and chloride concentration has also decreased over the years. Kannan and Joseph (2022) in their study opined that the high values of TDS, TH, TA and chloride concentration are due to the rock/soil-water interaction. The low values of these parameters in the present study could be because the decrease in vegetative cover in the land adjoining the river has reduced the soil available for interaction with water on account of soil erosion. It is worth noting that the concentration of nitrates has increased several folds over the years, which indicates the excessive use of fertilisers in the agricultural field in adjacent to the river. Although, there is a considerable amount of chemical oxygen demand (average COD = 12 mg/L) in the river water there are no previous studies available in the literature to make a comparative study.

The biological characteristics of the river water were studied by determining the concentration of total coliform (TC) present in the river water. The TC organisms were detected in all the water samples and the values ranged from 141 MPN/100 ml to 542 MPN/100ml. This confirms the presence of sewage and waste from septic tank in the river water. As per the CPCB criteria formulated for designated best use of water if the total coliforms organisms is ≤5000, pH is between 6–9, DO is ≥4mg/L, BOD_5 at 20°C is ≤3 mg/L, the source of water falls under class C which recommends the river water for drinking water applications only after conventional treatment and disinfection. It can be concluded from the values of TC, pH, DO and BOD_5 obtained for the Bharathapuzha river water that the river water can be made potable only after conventional treatment and disinfection. Under these circumstances, if appropriate and timely actions are not taken/implemented to rejuvenate or prevent the further deterioration of the Bharathapuzha river, it can open a Pandora's box of socio-economic-environmental-political woes.

5 Rejuvenation strategies

The remedial measures that can be adopted for the rejuvenation of Bharathapuzha river can be bifurcated into two verticals, namely implementing engineering/technical solutions and addressing administrative and social concerns.

Major technical solutions proposed for the study area are as follows;

i The people living along the river bank should practise the best domestic pollution control measures that are environmentally sustainable. This mandates the treatment and disposal of the liquid and solid waste generated from the household at source if possible. This can be achieved by constructing and maintaining a proper septic tank, soak pit, leach pit, compost pits and growing vegetative cover around the house. The domestic sewage is treated in septic tank, soak pit and leach pit. The dry kitchen waste can be composted at the backyard. The vegetative cover around the house can reduce the air pollution by eliminating the CO_2 produced as a result of various domestic activities besides enhancing the soil-moisture and augmenting ground water table.

ii The present study highlights that the illegal and unscientific disposal of solid waste from the three main municipalities (viz. Shornur, Pattambi and Ottapalam) located along the riverbank is detrimental to the pristine nature of river. Hence, for municipal level solid waste management, creative steps have to be implemented in these three municipalities for proper collection and treatment of all types of solid waste. In the state of Kerala a solid waste management project under the World Bank and Asian Infrastructure Investment Bank aid (Kerala Solid Waste Management project) is under implementation stage.

iii A sewage treatment plant (STP) of two million litres per day processing capacity is to be constructed which will treat the grey water and sewage generated at the railway station and wastewater generated from Shornur municipality. The STP is designed to treat the grey water and sewage separately as depicted in Figure 12. The grey water is physically treated by passing through screens and grit chamber. The larger sized particles are removed by screens and the grit present in the outflow flow is settled in the grit chamber. The grey water is then chemically treated by coagulation process wherein the pollutants in the grey water is removed by adding suitable coagulants so as to reduce the BOD and COD value of the grey water to 35 mg/L and 60 mg/L, respectively. The supernatant flow from the coagulation tank is then taken to moving bed biofilm reactor (MBBR) (minimum two units is to be provided) where it is treated along with the sewage. The outflow from MBBR is then subjected to sedimentation process. The end products from the STP are

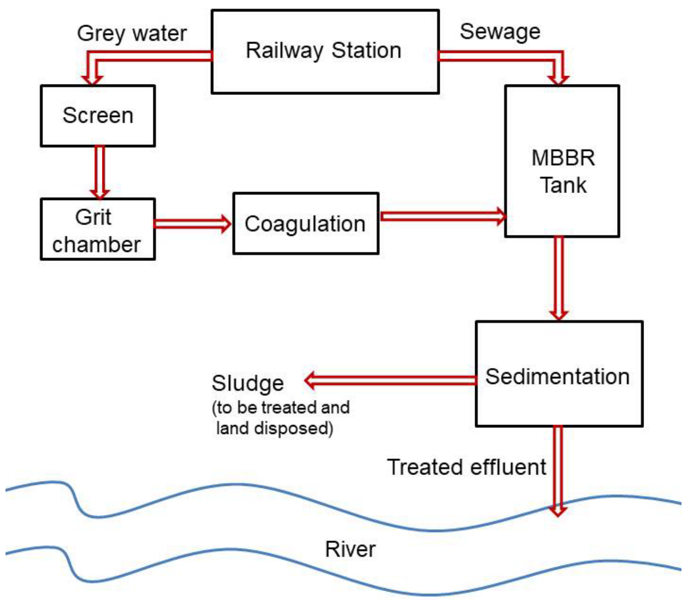
    i treated effluent, with a BOD value of 10–30 mg/L, which can be discharged into the river or used for irrigation

    ii sludge, which can be disposed in land, after proper treatment. If the end products from STP are not properly treated the environmental impact on the river and land upon its disposal would be escalate the existing issue (AL-Reyami et al., 2020).

iv It is also recommended to construct similar STPs at the other two major municipal areas namely, Ottappalam and Pattambi after carrying out site specific survey for design of sewerage system, estimating raw wastewater quality and conducting social survey.

The involvement and participation of the local communities and empowering them is crucial for the sustenance of any river restoration actions (Das, 2018). Furthermore, based on the feedback received from the social survey conducted in the study area, it is realised that to create public awareness and motivate people on river protection it is essential to take concrete steps. With this in view, a team mentored by social development specialist was assigned to conduct a transect study along the Bharathapuzha river. The team interacted with the local populace and various stakeholders of the river to understand the administrative and social aspects of interventions required for river rejuvenation and management.

Figure 12 The flow chart showing treatment of wastewater using moving bed biofilm reactor (MBBR) (see online version for colours)



The major administrative and social solutions proposed for the study area are as follows;

i A river protection authority, an apex body with the necessary administrative powers to protect the river is to be formed with necessary powers and competent to curtail any other type of illegal activities such as dumping of solid waste and septage.

ii Based on the studies carried out and conclusions drawn, the authors recommend applying the Asset Pentagon Framework (Tambe, 2022) for restoring the river health as depicted in Figure 13. Moreover, river management has to be addressed from an integrated perspective and the authors also suggest the following activities under the Asset Pentagon framework for Bharathapuzha river as conceptualised in Figure 13 and explained in Table 5.

iii The success or failure of a development project or program depends on how the project/programs 'interrelates with the surrounding socio-political context' (World Bank Brief, 2023). It is in this context that local development coalition should be thought of to rejuvenate Bharathapuzha. This development coalition may consist of Government departments at the district level (applies to all districts through which the river flows and forms a boundary of the district), the village level government and local community representing a wide variety of positive stakeholder interests. A brief mention of possible activities that may be entrusted to the coalition partners is illustrated in Figure 14.

Figure 13 Asset pentagon framework for sustainable Bharathapuzha river (see online version for colours)

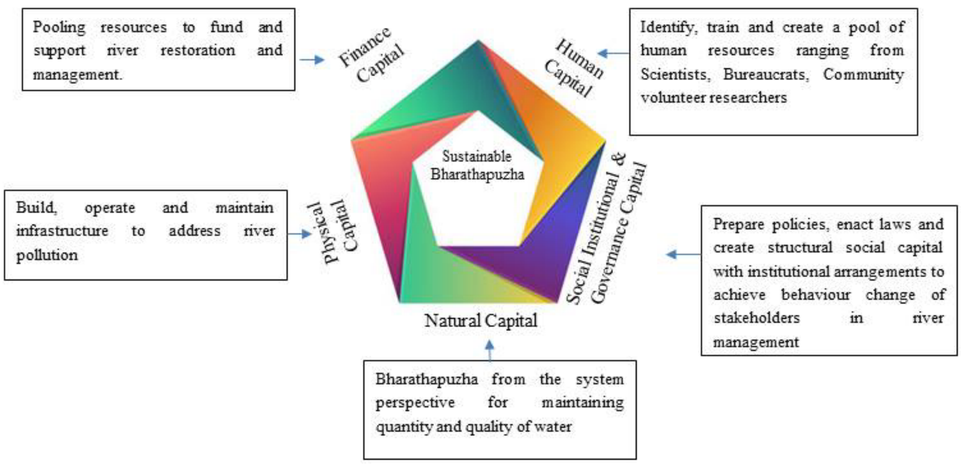


Figure 14 The river rejuvenation coalition (see online version for colours)

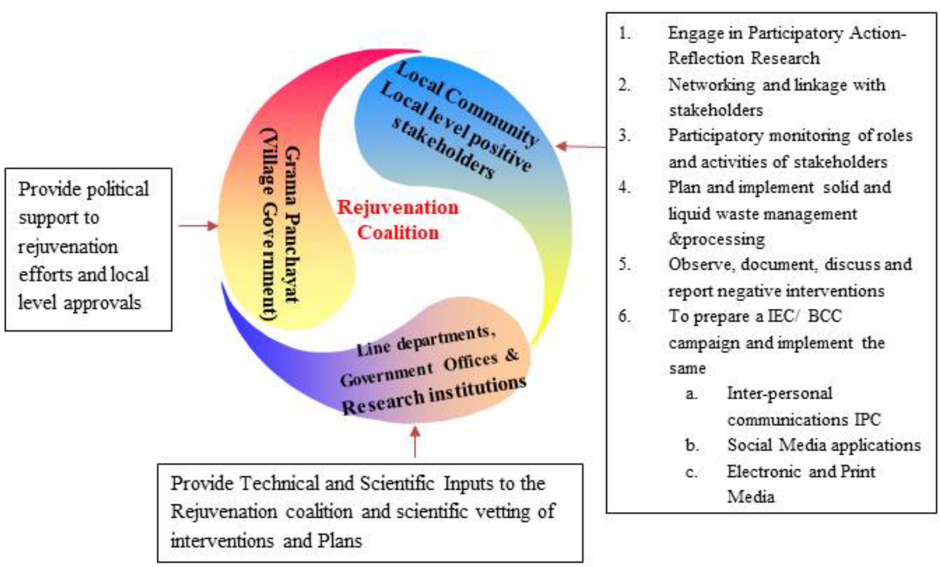


Table 5 Details of activities suggested under the asset pentagon framework for Bharathapuzha river

S. no.	*Component of Asset Pentagon*	*Application in the context of the study*
1	Natural capital	Continuously monitor river flows and the water quality at various points in the course of the river. Identify pollution sources and location
2	Physical capital	Create infrastructure to address pollution that are identified as point sources such as that of the Shornur Railway Station
3	Finance capital	Pooling of financial resources is necessary to raise sufficient funds to meet the cost of construction, operation and maintenance of infrastructure as mentioned under the physical capital
4	Human capital	Pooling of human resources representing various walks of life including, scientists, officials, people's representatives, activists, community volunteer researchers and voluntary organisations to support the rejuvenation of Bharathapuzha
5	Social, Institutional and Governance capital	Prepare policies, enact laws and create structural social capital (institutions) to achieve behaviour change of stakeholders in river management. This component is very crucial and the government has to involve in creating policies and laws to support policies. The entire task of river rejuvenation is not possible with the enactment of laws. Laws need to be implemented with rigour and dedication, which unfortunately is not the case with regard to general environmental sectors, giving exception to forests.
		Local level rejuvenation coalition for Bharathapuzha. This rejuvenation coalition shall include local self-governments such as the Grama Panchayats (Village governments), activists, volunteers, political party members, women groups, farmers and students. Information Education Communication (IEC) and Behaviour Change Communication (BCC) campaigns are proposed to energise the campaign for river rejuvenation

6 Conclusions

Issues and concerns pertaining to river pollution have aggravated in various parts of the world, especially in developing economies like India. The government has initiated measures to curtail this issue. In this context, the present study has focused on determining the level of pollution existing in Bharathapuzha river, one of the key river systems in Kerala, India. Firstly, a comprehensive pollution inventory specifying the direct and indirect sources of pollution along the study area was prepared. Subsequently, the spatial and temporal variations in the river water characteristics were assessed from Mayannur to V K Kadavu, a densely populated stretch along the Bharathpuzha river course. Following are the important inferences from the study;

- The increase in values of BOD and COD from upstream to downstream side of Bharathapuzha river indicated significant level of pollution in the river. Additionally, the presence of coliform bacteria confirmed the disposition of sewage into the river water. As per CPCB criteria for designated best use of water, the river water can be subjected to drinking water applications only after conventional treatment and disinfection. Moreover, without proper control, pollution levels will rise, making the river unsuitable for regular use and posing a risk to the residents in that vicinity.

- The technical strategies proposed for rejuvenating the river are to practice the best domestic pollution control measures that are environmentally sustainable and to set up sewage treatment plants at municipality level.
- The social strategy for river protection was to identify and involve the stakeholders of the river, to form a coalition for river rejuvenation, to establish a river protection authority and to resort to the essential tools and approaches for an efficient Information, Education and Communication (IEC) and Behaviour Change Communication (BCC) campaigns.
- River rejuvenation may be viewed from the Asset Pentagon lens, combining natural, physical, financial, human and social capitals.

The case study proves to be resourceful to assess the pollution existing in rivers of developing economies and also to formulate and implement pragmatic strategies directed towards conservation and rejuvenation of the polluted rivers.

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All subjects gave their informed consent for inclusion before they participated in the study. The authors confirm that the whole study meets the ethical guidelines and adheres to the legal requirements of the study country.

Consent for publication

All authors express their consent for the publication of this paper.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

No potential conflict of interest was reported by the authors. The authors have no relevant financial or non-financial interests to disclose.

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