Water Practice & Technology

 Water Practice & Technology Vol 18 No 5, 1284 doi: 10.2166/wpt.2023.056

Quality deterioration of an Indian urban water source near an open dumping site

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ABSTRACT

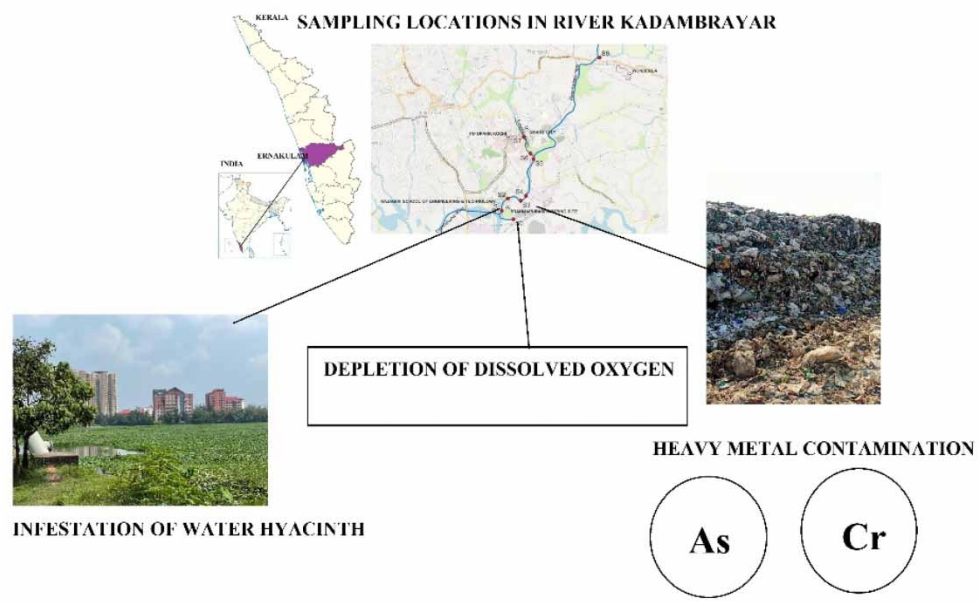
In developing countries, the stress of drinking water is often due to the increase in population, and rivers are the most important source of water. In this study, the pollution of the Kadambrayar River, located in southern India, was evaluated. The river flows through major establishments in the city, and an open dumping site is located near its bank. The river was infested with water hyacinth, which is considered a bioindicator of pollution in water bodies. Sixteen water quality parameters were analyzed across eight sampling stations in the river and compared with the standard limits as per IS 10500:2012 and IS 2296:1992, WHO, ICMR. It was found that parameters such as DO, BOD, and Coliforms did not comply with the limits at any of the stations. The heavy metals were also analyzed for water and sediment samples, in which the concentrations of arsenic in water were seven times higher and chromium was 50 times higher than the national standard limit. Thus, it can be concluded that the quality of this drinking water source is declining abruptly, especially downstream near the dumpsite, affecting the ecosystem as well as human health when exposed to carcinogenic metals.

Key words: drinking water, heavy metals, municipal solid waste, open dumping, urbanization, water quality

HIGHLIGHTS

- The river Kadambrayar is an important drinking water source for the surrounding urbanizing region.
- The river is infested with water hyacinth, which is a bioindicator of pollution.
- More than 500 MPN/100mL of coliforms are present in the river at all stations.
- The highest BOD of 228 mg/L and the lowest DO concentration was 0 mg/L for samples from a drain that carried the effluent from the industries to the river.
- The highest arsenic and chromium contamination in sediment and water samples was obtained downstream near the open dumping site.
- Exposure to heavy metal-contaminated drinking water can cause skin disorders, and cancer in humans and also threaten the survival of aquatic biodiversity.

GRAPHICAL ABSTRACT



INTRODUCTION

Historically it is found that urbanization started at the banks of the rivers and the major needs including freshwater, food transportation, and disposal of waste were satisfied. Thus, urban rivers are considered to be one of the most important features in an urban region and sometimes it is considered as an identity of that region (Francis 2012). But with the increase in urbanization, the quality of the urban stretches is deteriorating, which is a critical problem that has to be looked into (Wang *et al.* 2012). The possible sources for this deterioration include the discharge of sewage and effluents, agricultural runoff, and uncontrolled solid waste dumping near riverbanks (Singh *et al.* 2004, 2018, 2019; Zavaleta *et al.* 2021). Urban rivers can also contain a high amount of toxic and hazardous elements like heavy metals (Balaji & Thirumaran (2019). This study evaluates the quality of a river flowing through an urban zone comprising tourist destinations, agricultural areas, industries, residential zones, educational institutions, commercial parks, and a municipal solid waste (MSW) plant, which is now an open dumping site. The river plays a vital role as a host for drinking water in adjacent urban areas. However, according to the Comprehensive Report on Prevention and Control of Pollution in the Kadambrayar River, an Action Plan for Rejuvenation, 2018, the river was found to be polluted, and the pollution stretch was identified. The current study evaluated the pollution intensity in the Kadambrayar River along with the characterization of the dumping site. This study will help to assess pollution so that remedial measures can be taken for the abatement of pollution.

MATERIALS AND METHODS

Study area

The Kadambrayar River is a major urban water body (10°1′46.92″N, 76°22′52.32″E) that originates from the eastern part of Ernakulam district, Kerala, located in the southern part of India and extends approximately 27 km downstream. The river has a catchment area of approximately 115 km^2, and the major stretch of this river passes through the rapidly urbanizing and industrialized area of Ernakulam. It passes through the Panchayat Edathala, Kizhakkambalam, Kunnathunad, and Thrikkakara Municipalities and joins with the Champakara Canal at Kozhichira, where a temporary bund is provided to prevent saltwater intrusion. This study focuses on the stretch extending from Manakkakadav to Brahmapuram. The major establishments near the river draw water for their needs, and their sewage or effluent is mostly discharged into the river. Kadambrayar is a well-known tourist destination with an amusement park at Manakkakadavu, located upstream of the river. According to the Comprehensive Report on Prevention and Control of Pollution in Kadambrayar River, An Action Plan for Rejuvenation, 2018, the major drains toward the Kadambrayar River are Manakkakadavu Thodu and Edachira

Thodu, which join the river and flow downstream to Brahmapuram joining the Chitrapuzha River. The Edachira drain flows through residential areas and major industrial zones where industries and commercial parks, such as KINFRA, Infopark Phase-1, Phase-2, Smartcity, and Cochin Special Economic Zone (CSEZ), are adjacent to it and join the river at the Kadambrayar Bridge. Downstream, the river flows adjacent to the Brahmapuram MSW Plant which is now an open dumping site with about 33.3 acres of the area where all the generated waste from Cochin city is disposed of (Anupama *et al.* 2022; Detailed Project Report River Rejuvenation Committee 2021; Paul & Paul 2021) (Figure 1).

Reconnaissance survey

Sampling was performed from the river in the year 2020–2021 during the post-monsoon season at regular intervals. Before sampling, a reconnaissance of the study area was conducted to determine the sampling stations and identify possible pollution sources. Preliminary knowledge of the catchment area is needed before the application of tools to the variables measured for correct validation and interpretation (Alberto *et al.* 2001).

Water quality analysis

Eight sampling stations were chosen and grab sampling of water was conducted in triplicate from the cross-section of the river. To analyze the water quality parameters, samples were taken in clean 1-L polypropylene bottles rinsed with deionized water, and for analyzing the coliforms, the samples were taken in separate sterile bottles. The pH, temperature, and conductivity were measured on-site using a portable analyzer (Hanna pH meter; Thermo Scientific, EXPERT CTS Meter). To analyze the dissolved oxygen (DO) and biochemical oxygen demand (BOD), the oxygen was fixed on-site in 300-mL BOD glass bottles and titrated at the laboratory. The collected samples were preserved in an insulated box to prevent any changes in quality and transported to the laboratory. The other quality parameters were analyzed in the laboratory within 48 h of collection, following standard methods (APHA 2012). The reagents were prepared according to standard methods (APHA 2012). The trends of various parameters were compared using secondary data available from the Comprehensive Report on Prevention and Control of Pollution in Kadambrayar River: An Action Plan for Rejuvenation, 2018 (Action Plan for Rejuvenation 2018). A statistical analysis using the Pearson Correlation method for the physicochemical water quality variables was done based on the results obtained.

Heavy metal analysis in water and sediment samples

Grab samples were collected from these stations to determine the presence of heavy metals (As, Cr, Cd, Pb, Hg, and Cu) in the river. Among the heavy metals, As, Cd, Pb, Cr, Cu, and Hg are considered to be important because of the adverse health implications on human health when exposed (ATSDR 2015). Water samples were collected in 500-mL sterile inert bottles from the river, and Van Veen Grab sampler composite sediment samples were collected from the middle and shoreline of the river at stations S0, S1, S5, S7, and S8, representing each part of the river where possible sources of pollution exist (De Groot *et al.* 1982). The samples were analyzed for the presence of heavy metals using Inductively Coupled Plasma Mass Spectrometry (ICPMS) (Agilent 7700 Series ICP-MS). The spatial distribution of the key results was plotted using GIS to understand the variations in the variables.

Composition of dumpsite waste and leachate quality analysis

Because the present study focuses on the decrease in quality of the river near the dumping site, the characterization of the dumpsite in terms of the leachate characteristics and the composition of waste is necessary. Fresh representative municipal waste samples were randomly collected from the piles of dumped waste at the dumping site. Sampling was conducted at regular time intervals for 3 months in which four samples of 1 kg each were collected from different parts of the dumping site. The samples collected from the raw waste were reduced to subsamples using the quartering method for a representative sample and manually sorted to determine the waste composition (Trulli *et al.* 2018). Subsamples, each weighing approximately 10 g, were extracted from a representative composite sample to determine moisture content. In addition, the leachate samples were collected in 1-L inert bottles from the pools of leachate formed from the waste at different sites adjacent to the river. There is no proper scientific treatment for leachate at dumping sites. The leachate was analyzed for BOD, chemical oxygen demand (COD), and heavy metals using ICPMS (Agilent 7700 Series ICP-MS).

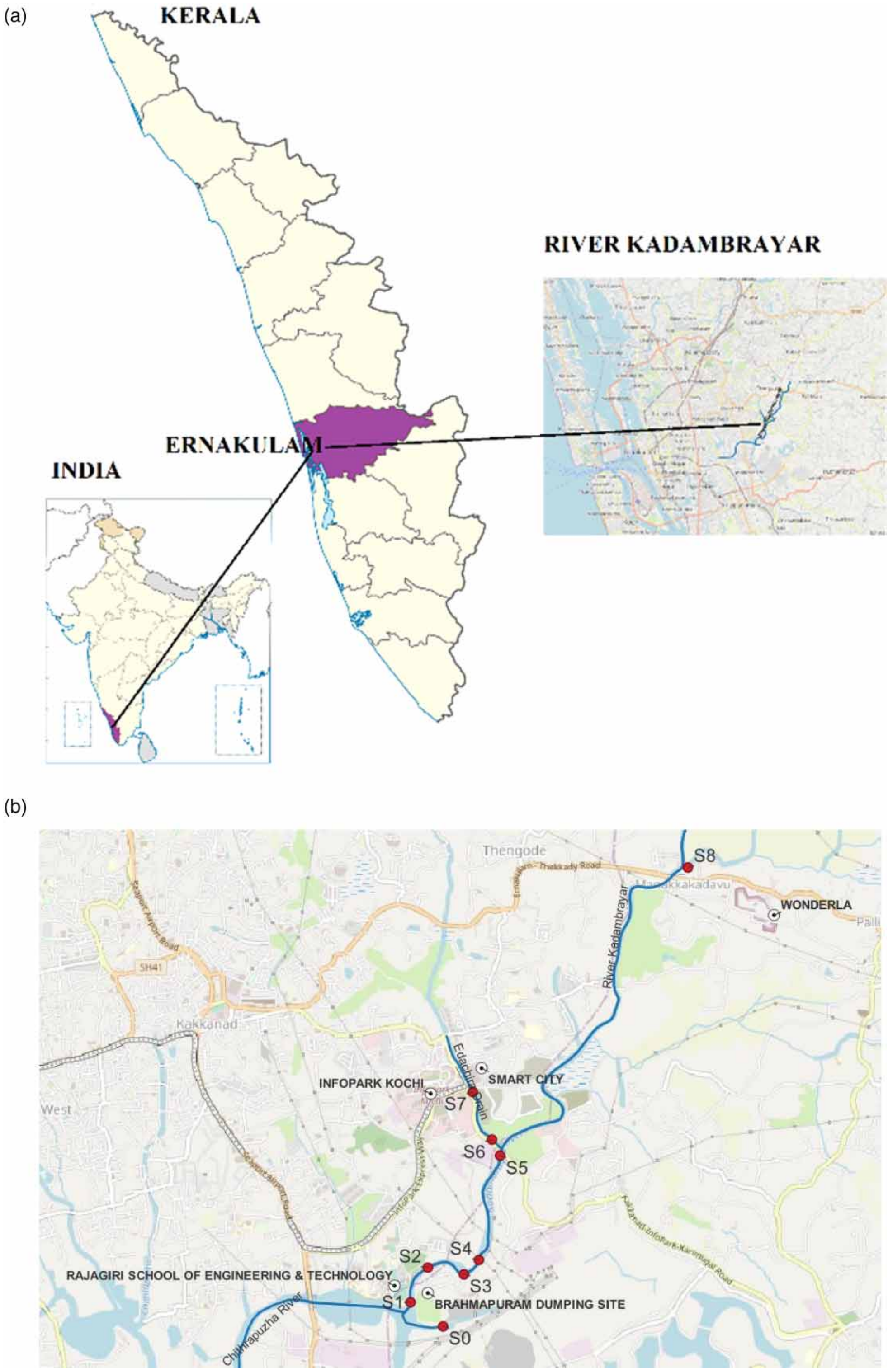


Figure 1 | (a,b) Sampling location map of River Kadambrayar.

RESULTS AND DISCUSSIONS

Based on the reconnaissance survey conducted at the study area, the possible source of pollution was identified which is shown in Figure 2. The river was infested with aquatic weeds, mainly water hyacinth (*Eichhornia crassipes*). The river, especially downstream of the river (stations S0–S5) and the drain (stations S6 and S7), were fully covered, obstructing the flow of the river. *E. crassipes* can form a pattern similar to that of a dense floating mat on

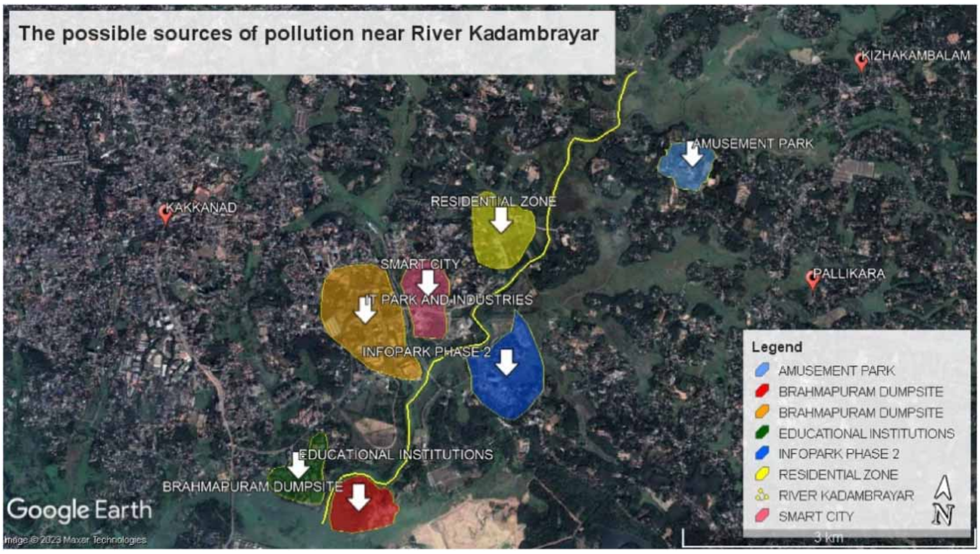


Figure 2 | The polluted stretch of River Kadambrayar considered for the study and the nearby possible sources of pollution (Google Earth).

a river, affecting the water quality parameters of the river. The condition of the river in 2021 with the water hyacinth cover is given in Figure 3 compared with 2020.

The values obtained for the various water quality parameters observed in the Kadambrayar River are tabulated in Table 1, in which the minimum and maximum values obtained are compared with the standard limits as per the different agencies. From the statistical analysis using the Pearson Correlation method for the physicochemical water quality variables (Supplementary material, Tables S1 and S2), it was found that there was a strong correlation between BOD, COD, DO, nitrate, ammoniacal nitrogen, and phosphate. Most of the parameters were within the limits, but the most important parameters, such as DO, BOD, and Coliforms (total and fecal coliforms), failed to satisfy the limits at all stations. The presence of the water hyacinth covers considerably influenced the reduction in nutrients, which might be the cause of the low concentrations of nitrate and phosphate, even though the pollution load was high. This causes a decrease in temperature, pH, DO, and nutrients in surface water, thereby deteriorating water quality and threatening aquatic life (Rai & Munshi 1979; Howard & Harley 1997; Güereña *et al.* 2015; Dersseh *et al.* 2019). Therefore, this aquatic plant can be used as a bioindicator of pollution (De Laet *et al.* 2019).

The study has incorporated various standards to compare the values obtained for various variables. Most standard limits were referred from IS 10500:2012 (BIS 2012), which is the Indian standard for drinking water as per BIS and IS 2296:1992 (BIS 1992) which is the Indian standards for surface water quality according to various uses. The WHO (World Health Organization) and ICMR (Indian Council of Medical Research) standards in water are used for Electrical conductivity and Phosphate respectively as the limits were not available in the previously mentioned IS standards.

In this study, it was found that the mean pH value ranges from 6.2 to 6.6 across the sampling stations in the river. Compared with the standard limits as per IS 2296:1992 (BIS 1992), where the range of pH for the Class B category, station S1 has the lowest pH of 6.2, which is slightly less than the minimum pH required for the river (6.5). The turbidity of the river was found to be more than the limits as per IS 10500:2012 (BIS 2012) with a minimum value of 22.1 NTU and a maximum value of 22.9 was reported at Edachira drain (station S6). Colloidal materials that cause turbidity can act as adsorption sites for biological organisms, causing odors and tastes (Peavy *et al.* 1985). According to IS 2296:1992 (BIS 1992), the total coliforms organism MPN/100 mL should be $\leq$500. However, the lowest count of coliforms reported in the river is 920 MPN/100 mL, which is more than the prescribed limit. The presence of fecal coliform is confirmed which evidently means that the river is polluted with fecal matter. Temperature is an important parameter that regulates the activity rates of biological species in natural surface water systems (Bhateria & Jain 2016). The health of a river system can generally be defined by parameters such as river water temperature and DO (Rajesh & Rehana 2022). In the present study, the temperature observed in the river Kadambrayar ranges from 28.1 to 29 °C

Figure 3 | Infestation of water hyacinth in the river.

with a mean value of 28.3 °C during the post-monsoon season 2021. From the secondary data obtained, it was observed that the temperature of the river increased to 31 °C by 2020 (An Action Plan for Rejuvenation 2018), which shows a variation of approximately 3 °C. The general reasons for the temperature rise in an urban area include the weather and the discharge of cooling water from industries back to the river (Spellman 2017). Global climate change also plays a vital role in the intensification of air temperature, thereby increasing river water temperature (Vliet *et al.* 2013). The rise in river temperature adversely affects the DO levels by affecting its self-purification capacity, thereby deteriorating the quality of the water body (Danladi Bello *et al.* 2017; Khani & Rajaee 2017). As per IS 2296:1992 (BIS 1992) norms, DO should be 5 mg/L or more in a river for Class B, which is categorized based on its use. In the present study, none of the water samples from the stations satisfied this criterion. The variation in the DO values throughout the river is shown in Figure 4.

The highest reported value of 4.6 mg/L is at station S8 Manakkakadav, located upstream (Figure 5). The DO levels decreased toward Brahmapuram, which is located downstream. At station S7, located at the Edachira drain, which joins the river, the DO value is 0 mg/L, and station S1 downstream is reported to be 0.2 mg/L. The trend in the DO values of the river over the years is shown in Figure 5. The DO levels showed a decreasing trend downstream of the river (toward station S0) from a DO value of 2.6 mg/L in 2019 to 0.2 mg/L. However, upstream of the river, there is an improvement in the DO value from 2.9 in 2020 to 4.6 mg/L in 2021 (Action Plan for Rejuvenation 2018).

BOD directly affects DO levels in water bodies. Oxygen is rapidly depleted when the BOD is higher in the stream, which threatens the survival of flora and fauna in the ecosystem. The variation in BOD in the river is shown in Figure 7. The highest value reported was 228 mg/L at Station 4, located downstream near the open dumping site. At station S8, located upstream of the BOD, it was found to be 90 mg/L, and at station S7 in the Edachira drain, it was 114 mg/L. The lowest value of 9.8 mg/L was reported at station S1, located

Table 1 | The water quality variables analyzed in water samples from River Kadambrayar

Variables	Minimum value	Maximum value	Standard limits	Recommended agency
Physical				
Temperature (°C)	28.1	29	–	–
Turbidity (NTU)	21.1	22.9	1	IS 10500:2012 (BIS 2012)
Chemical				
pH	6.2	6.6	6.5–8.5	IS 10500:2012
Electrical Conductivity (µS/cm)	2.049	157.9	300	ICMR (Prajapati & Bilas 2018; Jyothi *et al.* 2021)
Total Alkalinity (mg/L as $CaCO_3$)	8	80	200	IS 10500:2012 (BIS 2012)
Hardness (mg/L)	20	210	200	IS 10500:2012
Chloride (mg/L)	24	53.03	250	IS 10500:2012
Sulphate (mg/L)	15.9	28.5	200	IS 10500:2012
Nitrate (mg/L)	ND	0.5	45	IS 10500:2012
Ammoniacal Nitrogen (mg/L)	0.5	1	50	IS 2296:1992
Phosphate (mg/L)	0.5	1	0.1	WHO (**Edition 11**)
Dissolved Oxygen (mg/L)	0	4.6	5	IS 2296:1992
Biochemical Oxygen Demand (mg/L)	9.8	228	3	IS 2296:1992 (BIS 1992)
Chemical Oxygen Demand (mg/L)	24	696	–	–
Biological				
Total Coliform	920	>1600	0	IS 10500:2012
Fecal Coliform	13	220	0	IS 10500:2012

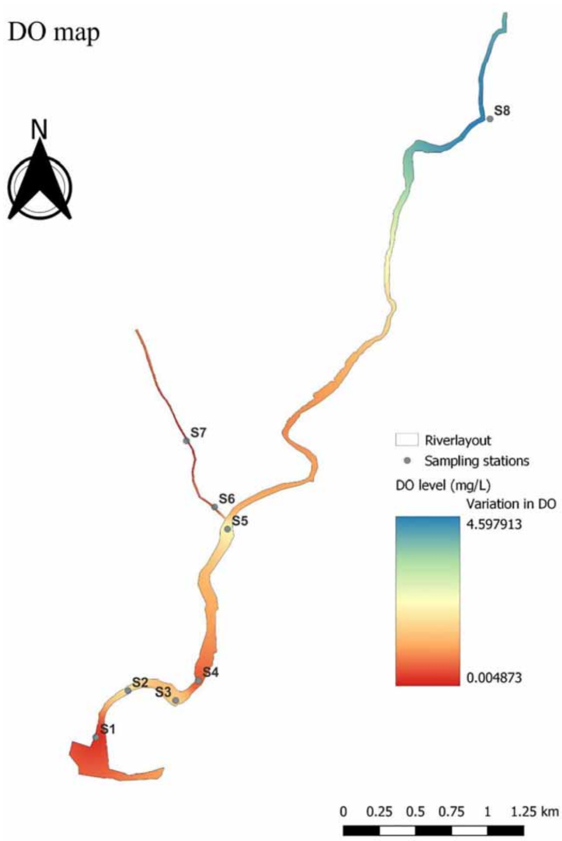


Figure 4 | Variation of DO in River Kadambryar in 2021.

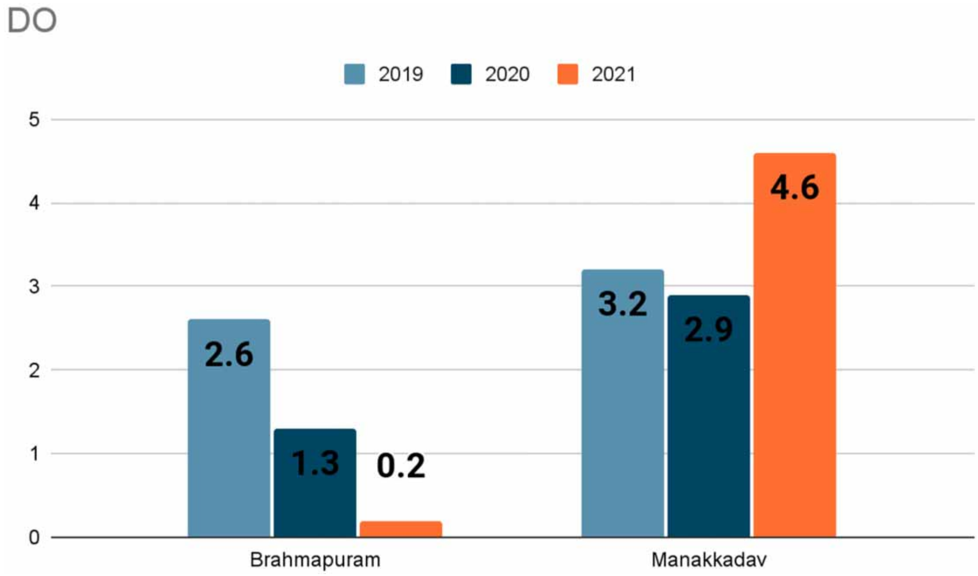


Figure 5 | Trend of DO levels in River Kadambrayar from 2019 to 2021.

downstream. As per IS 2296:1992 (BIS 1992) for Class B rivers categorized for outdoor bathing purposes, the BOD for 5 days at 20 °C should be 3 mg/L or less. However, at all stations, the BOD values were found to be higher than the standard limits (Figure 6). A drastic increasing trend is shown for the BOD values in the river both upstream and downstream of the river concerning the previous 3 years' values (Figure 7). The BOD at Brahmapuram downstream increased about 48.75 times in 2021 and at Manakkadavu there was an increase of about 37.5 times than in 2020 (Action Plan for Rejuvenation 2018).

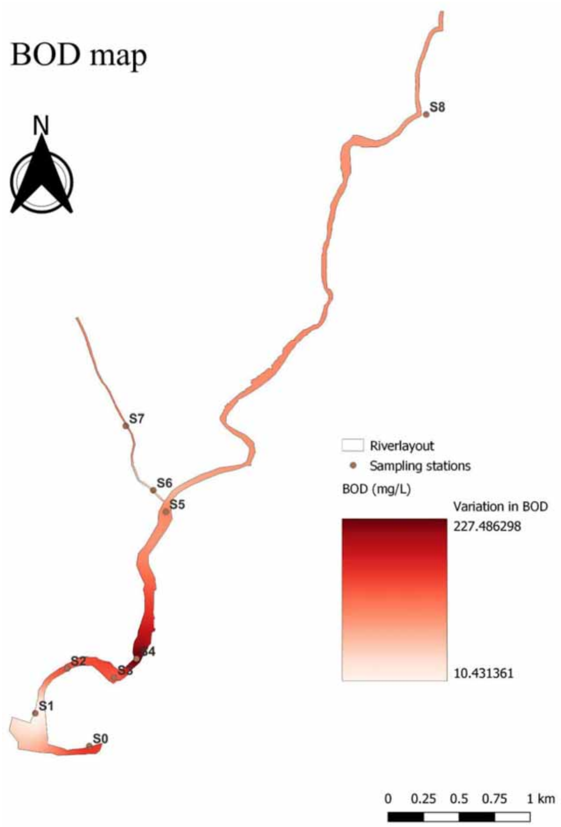


Figure 6 | Variation of BOD in River Kadambrayar in 2021.

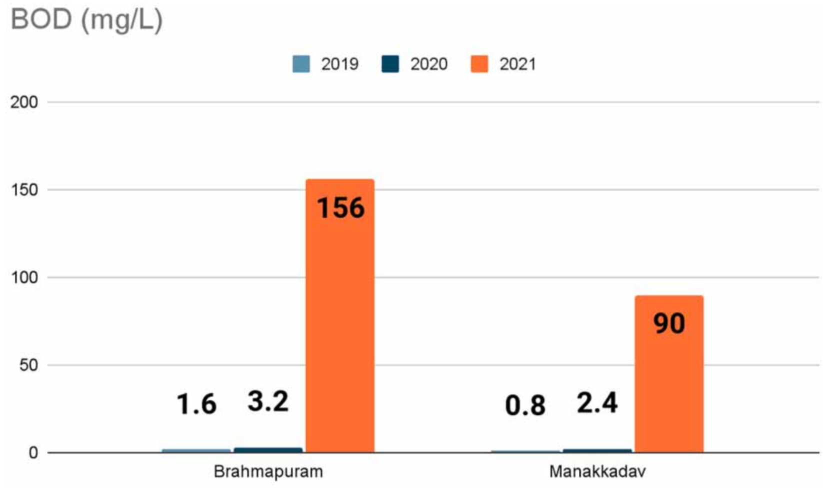


Figure 7 | Trend of BOD levels in River Kadambrayar from 2019 to 2021.

The high concentration of BOD may be due to the discharge of sewage or effluents into rivers (Penn *et al.* 2003). From the reconnaissance in the study area, it was observed that the upstream area was a tourist spot and an agricultural rural area devoid of any industries, except for an amusement park. However, the waste from poultry and other farming practices, along with sewage from nearby residential areas, might have resulted from the high BOD. The Edachira drain (stations S6 and S7) flows through the most important part of the city which includes IT parks. Commercial industries, restaurants, and effluents are discharged to rivers where some of the establishments have effluent treatment plants (ETPs). The highest COD of 696 mg/L was obtained from samples from the Edachira drain. The drains transport the effluent discharge to the river, which can affect the water quality (An Action Plan for Rejuvenation 2018). The drain joins the river at the Kadambrayar Bridge (station S5), which flows downward to Brahmapuram, where the open dumping site is located adjacent to the river. As per the details from the study conducted by Abhirami *et al.* (2021) as of December 2020, 314 tons of waste is generated by Cochin Corporation and transported to Brahmapuram.

By analyzing the composition of the type of waste in this study, it was found that the presence of organic matter, especially food waste, was relatively high, followed by paper and plastic waste (Figure 8). In total, 85.95% of organic matter, 12.66% of paper waste, and 4.22% of plastic were present. The amount of organic matter is higher because of the regular dumping of MSW. Segregation of waste is done by Kudumbasree units from the source of waste generation itself, which helps to reduce the presence of plastic, paper, and other miscellaneous materials, along with food waste. Plastic waste is carried by separate vehicles and dumped. A small fraction of metals, glass, paper, and cloth is present in the MSW obtained. Hridya *et al.* reported that from a

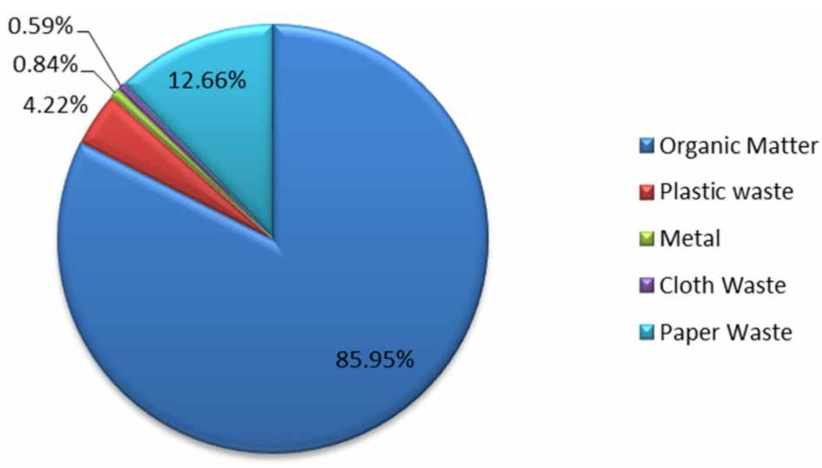


Figure 8 | Composition of MSW from the open dumpsite.

questionnaire survey conducted within a 5 km radius of the Brahmapuram plant, human health and the water environment near the plant are adversely affected. The increase in waste generation in the Brahmapuram Open dumping site is shown in Figure 9 (City Sanitation Plan for Kochi-Status Report 2010; Hridya *et al.* 2016; Arunbabu *et al.* 2017; Final EIA/EMP Report GJ Eco Power Private Limited 2019; Kerala Solid Waste Management Project Report 2020; Detailed Project Report, River Rejuvenation Committee 2021).

Figure 9 | The increase in the waste generation (shown in white) in the Brahmapuram dumping site over years (a) 2011, (b) 2015, and (c) 2020 (Google Earth).

Based on laboratory analysis results, the moisture content of different sample wastes in Brahmapuram ranges from 30 to 50%. This could result in a higher amount of leachate (Arunbabu *et al.* 2017). Paul & Paul (2021) evaluated MSW management in Kochi and reported that the percolation of leachate from the Brahmapuram dumping site polluted the Kadambrayar River. The results obtained by analyzing the leachate BOD, COD, and heavy metals are tabulated in Table 2. In a study by Arunbabu *et al.* (2017), the presence of metals such as Fe (60.938 mg/L), Cu (0.107 mg/L), Ni (0.531 mg/L), Zn (0.273 mg/L), Pb (0.017 mg/L), Cr (0.125 mg/L), Hg (0.005 mg/L), and As (0.061 mg/L) was reported in the leachate from Brahmapuram in 2015. In the present study, dangerous heavy metals such as arsenic (0.24 mg/L) and chromium (2.74 mg/L) were found. Iron, nickel, and other metals such as mercury, copper, lead, cadmium, and zinc were not found. Other elements include boron, gallium strontium, and titanium. However, in the present study, the concentration of arsenic was approximately four times higher and that of chromium was 22 times higher than that in the previously stated study. The BOD/COD ratio of leachate is considered an indicator of biological treatability, and a high ratio indicates that the leachate should be more treatable (Miller & Clesceri 2002). This study found that the BOD/COD ratio of leachate collected in 2021 was 0.55. ArunBabu *et al.* analyzed the leachate at the Brahmapuram dumping site in 2015 and found a high BOD/COD ratio of 0.69. The site does not have any treatment facilities for the leachate produced from waste (Arunbabu *et al.* 2017), and the high ratio highlights the possibility of biological treatment. Ganesan (2017) analyzed the management of solid waste in landfill sites and reported that there is a great environmental threat from the Brahmapuram open dumping site to the Kadambrayar River.

Table 2 | Leachate characteristics from Brahmapuram dumpsite in 2021

Metal	Leachate (mg/L)
BOD	222
COD	400
Arsenic	0.24
Chromium	2.74
Aluminum	0.07
Boron	0.76
Barium	0.21
Calcium	72.4
Cobalt	0.01
Iron	2.49
Gallium	0.19
Potassium	282.03
Magnesium	43.15
Manganese	0.04
Sodium	342.5
Nickel	0.03
Strontium	0.36
Titanium	0.03

Presence of heavy metals and trace elements in water and sediment samples

Heavy metals were found in the water samples, and the values are listed in Table 3. Only the concentrations of arsenic and chromium found from stations (S0, S1) near the dumping site downstream were beyond the standard limits, as per IS 2296:1992 (BIS 1992). The concentration of arsenic was reported to be 0.22 mg/L at S0 and at S1 the concentration was 0.36 mg/L. The Cr concentrations in S0 and S1 were 2.54 and 1.25 mg/L, respectively. The standard limit of arsenic and chromium is 0.05 mg/L as per standard limits. The variations in As and Cr concentrations are shown in Figure 10. The maximum value found at station S0 had a concentration of arsenic seven times higher than the safe limit and approximately 50 times more than the safe limit of chromium. As and Cr are carcinogenic and can be disastrous to the environment and human health upon exposure (Chowdhury

Table 3 | Heavy metals found in water compared to standard limits by IS 2296:1992

Metal (mg/L)	Maximum value	Minimum value	Standard limit	Recommended agency
As	0.36	0	0.05	IS2296:1992
Cr	2.54	0	0.05	IS2296:1992
Cd	0.00001	0	0.01	IS2296:1992
Pb	0.00052	0	0.1	IS2296:1992
Cu	0.00231	0	1.5	IS2296:1992

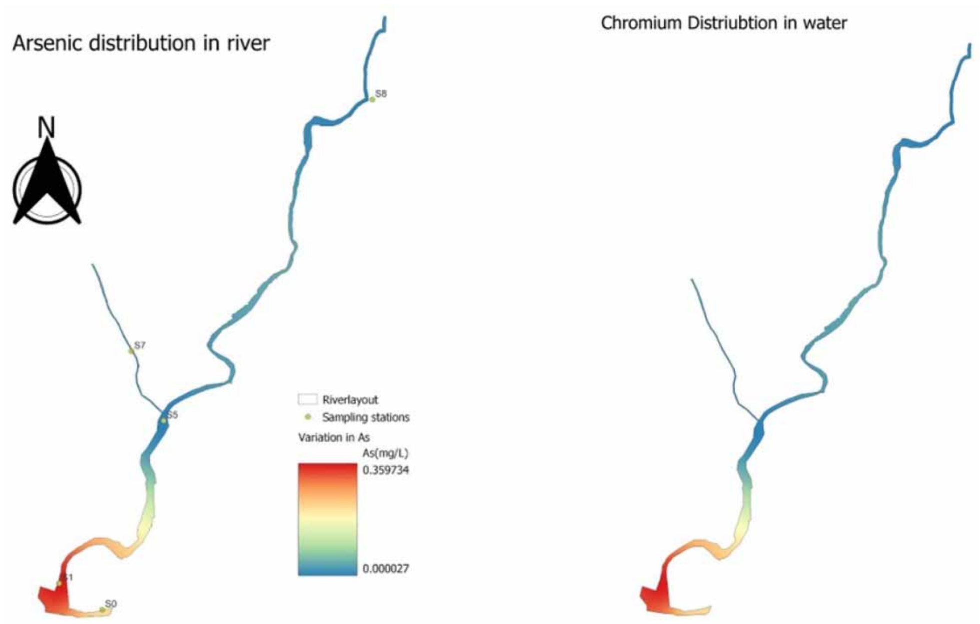


Figure 10 | Variation of arsenic and chromium in the water samples of River Kadambryar in 2021.

et al. 2016). Exposure to As-contaminated drinking water at a liter per day of concentration of 50 μg/L for a lifetime can lead to skin, liver, and kidney cancers in every 13 persons in 1,000 (Smith *et al.* 1992). Intake of arsenic-contaminated drinking water can cause adverse effects on the respiratory and nervous systems in children and increase the risk of stillbirth in pregnant women (von-Ehrenstein *et al.* 2006; Rosado *et al.* 2007). Chromium also causes ulcers and skin disorders and can be fatal in liver and kidney cancer (Gowd & Govil 2008; Linos *et al.* 2011). Common sources of contamination include industrial effluents and anthropogenic activities. In this study, leachate and runoff from the dumpsite contributed to pollution in the river downstream. In particular, during the wet season, runoff from the dumping site along with leachate containing heavy metals (Toufexi *et al.* 2013) pollutes the environment in its vicinity (Hossain *et al.* 2018). Thus, there is a great need to monitor the quality of water bodies, especially when they are considered as drinking water sources.

In the Kadambrayar River, heavy metals were found in sediments collected from all stations (Table 4). Five metals were compared to the values in the EPA guidelines, and it is clear that the sediment sample was heavily polluted with Cr, As, and Cu at station S0 near the dumpsite (Table 4), in the order Cr > As > Cu. Other metals, such as lead and cadmium, were less than the given limits as per the EPA guidelines for a non-polluted scenario (Ogbeibu *et al.* 2014). At other stations upstream, the concentrations were negligible compared to the downstream concentrations.

Thus, it can be understood that upstream the presence of arsenic and chromium was negligible and safe limits compared to downstream, which indicates the contribution of the uncontrolled open dumping site as a major source of heavy metals to the river causing heavy metal pollution. Heavy metals in sediments enter the food web through benthic fauna in the ecosystem. The heavy metals thus accumulate over time and during

Table 4 | Heavy metals found in sediments compared to EPA guideline values (Taylor 1964; Ogbeibu *et al.* 2014; Onjefu *et al.* 2020)

Metals (mg/kg)	Not polluted	Moderately polluted	Heavily polluted	Maximum value	Background values
As	ND	ND	ND	7.49	0.005
Pb	<40	40–60	>60	32.62	0.007
Cr	<25	25–75	>75	205.49	0.08
Cd	–	<6	>6	0.29	PDF
Cu	<25	25–50	>50	56.04	0.006

resuspension, and the metals can be transported further, thus acting as a good source of contamination (Chowdhury *et al.* 2004, 2016; Wu *et al.* 2014; Wang *et al.* 2015). Joseph *et al.* have identified trace metals in the sediments of Chitrapuzha located downstream of the Kadambrayar River (Joseph & Chacko 2006) and ultimately joined the Ramsar site Vembanad lake, where heavy metals were reported by Shyleshchandran *et al.* (2018).

Heavy metal pollution has been reported in similar studies, where the surface water quality is detrimentally affected near an open dumping site. Studies that focused on the surface quality near landfills or dumping sites reported that the quality near the site is highly polluted (Parvin & Tareq 2021). A study by Jahan *et al.* (2016) near Matuail landfill sites on reported that the DO in surface water near the site decreased which will threaten the fish over there as the area is a source for fisheries. A study by Azim *et al.* However, Azim *et al.* 2011) however stated that most variables were under safe limits near the same landfill site, except Cr (1.03 mg/L) and DO (2.3 mg/L). A study by Alam *et al.* (2020) in the Mogla Bazar landfill site found that Pb was above the safe limit in surface water near the site. A study by (Hossain *et al.* 2014, 2018) reported that the surface water in the surroundings of the Rowfabad landfill site contains a high concentration of iron, chromium, and cadmium.

CONCLUSION

In this study, by analyzing the quality of a stretch of the Kadambrayar River, which flows through an urbanized and industrialized region of a city during the post-monsoon season in 2021, it can be concluded that

- The river is infested with aquatic weeds, especially water hyacinth, which can be considered a bioindicator of pollution.
- The key parameter such as DO, BOD, and Coliforms which can be considered as a measure of the health of the river system fails to comply with the standard limits as per the surface water quality standards IS2296:1992. The presence of fecal coliforms is also confirmed which indicates fecal pollution in this drinking water source.
- An increasing trend is shown in the BOD values in the river compared to the previous year's data, and a decreasing trend is observed downstream. Thus, when compared to the upstream it can be understood that the downstream is more polluted in terms of the depletion of DO and BOD levels.
- The concentrations of arsenic and chromium obtained at the stations located downstream near the dumpsite were beyond the standard limits.
- The Edachira drain, located upstream, contributes to a significant level of pollution in the river by transporting sewage and effluents.
- There is no treatment for leachate at the dump site, and leachate along with runoff is a major source of pollution downstream of the river (at station S0, which joins river Chithrapuzha).

Apart from the regular monitoring of the river to control the pollution in the river. Timely sediment dredging of the river and removal of water hyacinth at infested places will enhance the flow of the river and thus the natural aeration will improve the quality of the river (Wang *et al.* 2012). The leachate at the dumpsite should be treated and phytoremediation is one of the low-cost methods (Arunbabu *et al.* 2017). The study will thus help in a better understanding of the pollution and its sources in the river; therefore, remedial measures can be framed for improving water quality for sustainable development.

ACKNOWLEDGEMENTS

We thank the Kerala State Irrigation Department, Kerala State Pollution Control Board, Kerala Water Authority, and Cochin Municipal Corporation for their assistance in sampling and data collection.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 15 December 2021; accepted in revised form 29 March 2023. Available online 20 April 2023