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Characterization of Water Quality and Carbon Flux in the Karuvannur River Basin, Southern Western Ghats, India

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Abstract

River water quality is receiving increasing attention worldwide due to its vital role in supporting ecosystems, agriculture, and human livelihoods. To maintain the stability of the ecosystem, it is essential to assess the water quality and contamination status of surface water resources. To create baseline data on the water quality and pollution status, surface water samples were taken from 20 different locations of the Karuvannur River, originating from the Southern Western Ghats and traversing the Kole Wetlands in the Thrissur District of Kerala state, India. The samples were analysed for physico-chemical parameters such as pH, EC, TDS, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, Mg^{2+}, Alkalinity, Hardness, DO, and BOD. The concentration of the tested parameters was within the permissible limit for domestic and agricultural purposes recommended by the World Health Organization and the Bureau of Indian Standards. The Water Quality Index (WQI) was calculated, and according to the results, all the samples fall under the 'good' category, ranging from 26.42 to 46.84 with an average of 34.48, and are presently devoid of any potential contamination risks. The partial pressure of CO_2 (pCO_2) of the surface water of the Karuvannur River ranges from 1,076 to 13,908 µatm, which is comparatively higher than the typical atmospheric concentration of 380µatm. The oversaturation of pCO_2 signifies that the river actively contributes to the global carbon budget by releasing CO_2 into the atmosphere. By quantifying pCO_2 and linking it with hydrochemical characteristics, this study provides critical insights into carbon flux dynamics in tropical river systems, improving understanding of their contribution to regional and global carbon budgets and informing strategies for sustainable watershed management.

Keywords: Karuvannur River Basin, Kole Wetlands, pCO_2, Water Quality Index, Western Ghats

Introduction

The primary source of fresh water is the river system. It transports a sizable amount of matter, either in dissolved form or as particulate matter, along its path and the tributaries. These could have come from both manmade and natural sources. Rivers are well known for being important in the transfer of goods and services. Additionally, they are involved in the transportation of domestic, commercial, and industrial waste. Runoff from farms and other sources that produce pollution eventually gets deposited in river water columns, introducing pollutants to the river. Discharges of garbage into the aquatic environment are increasing as a result of the constant population growth, which is accompanied by fast urbanization and industrial activity (Krishnakumar *et al.,* 2022; Reza and Singh, 2010; Krishnakumar *et al*., 2025; Khatri and Tyagi, 2014; Devic *et al*., 2014; Kumar *et al*., 2016; Krishnakumar *et al*., 2017a,b; Nair *et al*., 2018; Ramachandran *et al.,* 2018; Kaliraj *et al*., 2019). Since aquatic plants and wildlife are constantly in contact with water, every change in water quality must have a direct impact on them. Toxic compounds are deposited in the ecosystem as a result of overusing and exploring the natural world without following established laws or principles. When contaminants from agricultural waste, factory discharges, and effluent sources are released into the environment, the overall contamination burden of the receiving ecosystem is enhanced or increased. Likewise, the characteristics of the source and receiving environments influence the extent of contamination. The long-term interaction between the water and the surrounding environment reflects on the hydrochemical composition of water (Lin *et al*., 2023).

It is significant that around 70 percent of Indian rivers have been reported to be contaminated to varying degrees (Singh *et al*., 2020). Numerous physicochemical factors affect the water quality of riverine ecosystems. These factors are crucial in assessing whether the water is suitable for various uses, including drinking, agriculture, industry, and fisheries. In many developing countries, water pollution and its management demand immediate attention, as nearly 80% of disease outbreaks and related deaths are associated with the consumption of unsafe water (Jose and Krishnakumar,

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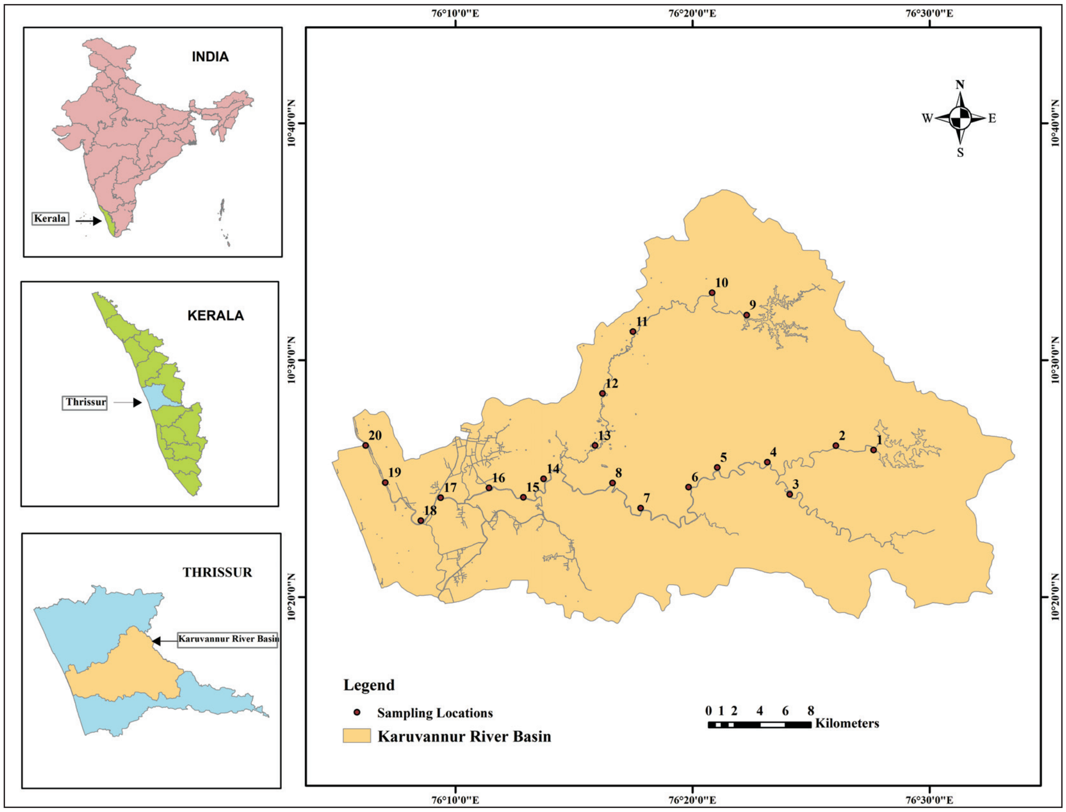

Fig.1. Location map of Karuvannur River Basin along with sampling sites

2025). Multiple parameters, including pH, temperature, total dissolved solids, conductivity, turbidity, alkalinity, total hardness, biochemical oxygen demand, chlorides, sulphates, nitrates, calcium, magnesium, *etc.*, are typically measured when analysing the physicochemical properties of water. It's important to remember that studying the features of surface water quality is crucial for maintaining and protecting water resources. The quality of surface water can also be impacted by a variety of variables, including climate change, human activity, and natural changes.

Water Quality Indices (WQI) have been developed to integrate various water quality parameters, summarizing large amounts of data into simpler categories such as excellent, good, poor or unsuitable (Nikoo *et al.,* 2011). It is also used to monitor changes in a specific river reach over time and to compare water quality across multiple river reaches. Furthermore, the WQI makes it possible to compare several rivers. Numerous studies have been conducted to assess the water quality of the world's major rivers (Biose *et al.,* 2024; Gupta and Gupta, 2021; Kushwaha *et al.,* 2024; Parker *et al.,* 2018; Stackpoole *et al.,* 2019; Bouslah *et al.*, 2017). Research has also been conducted in India's major rivers (Lkr *et al.,* 2020, Kushwaha *et al.,* 2024). India's peninsular rivers, however, are barely studied and may be overlooked because of their small size, even though people heavily rely on them. (Thomas *et al.,* 2015a,b). Due to increasing industrialisation, agricultural expansion, and urbanisation, the densely populated peninsular area of India has experienced fast economic growth in recent decades, which has placed the rivers under a lot of stress over time (Thomas *et al.,* 2015a; Saha *et al.,* 2020a, b). The teeming populace in this area depends heavily on the small rivers for their drinking water (Saha *et al.,* 2021a). Therefore, better management of these important water resources is required, and this requires a better understanding of the ways in which different natural and man-made stresses affect the quality of river water. To track changes and take appropriate action, it is crucial to perform ongoing monitoring and assessment (Krishnakumar *et al*., 2021)

River systems, which are typically thought of as a "Pipe" that transport a significant amount of carbon from the land to the ocean. They also serve as vital bioreactors for the active processing of carbon and have the potential to release carbon emissions into the atmosphere. (Aufdenkampe *et al*., 2011, Wang *et al*., 2021). The concentration of dissolved CO_2 in rivers, lakes, and coastal regions is higher than its equilibrium concentration in relation to CO_2 in the atmosphere (*i.e.,* 380 µatm). According to recent research, surface waters can degas CO_2 to the atmosphere in considerable amounts (Aditya *et al*., 2024; Liu and Han, 2021; Ciba and Upendra, 2024). River-to-atmosphere CO_2 evasion is thus a major contributor to the net carbon budget on a global and regional scale.

The present paper aims to investigate the surface water quality of the Karuvannur River, which flows through the Kole Wetlands of Thrissur District of Kerala. The main objectives of the study are (i) to assess the physicochemical parameters of Surface water of the Karuvannur River, (ii) to determine the domestic and irrigational water suitability of surface water, and (iii) to investigate pCO_2 dynamics in order to represent the intensity of gas exchange at the water-to-air interface.

Study Area

The Karuvannur River Basin (KRB) is located in the Thrissur district of Kerala, southwest India. Its boundaries are the Arabian Sea on the west, the Alathur and Chittoor taluks of Palakkad district on the east, the Thrissur and Chavakad taluks of Thrissur district on the north, and the Mukundapuram and Kodungallur taluks of Thrissur district on the south. The Karuvannur River originates from the Western Ghats and is fed by its two main tributaries, namely the Manali and the Kurumali. The Manali River originates from Ponmudi, in the boundary of Thrissur and Palakkad districts, at an elevation of 928 m, and the river travels west to Mundanchira before turning south to Nenmanikkara. It then bends west and then south until reaching the Kurumali near Pazhanji. The Chimony and Muply rivers, the two sub-tributaries of the Kurumali, originate from Pundimudi at an elevation of 1116 m, flow west through dense forest before merging at Elikode to become the Kurumali River. Both rivers merge at Arattupuzha and form the Karuvannur River. Then, the river flows to the Kole wetlands. The river flows west and splits into two, one falling into Enamakkal Lake, which joins Conolly Canal in Thrissur District and the other into Periyar River. The river is 48 kilometres in length, drains an area of 1,054 km^2 (10^o 15' to 10^o 40' North latitude and 76^o 00' to 76^o 35' East longitudes) and gives drinking water to many Panchayats in Thrissur District. From west to east in the Karuvannur River Basin (KRB), the major geomorphological landform components are beaches, alluvial plains, flood plains, valley fills, Kole wetlands, local planation surfaces (lateritic), denudational slopes, and structural hills. The research area is divided physiographically into four distinct units: highland, midland, Kole lands, and coastal lowlands. KRB is surrounded by the Ponnani River Basin (north) and the Chalakkudi River Basin (south). The basin experiences a tropical monsoonal climate with an average of 2833mm of annual precipitation. The Charnockite group of rocks makes up the majority of the KRB's basement rocks in the east, followed by migmatite rocks in the central portion and coastal sands and alluvium in the west (Bhadran *et al.*, 2018). Forest land and water bodies dominate the upper portion of the region, while agricultural fields and deciduous forests make up the middle portion. The lower portion is mostly made up of agricultural land, which plays a vital role in the Karuvannur Basin (Siji *et al.*, 2025). All these factors have made this area one of the most fascinating for learning about the relationship between environmental changes and human activity.

Materials and Methods

Sample Collection and Analysis

A total of 20 samples were collected from different locations (Fig.1) of the Karuvannur River in March 2024 (post-monsoon period) for quality analysis. At a depth of roughly 20 cm, water samples were taken with pre-rinsed plastic bottles and promptly corked, and the samples were transported to the laboratory. At the time of sampling, the GPS location and the surrounding environment of each sampling site were recorded. The following physicochemical properties of the water samples were examined: turbidity, measured with a turbidity meter. Total Dissolved Solids (TDS), Electrical Conductivity (EC), Temperature, Hydrogen ion Potential (pH), and Dissolved Oxygen (DO) were all measured *in situ* using an Aquaread AP 2000 water quality analyser. After the sample had been incubated for five days in a dark cabinet (the BOD cupboard), the Biochemical Oxygen Demand (BOD) was measured. The Continuous Flow Analyser (CFA) was used to measure Nitrate, sulphate, Chlorides, Total Alkalinity (TA), and Total Hardness (TH). Microwave Plasma Atomic Emission Spectrophotometer (MP-AES, Agilent 4210, USA) was used to measure calcium and magnesium. The results were then compared with the WHO (2017) and BIS (2012) standards. Quality control measures included the use of blanks, replicates, and standard reference materials, ensuring a relative standard deviation of less than 5%. The Normalised Inorganic Charge Balance (NICB) was computed to ensure data accuracy (Friedman and Erdmann, 1982), confirming that the charge balance error was under the recognised analytical threshold of ± 10%.

The spatial variation of various physicochemical parameters throughout the study area was mapped using the Inverse Distance Weighting (IDW) technique within the GIS framework, utilizing ArcGIS 10.7 software. During the IDW process, a 250-meter buffer was used to improve data comprehension and interpretation.

Evaluating the Water Quality Index (WQI)

The Water Quality Index (WQI) is a mathematical computation that combines physical, chemical, and biological factors to produce a score that indicates the general condition of the water quality in consideration (Saha *et al*., 2021b). The impact of both natural and man-made activity on various parameters can be found using this method (Sudhakaran *et al.,* 2020). The concept was initially introduced by Horton (1965) and later refined by Brown (1972). The present study adopts the five-step Water Quality Index (WQI) method. The WQI values are classified according to Brown (1972) to assess the suitability of water for domestic purposes as excellent (0–25), good (26–50), poor (51–75), very poor (76–100), and unsuitable for drinking (>100).

The five important steps applied to determine the WQI are:

Step 1: Collection of data regarding the relevant physicochemical water quality parameters.

Step 2: Calculation of the proportionality constant '*K*' value using the formula:

$$K = 1/(1/\Sigma nisi) \qquad ......1$$

where '*si*' is the standard permissible for the n^{th} parameter.

Step 3: Calculation of quality rating for the n^{th} parameter (Qn), where there are n parameters.

$$Qn = 100 \times [(Vn - Vi)/(Sn - Vi)] \qquad ....2$$

where Vn refers to the estimated value of the n^{th} parameter of the given sampling station. Vi refers to the ideal value of the n^{th} parameter in pure water. Also, Sn refers to the standard permissible value of the n^{th} parameter.

Step 4: Calculation of unit weight (*Wn)* for the nth parameter.

$$Wn=K/Sn \qquad ....3$$

Step 5: Calculate the *WQI* using the formula,

$$WQI = (\Sigma Wn \times Qn)/(\Sigma Wn) \qquad ....4$$

Evaluating the water for pCO_2

Rivers' partial pressure of aqueous carbon dioxide (pCO_2) indicates the source or sink of atmospheric CO_2 and the degree of gas exchange at the water-to-air interface, reflecting both internal carbon dynamics and upstream terrestrial biogeochemical processes (Liu and Han, 2021). In river systems, bicarbonate

(HCO_3^-), carbonic acid (H_2CO_3), carbonate (CO_3^{2-}), and dissolved carbon dioxide (CO_2aq) make up the total dissolved inorganic carbon (DIC). All these elements, including the equilibrium between atmospheric and aqueous CO_2 and the dissolved ions created by CO_2, are reliant on each other for both temperature and pH. Henry's Law (Stumm and Morgan, 1970) can be used to calculate the concentration of DIC species.

The equilibrium reactions of dissolved inorganic carbon (DIC) species in water can be expressed as follows:

$$CO_2 + H_2O \leftrightarrow H_2CO_3^* \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

where $H_2CO_3^*$ represents the combined concentration of aqueous CO_2(CO_2aq) and true carbonic acid (H_2CO_3).

The equilibrium constants governing these reactions are defined as:

$$K_0 = [H_2CO_3^*] / [pCO_2]$$

$$K_1 = [H^+] [HCO_3^-] / [H_2CO_3^*]$$

$$K_2 = [H^+] [CO_3^{2-}] / [HCO_3^-]$$

Here, K represents the Henry's constant, which is temperature-dependent and used to describe the dissociation equilibria of DIC species in river water. These constants are calculated using the following temperature-based equations:

$$pK0 = -7 \times 10^{-5}T^2 + 0.016T + 1.11$$

$$pK1 = 1.1 \times 10^{-4}T^2 - 0.012T + 6.58$$

$$pK2 = 9 \times 10^{-5}T^2 - 0.0137T + 10.62$$

where $pK = -\log K$

Accordingly, the partial pressure of dissolved carbon dioxide (pCO_2) can be expressed as:

$$pCO_2(\mu atm) = [H_2CO_3^*] / K_0 = [H^+][HCO_3^-] / (K_0K_1)$$

Results and Discussion

Hydrochemistry

The various physicochemical characteristics of the water samples from the Karuvannur River basin are presented in Table 1. The pH values of the samples range from 6.5 to 6.9(mean 6.72), which are mildly acidic and fall within the reference values. The pH range of 6.5 to 8.5, which is ideal for drinking water and aquatic life, was met by the water in the Karuvannur River. Alkalinity values ranged from 6.01 to 60.84 mg/L, with a mean of 16.91 mg/L, and all samples had total alkalinity below the standard limit of 600 mg/L. The Total Alkalinity is primarily governed by the dissolution of carbonate minerals at lower pH values (Kumar *et al.*, 2020).

Electrical conductivity (EC), a key indicator of dissolved salts and water quality (Nguyen *et al.*, 2023), ranged from 24.92 to 383.5 µS cm^{-1}, with an average of 90.44 µS cm^{-1}. Greater numbers suggest that there are more dissolved salts in the water (Nau-Hix *et al.*, 2021). Correspondingly, Total Dissolved Solids (TDS) varied between 20 and 230 mg/L (mean 53.5 mg/L), with the highest TDS recorded near the Chettuva backwater, likely influenced by nutrient enrichment. Water can be classified into fresh (TDS < 1000 mg/L), brackish (>1000 mg/L), saline (>10,000 mg/L), and brine (>100,000 mg/L) categories on the basis of TDS concentration (Tiwari et al., 2017). According to this classification, all samples fall under the freshwater category. Elevated TDS in the coastal stretch may be attributed to seawater intrusion, human activities, and redox conditions (Edori and Kpee, 2016; Kumar *et al*., 2016; Krishnakumar *et al*., 2017a, b).

Turbidity ranged from 0.98 to 9.14 NTU (mean 4.16 NTU), with five samples exceeding the BIS limit of 5 NTU. The highest turbidity was recorded at location 14. High turbidity reflects suspended and dissolved particles, reducing light penetration, inhibiting photosynthesis, and affecting aquatic life (Asma'u and Sani, 2025; Edori and Kpee, 2016; Gupta *et al*., 2017). Total hardness varied from 6.07 to 53.29 mg/L (mean 20.29 mg/L), which falls within the highest desirable limit of WHO. Dissolved oxygen (DO) levels ranged from 4.65 to 6.51 mg/L (mean 5.68 mg/L). A number of factors, including low temperature, high altitude, turbulence, and a lack of anthropogenic activity, may have contributed to comparatively high DO at the upper stretch, as shown by the interpolation map (Fig. 2) and a comparative decline at the middle stations, which have higher levels of human activity. Low dissolved oxygen levels may be caused by the addition of sewage and other waste.

Biochemical Oxygen Demand (BOD) ranged from 0 to 2.64 mg/L (mean 1.09 mg/L), with elevated values in the lower river stretch (Fig. 2), likely influenced by human activities such as cattle bathing and washing (Mitra *et al*., 2018; Ustaoglu *et al*., 2020).

Table 1: Summary of Physico-chemical parameters of Surface water samples from the Karuvannur River, compared with WHO (2017) and BIS (2012) standards

Parameters	Minimum	Maximum	Average	WHO		BIS	
				Highest desirable limit	Max. permissible limit	Highest desirable limit	Max. permissible limit
Temperature(°C)	28.1	31.4	29.4	--	--	--	--
pH	6.5	6.9	6.72	7-8.5	6.5-9.2	6.5-8.5	6.5-9.2
EC (µs/cm)	24.92	383.5	90.44	1,500	3,000	1,500	3,000
TDS (mg/L)	20	230	53.5	500	1000	500	2,000
Turbidity (NTU)	0.98	9.14	4.16	--	--	1	5
DO (mg/L)	4.65	6.51	5.68	--	--	--	--
BOD (mg/L)	0.01	2.64	1.13	--	--	--	--
Alkalinity(mg/L)	6.01	60.84	16.91	--	--	200	600
Total Hardness(mg/L)	6.07	53.29	20.29	100	500	--	--
Chlorides(mg/L)	2.06	77.14	13.36	200	600	250	1000
Sulphates(mg/L)	0.01	6.75	1.47	200	400	200	400
Nitrates(mg/L)	0.04	0.79	0.16	45	--	45	--
Calcium(mg/L)	0.14	0.82	0.4	75	200	75	200
Magnesium(mg/L)	0.01	0.53	0.09	30	150	30	100

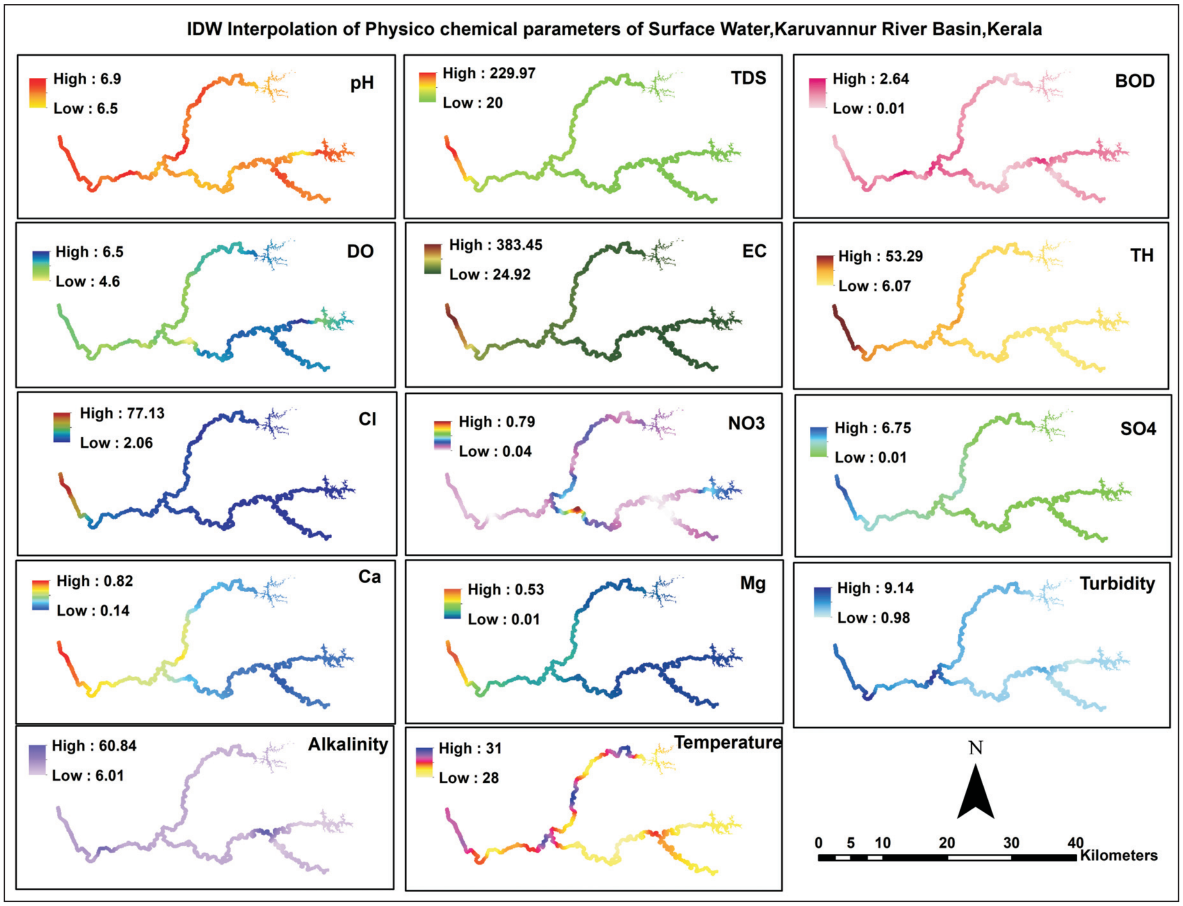

Fig.2. Spatial distribution of key physico-chemical parameters (pH, EC, TDS, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, Mg^{2+}, Alkalinity, Hardness, DO, BOD, Temperature and Turbidity) in surface water of the Karuvannur River, indicating relatively higher values for most of the parameters near the downstream stretch (IDW: Inverse Distance Weighting)

Nitrate concentrations ranged from 0.03 to 0.79 mg/L (mean 0.16 mg/L), while Sulphate levels were low, between 0.01 and 6.75 mg/L (mean 1.47 mg/L). Chloride concentrations ranged from 2.06 to 77.14 mg/L (mean 13.36 mg/L), with higher values in the lower stretches due to seawater intrusion. Calcium and magnesium levels varied from 0.13 to 0.82 mg/L (mean 0.40 mg/L) and 0.01 to 0.53 mg/L (mean 0.10 mg/L), respectively. The spatial distribution of these parameters across the Karuvannur River is illustrated in Figure 2, highlighting variations influenced by both natural processes and anthropogenic activities.

Water Quality Index (WQI)

The Karuvannur River, which flows through the Kole Wetlands, plays a crucial role in agriculture and food production, serving two primary functions: providing drinking water and facilitating irrigation. The significance of these two functions cannot be overstated, as they play an essential role in the livelihoods of residents and the advancement of social development. Table 2 below reveals that the water quality index value ranged between 26.42 and 46.84 with an average value of 34.48, and all the samples are in the 'good' category (26-50).

Quality Comparison of Karuvannur River Basin with Other Systems

The ranges and averages of physicochemical characteristics of surface water in the Karuvannur River were compared with some other rivers in Kerala and significant rivers in India and the World (Table 3). The pH value of the surface water of Karuvannur River is relatively the same as that of other rivers of Kerala, India, and the world. The EC, TA, and TDS values determined in this study are lower than those of Indian and world rivers, although they are almost the same when compared to other rivers of Kerala.

Table 2: Water Quality Index of surface water samples

Samples	WQI	TYPE
1	37.24	Good
2	30.59	Good
3	27.46	Good
4	39.75	Good
5	28.05	Good
6	30.18	Good
7	28.51	Good
8	39.62	Good
9	28.51	Good
10	26.42	Good
11	34.25	Good
12	35.33	Good
13	40.71	Good
14	40.89	Good
15	34.30	Good
16	46.84	Good
17	35.86	Good
18	38.80	Good
19	36.35	Good
20	31.83	Good

Table 3: Ranges and averages (in brackets) of various parameters in surface waters of Karuvannur River compared with other Indian and world rivers

Rivers	pH	TDS	EC	TA	TH	DO	BOD	Ca^{2+}	Mg^{2+}	Cl^{-}	NO_3^{-}	SO_4^{2-}	Reference
Karuvannur River Basin,Thrissur, India	6.5-6.9 (6.72)	20-230 (53.5)	24.92-383.5 (90.44)	0.01-60.84 (15.63)	6.07-53.29 (20.29)	4.65-6.51 (5.68)	0-2.64 (1.09)	0.14-0.82 (0.40)	0-0.53 (0.09)	2.06-77.14 (13.36)	0.04-0.79 (0.16)	0.01-6.75 (1.47)	Present study
Periyar River Basin Kerala, India	5.45-8.11 (6.58)	42-1594 (92)	66-2453 (141)	10-92 (30)	2-25 (10.4)	3.9-9.92 (7.30)	3.7-8.54 (6.65)	0.16-8.8 (2.20)	0.41-2.91 (1.22)	3-25 (14)	0.02-1.14 (0.49)	0.1-84 (3.54)	Aditya *et al.*, 2024
Kallada River Basin, Kerala, India	6.2-6.59 (6.45)	0-25160 (3249.8)		0-117.12 (30.54)	12-580 (122.3)	6.16-9.49 (7.75)		0.4-6.18 (3.46)	0.3-14.65 (3.15)	9.73-11864.5 (1121.7)	0.03-0.74 (0.26)	0.27-38.1 (8.85)	Mohan and Krishnakumar, 2021
Thuthapuzha Kerala, India	6.8-7.8 (7.31)	17.4-48 (29.47)	33-80 (49.55)	13.04-34.5 (21.1)				3.21-6.41 (4.86)	0.49-2.92 (1.89)	3-11.27 (6.13)	0.18-0.56 (0.32)	0.76-2.5 (1.43)	Manjula and Unnikrishnan , 2019
Karamana River Basin Kerala, India	6.2-7.96 (7.2)21				14-2 (82)			8.8-190 (69.2)	0.36-29.02 (10.2)	12-1012.2 (317.9)	1.2-52 (19.9)	3.3-376.2 (65.7)	Sukanya and Sabu, 2020
Chaliyar River, Kerala, India	5.8-7.3 (6.76)	27.9-4118.5 (310.6)	41.7-131.3 (78)		4-100 (39.9)	3.6-7.97 (6.9)					0.007-0.05 (0.026)		Saha *et al.*, 2022
Neyyar River, Kerala,India	6.89	298	1.87	10	112.22	6.08	3.34	17.60	46.36	130.4	0.07	0.95	Krishnakumar et al., 2017b
Kabini River basin Kerala and Karnataka, India	4.62-8.93	44-1059	44-2322	44.04-335.52				7.22-38.6	1.97-33.36		0.22-9.3	0.35-16.81	Gupta *et al.*,2024
Pambar River, India	7.15	151	237	59	52			9.67	6.77				Thomas *et al.*, 2015b
Ganga River, India		6.54 -163.76 (54.02)	99.08 -242.44 (140.56)	43.11- 229 (89.78)	54.88- 246 (90.06)	7.62- 11.19 (9.29)	0.68- 2.94 (1.76)			1.94- 8.76 (5.68)		17.8 -22.4 (20.06)	Matta *et al.*, 2020
Kolong River, Assam, India	6.59-6.75 (6.65)	210.75-299 (257.69)	60-410 (170)	100-360 (231.43)	88-288 (140.71)	0.81-4.05 (2.96)	7.06-17.8 (10.98)			45.44-71 (55.6)		9.82-21.9 (15.45)	Bora and Goswami, 2017
Doyang River, Nagaland, India.	7.41-8.29 (7.84)	64-80.09 (70.35)	144.03-171.23 (151.50)	77.50-100.84 (82.87)	67.17-79.34 (72.52)	7.75-10.61 (9.12)	1.22-3.34 (2.18)	11.09-16.10 (12.99)	8.66-10.88 (9.72)	14.55-17.51 (16.41)	0.49-0.71 (0.64)	12.42-16.94 (14.60)	Lkr *et al.*, 2020
Yamuna River, India	6.6-7.45 (7.18)	332-586 (451.89)	484-874 (665.78)	255-485 (362.22)	855-555 (666.1)	3.2-6.8 (5.66)	1.42-5.32 (2.92)	9.21-104.8 (80.39)	0.55-6.35 (4.87)	141.8-354.5 (200.1)		133.8-385.7 (190.25)	Isaac *et al.*, 2024
Mahi, Gujarat, India	7.6-8.3 (8)		260-1447 (513.53)			1.5-8.2 (6.81)	1.2-11.1 (2.86)				0.1-2.3 (0.86)		Nihalani and Meeruty, 2021
Narmada River, India	7.4-10.05 (7.92)		198.1-2305.5 (473.82)			4.4-8.55 (7.28)	0-4.55 (1.43)				0.25-3.65 (1)		Nihalani and Meeruty, 2021
Tapi River, India	7.2-8.25 (7.74)		297.5-4451 (802.32)			3.45-7.95 (6.15)	0.85-10.7 (4.23)				0-5.55 (0.89)		Nihalani and Meeruty, 2021
Sabarmati River, India	7.6-8.3 (8)		260-1447 (513.52)			1.5-8.2 (6.81)	1.2-11.1 (2.86)				0.1-2.3 (0.86)		Nihalani and Meeruty, 2021
Tigris River, Baghdad, Iraq	7.33-7.7 (7.98)	384.75-649.27 (530.26)	540.91-1201.48 (845.37)	117.84-180.7 (145.16)	242.13-400.11 (328.5)			64.56-112.52 (86.65)	21.76-34.73 (28.5)	46.32-86.13 (66.54)	0.35-0.97 (0.8)	137.18-283.3 (208.95)	Khudair, 2013
Min river basin, Tibet	7.92-8.3	198.2-282.2 (229.9)		106.1-139.7 (120.2)				33.6-44.6 (38.4)	6.1-12.9 (8.4)	3.9-15.2 (7.3)		22.5-46.8 (30.7)	Zhong *et al.*, 2017
Aksu River, Turkey	7.6-8.5 (8.06)		430-1685 (690.37)	22.04-650.26 (255.63)		2.51-9.3 (6.96)		48.09-184.37 (86.7)	29.17-384.13 (80.83)	11.34-1099.26 (97.21)	1.35-5.68 (2.58)	9.12-3091.19 (376.68)	Şener *et al.*, 2017
Meghna River, Banglades	7.8-8.4	160.4-229.9	284.5-466	110.7-119.6	107.2-143.7	7.3-7.5	5.4-6.2						Flura *et al.*, 2016

From Table 3, it is clear that the majority of the world and Indian rivers, and the Kallada River (Mohan and Krishnakumar, 2021), Karamana River (Sukanya and Sabu, 2020), and Neyyar River (Krishnakumar *et al*., 2017b) of Kerala have significantly higher values of TH and Cl^- than Karuvannur River. When compared to other Kerala rivers, the Ca^{2+}, Mg^{2+}, and SO_4^{2-} values found in this study are nearly the same, but they are lower than those of Indian and world rivers. The nitrate content of the majority of the rivers of Kerala is considerably low, similar to the present study, and almost equal to the world average.

Partial Pressure of CO_2

Large CO_2 degassing, often referred to as CO_2 evasion into the atmosphere, is a capability of inshore water bodies worldwide, such as rivers, streams, and seas, and it is essential to the net and global carbon budget. Riverine pCO_2 shows the dynamics of carbon and terrestrial biogeochemical processes, as well as the relative source or sink of the river carbon pool for the atmospheric carbon pool. (Liu *et al*., 2019; Wang *et al*., 2021). In the study area, pCO_2 concentrations were calculated based on the results obtained for pH and HCO_3^- content since the dissolved inorganic carbon species (DIC) concentrations depend on them. In the surface water of the Karuvannur River, the pCO_2 value ranges from 1076 to 13908 µatm. The results showed that the values of pCO_2 were 3 to 36 times higher than the typical atmospheric concentration of 380µatm. The Karuvannur River may be considered net heterotrophic since it is oversaturated with respect to atmospheric CO_2, which indicates a greater value of pCO_2 production. Although Karuvannur River samples have greater pCO_2 values than ambient CO_2, they exhibit a specific pattern with regard to pH levels. Specifically, as seen in Fig. 3, the pH value decreases as the pCO_2 increases. This is because the production of bicarbonate (HCO_3^-) and hydronium ion (H_3O^+) results from an increase in pCO_2, which lowers pH levels. Similar findings were found for several Indian water systems in studies by Thomas *et al.* (2015b), Aditya *et al.* (2024), Liu and Han (2021), and Ciba and Upendra (2024). According to Yu *et al.* (2017), most rivers in the world are supersaturated with pCO_2, whereas the Amazon's tributaries are about forty times supersaturated due to the decomposition of organic matter and the respiration of roots. (Aditya *et al*., 2024; Ciba and Upendra, 2024). Concern over the global carbon cycle has grown as a result of CO_2 escaping into the atmosphere due to the high partial pressure of carbon dioxide (pCO_2) in the river water compared to the atmosphere (Liu and Han, 2021). Increased pCO_2 levels are associated with agricultural and urban effects and murky, deep waters that are perfect for respiratory and in-stream oxidation processes (Zhang *et al*., 2009). As the Karuvannur River flows through the Kole Wetlands, the higher level of pCO_2 may be due to the root respiration and decomposition of organic matter.

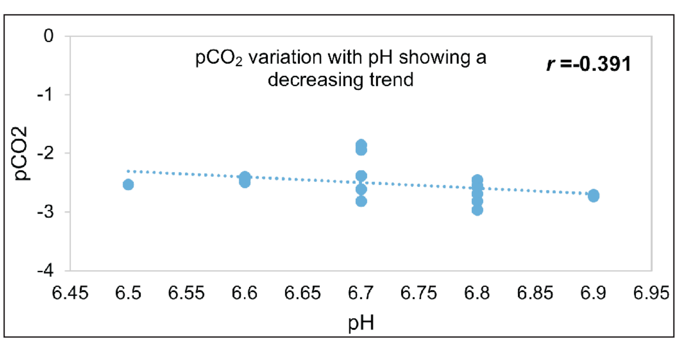

Fig. 3. Relationship between pCO_2 and pH in the Karuvannur River

Conclusions

Assessing water quality and pollution of surface water resources is crucial to maintaining the integrity of the riverine ecosystem. A detailed physico-chemical analysis was performed to assess the potential use of surface water of the Karuvannur River for irrigation and domestic purposes and to create baseline reference data for all upcoming research.

The assessment of the Karuvannur River reveals that its water quality is generally appropriate for domestic and agricultural uses, indicating that the river maintains a stable physicochemical balance with limited signs of environmental degradation. The stability of key water quality parameters within acceptable limits demonstrates the river's capacity to support local livelihoods. However, the measured partial pressure of CO_2 (pCO_2) shows a distinct oversaturation relative to atmospheric levels, signifying that the river acts as a net emitter of CO_2 rather than a carbon sink. This elevated pCO_2 likely results from ongoing biogeochemical activities such as microbial respiration, the breakdown of organic matter, and the influx of soil-derived carbon from surrounding landscapes. These findings underscore the river's dynamic role in regional carbon cycling and its meaningful contribution to the broader global carbon budget.

In alignment with the United Nations Sustainable Development Goals SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15 (Life on Land), this study emphasizes the critical importance of adopting sustainable water management and climate-adaptive governance practices. Sustaining the ecological integrity of the Karuvannur River demands the institutionalization of regular water quality monitoring to detect variations and emerging contamination patterns. Implementing carbon management measures, such as conserving riparian vegetation, controlling organic waste discharge, and minimizing nutrient runoff, can effectively mitigate CO_2 emissions and enhance carbon retention within the watershed. Furthermore, policy frameworks should prioritize integrated river basin management that actively involves local communities, promotes sustainable agricultural practices, and enforces stringent regulation of industrial effluents and riverbed mining. Such coordinated actions will support the maintenance of ecological balance, safeguard water resources, and align with sustainable development objectives.

Authors' Contributions

SS: Conceptualization, Formal analysis, Writing – Original Draft, Visualization, Software, Methodology, Data Curation, Review and Editing. **AK**: Supervision, Investigation, Conceptualization, Review and Editing, Validation. **KA**: Data Curation, Software, Visualization. **SH**: Investigation, Visualization, Validation.

Conflict of Interests

The authors declare no competing interests.

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Data Availability

Data will be made available on request.

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