Spatial and temporal variation in surface water chemistry of a tropical river, the river Bharathapuzha, India

Nikhil Raj* and P. A. Azeez

Environmental Impact Assessment Division, Sálim Ali Centre for Ornithology and Natural History, Anaikatty (PO), Coimbatore 641 108, India

The study examines the spatiotemporal variation in water quality and quantity of Bharathapuzha river basin using multivariate statistical analysis tools. The sub-basins varied notably in terms of river discharge, elemental concentration as well as elemental load. It was found that in basins that are more disturbed, monsoonal discharge was much higher than the discharges in other seasons, while the slightly disturbed basin had consistent level of discharge throughout the season. Changes in land use and the impact of dams are major reasons for the spatiotemporal variations in the surface water chemistry of the river.

Keywords. Element load, multivariate analysis, spatio-temporal variation, water discharge, water quality.

RIVERS play a major role in integrating and organizing the landscape, and moulding the ecological setting of a basin. They are the prime factors controlling the global water cycle and in the hydrologic cycle, they are the most dynamic agents of transport[1]. Rivers carry elements, in suspended or in dissolved form, from their source and deposit them sequentially based on their physico-chemical nature at different locations. The suspended load in the river can act as a sink for nutrients and other elements in certain cases, and as a source in certain other cases[2–4]. In spite of their wide-ranging role, presently rivers are under severe threat due to various anthropogenic pressures[5]. Monitoring the surface run-off of a river on a regular basis provides valuable information on the eco-hydrologic conditions of a river basin. Such data provide valuable insights into spatial and temporal variation in water quantity and quality, considered as a measure of the health of a river. Such data are also a measure of the reliability of water-quality models and their predictability[6].

The quality and quantity of surface water in a river basin is influenced by natural factors such as rainfall, temperature and weathering of rocks, and anthropogenic changes that curtail natural flow of the river, or alter its hydrochemistry. Rivers and streams are highly heterogeneous at spatial as well as temporal scales, and several investigators have documented this heterogeneity focusing on the physico-chemical dynamics of rivers. Variation in the quality and quantity of river water is widely studied in the case of several world rivers. Riedel *et al.*[7] examined the spatio-temporal variation in trace elements in Patuxent river, Maryland, while Sileika *et al.*[8] reported the variations in nutrient level in the Nemunas river of Russia. Schaefer and Alber[9] studied nitrogen and phosphorus in Altamaha river, Georgia, while Quadir *et al.*[10] studied the Nullah Aik, a tributary of the river Chenab. Gupta and Chakrapani[11] studied the Narmada river basin; Kannel *et al.*[12] the river Bagmati, and Sundaray *et al.*[13] the Mahanadi basin. Compared to the northern rivers in India, the southern rivers are less studied perhaps due to their smaller size and discharge. Most of the peninsular Indian west-flowing rivers are highly seasonal in discharge and shorter, although they form an effective water realm in their basin and major sources of sediment transport to the Arabian Sea[11].

Among Indian rivers, those flowing through the Indo-Gangetic Plains are the most studied. Subramanian[14] documented inconsistent down-stream variations in river water chemistry. Singh and Singh[5], and Mukherjee *et al.*[15] documented the physical, chemical and biological aspects of the Ganga river. Heavy metals such as Cr, Mn, Fe, Co, Ni, Cu, Zn, and Pb in the sediments of the Ganga river basin have been analysed[16,17]. There are several studies on the tributaries of the Ganges, including the rivers Yamuna[18–20], Gomti[4,21] and Hindon[22] documenting different physico-chemical aspects. Panigrahy and Raymahashay[23] studied the Mahanadi basin, and Singh and Hasnain[24] the Damodar basin. Down south of India, Avvannavar and Shrihari[25] documented the water quality of river Netravathi in Karnataka, and Jeevanandam *et al.*[26] studied the hydro-geochemistry and ground water quality of the Ponnaiyar river basin in Tamil Nadu. Specifically on the rivers of Kerala, Joseph[27] prepared a status report of the Periyar river basin. Sreedharan[28] explored the Valapattanam river basin in Kerala, with special emphasis on the ecology and socio-cultural aspects.

The present study focuses on the river Bharathapuzha that flows through Kerala, one of the populous states in India, catering to the needs of several millions of people. The river is currently facing tremendous pressure due to encroachments, sand and clay mining, and illegal diversion

*For correspondence. (e-mail: ppnraj@gmail.com)

of water. However, the basin remains less examined with regard to important base-line information. The present article focuses on the spatio-temporal variation in water quality of the river.

The Bharathapuzha basin

Kerala, located in the southwest corner of India (8.5°–11°N and 76°–77°E), apparently is rich in water bodies. The Forest Survey of India[29] has estimated that 10,336 km^2 forest area spread over the Western Ghats falls within the State. These forests are the point of origin for 41 rivers flowing towards west to join the Arabian Sea. The Bharathapuzha is the second longest among the west-flowing perennial rivers of the State. Flowing between 10°25′–11°15′N and 75°50′–76°55′E, the river is about 209 km long. Small rivulets originating from different locations in the Western Ghats join to form the four major tributaries of the river, that finally discharges to the Arabian Sea at (Figure 1) Ponnani. The river has a well-developed flood plain and fluvial terrace of recent origin[30]. The total area of the basin is 6186 km^2, of which 4400 km^2 falls within Kerala and the rest in Tamil Nadu. One-ninth of the total geographical area of Kerala is covered by the dendritic drainage network of the river.

The four major tributaries of the river are Kalpathipuzha, Gayatripuzha, Tootha and Chitturpuzha. The Chitturpuzha, the most upstream tributary, joins the Kalpathipuzha at Parali, and forms the river Bharathapuzha. The flow regime of the river includes highlands (>76 m), midlands (76–8 m) and lowlands (<8 m). The Bharathapuzha has nine dams and at several locations smaller check-dams and sub-surface dykes. In recent years, the basin is facing severe water scarcity and drought, especially due to anthropogenic pressures. Unsustainable exploitation of water, instream sand mining and clay mining for brick kilns are among the striking threats to the flow of the river. The river is a crucial water source for the population residing in the four administrative districts, namely Malappuram, Trissur and Palakkad of Kerala, and Coimbatore District of Tamil Nadu.

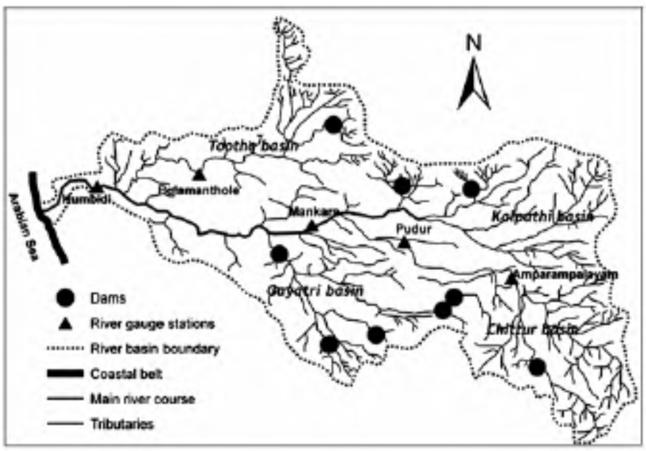


Figure 1. The Bharathapuzha river basin (not to scale) with river gauge stations.

Data collection and analysis

Data on water quality for ten water years (1993–2003) were procured from five river gauge stations under the Central Water Commission (CWC; Government of India). The stations are Amparampalayam, Pudur, Mankara, Pulamanthole and Kumbidi (Figure 1). Amparampalayam lies in the Chittur river basin, located in the upper reaches of the Bharathapuzha basin. It is located in the downstream reaches of the river Aliyar, which is dammed in the Coimbatore District, Tamil Nadu. Amparampalayam is the only river gauge station in the basin located in Tamil Nadu. The gauge station Pudur is located in the lower reaches of Chittur river. The station at Mankara near Palakkad town falls in the main river course. Pulamanthole on the other hand is located in the lower reaches of Tootha river. Kumbidi is the lowermost gauging station and it falls in the river course (Table 1).

Multivariate statistical techniques like hierarchical cluster analysis (HCA), and principle component analysis (PCA) were used to segregate and examine the water quality data procured from CWC, of the five river gauge stations in the river basin for 10 water years (1993–2003). For spatio-temporal analysis, multivariate statistics is considered to be an appropriate tool, and a number of studies have revealed its efficiency[10,13,21]. HCA is used to study the spatial variation in water quality as well as quantity among stations.

Results and discussion

Variation in the river water discharge

The annual total discharge at the five river gauge stations in the basin varied considerably. The discharge also varied with season, with the river getting its bulk supply of water during monsoon. The average annual water discharge of the river at Kumbidi, the lowest location was 3.94 km^3, varying between 3.40 and 10.83 km^3. Among the tributaries, the highest average annual discharge was seen at

Table 1. River gauge stations

River gauge station	Location	Tributary
Amparampalayam	10°37′N/76°56′E	Chittur river
Pudur	10°46′N/76°34′E	Chittur river
Mankara	10°44′N/76°28′E	Main river
Pulamanthole	10°53′N/76°11′E	Tootha river
Kumbidi	10°50′N/76°2′E	Main river

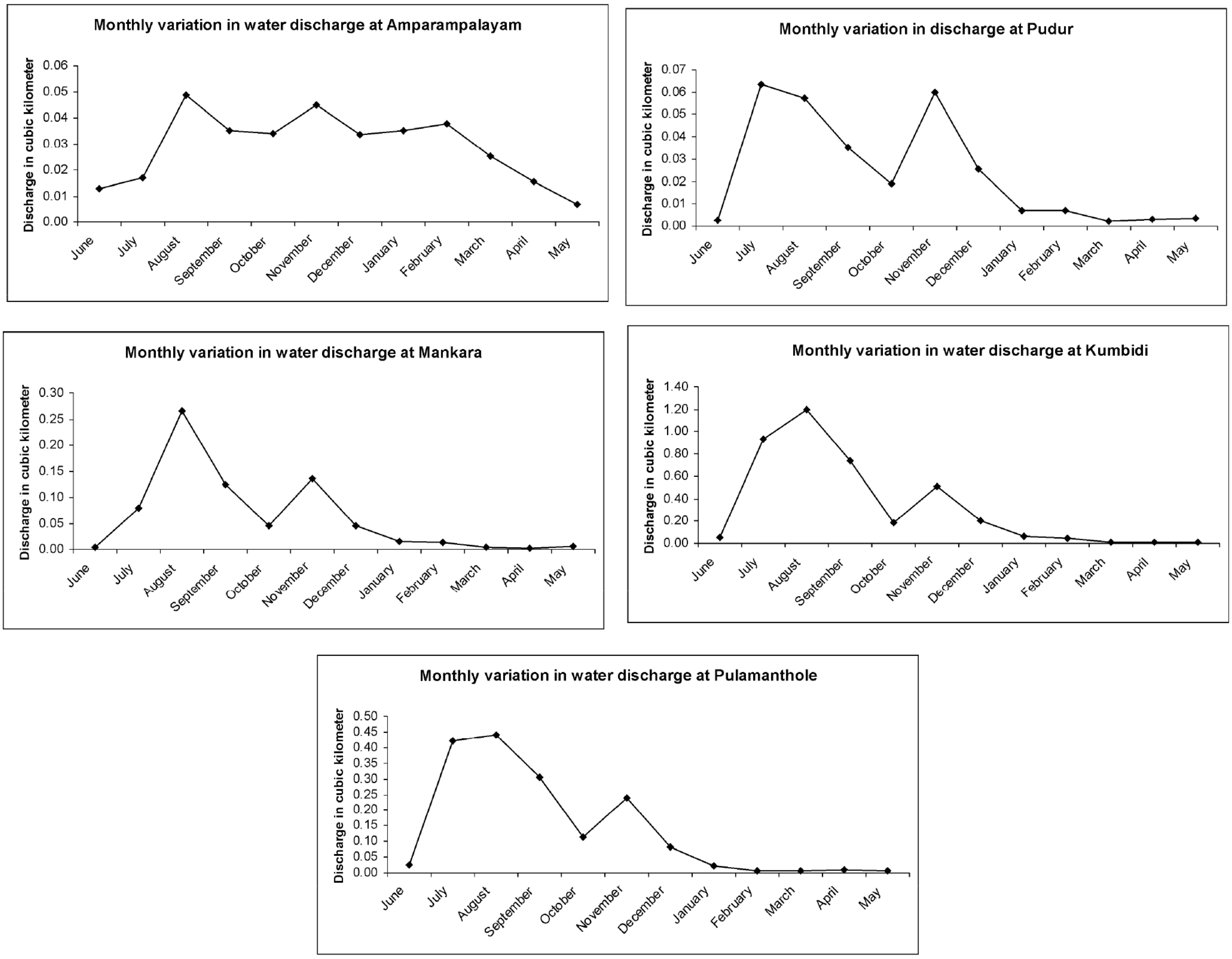


Figure 2. Monthly variation in water discharge at different gauge stations in the Bharathapuzha river basin.

Table 2. Discharge profile at various stations in the Bharathapuzha river

Station	Average discharge (km^3)	Lowest discharge (km^3)	Highest discharge (km^3)
Amparampalayam	0.35	0.06	0.75
Pudur	0.29	0.03	0.75
Mankara	0.74	0.05	1.72
Pulamanthole	1.67	0.11	3.00
Kumbidi	3.94	3.40	10.83

Pulamanthole (1.67 km^3). The lowest average discharge was seen at Pudur (0.29 km^3) ranging between 0.03 and 0.75 km^3 among the years (Table 2). The high contribution from the river Tootha maybe for the large stretches of comparatively less-disturbed evergreen forests such as Silent Valley, Siruvani and Muthikkulam on the upper reaches of the river basin. The forested area may be a significant factor for the consistently high discharge of water round the year. Moreover, the basin apparently falls under 'slightly disturbed area', according to the classification proposed by Gordon *et al.*[31]. The richly forested area, apparently sponging the rainwater[32,33], enhances its retention, promotes percolation and recharge of groundwater, and allows slow release to the river[34]. Thick vegetation cover is also known to reduce the evapotranspiration loss[35]. However, increase in evapotranspiration and possible induction of rainfall is also suggested by Calder[36]. Compared to other parts of the Bharathapuzha basin in this region, agriculture is less extensive, illicit water diversion from the river basins is low and urban pressure is much lower. All other tributaries of the Bharathapuzha river are dammed up for irrigation projects and exploitation of water for agriculture and other human uses is high.

The water discharge of the Bharathapuzha river is almost fully under the control of the monsoon rainfall. The monthly average discharge among the stations was highest during June–July for all the four stations, except Amparampalayam. In Amparampalayam, the peak flow was during the November–December period, since the area receives more water during the northeast monsoon (Figure 2).

It was found that the monsoon contributes more than 90% of the total annual discharge in all the stations, except the Amparampalayam. In the case of Amparampalayam, the monsoon discharge was almost 65% of the total discharge (Figure 3). The discharge during non-monsoon at Amparampalayam, Pudur and Mankara is likely due to discharges from the reservoirs located upstream in these tributaries; Aliyar dam controls water flow at Amparampalayam and Pudur and Malampuzha dam and Walayar dam in the case of Mankara (Figure 1). However, the influence of upstream dams in the river is highest in case of Amparampalayam, while such influence is lowest on the discharge at Kumbidi. The tributary significantly influencing the discharge at Kumbidi might be the river Tootha, where forest patches at locations like the Silent Valley, the evergreen forest patch of 89 km^2, ensure consistent flow even during lean seasons[34,37,38]. Though the tributary is also embanked by the Kanjirapuzha irrigation project in the Kanjirapuzha river, a tributary of the river Tootha, its influence is apparently lesser compared to the river Kunthi, another sub-tributary flowing from the Silent Valley National Park[39].

Variation in water quality

To explore the spatial variation among different stations, HCA was done (Figure 4). HCA grouped the stations on the basis of spatial similarities. Among the five stations, the water quality of Amparampalayam, Pudur, Mankara and Pulamanthole was relatively similar, while that of Kumbidi was different from all others. This is possibly due to the mixing of water from all the other tributaries, Kumbidi being the lowermost location along the river course. The likely sea-water incursion in the area also may have an influence[40]. Stations located downstreams of high-level water regulators in the form of dams and dykes as in the case of Amparampalayam, Pudur and Mankara were found closer, while Pulamanthole, the only station with least number of dams upstream, was found to lie aside from other stations.

PCA was carried out on the whole dataset, on the chemical composition of the river water to identify the set of factors that could capture the variance of the dataset satisfactorily. PCs with eigenvalues >1.32 were selected, since the plot of eigenvalues against the PCs showed a trend of gradual tapering after the PC 3. On the first PC, the factor loadings of Ca, Cl, K, Na, Mg, PO_4 and SiO_3 were high. On the other hand, Fe, NO_3, F, Al and NO_2 had low factor loadings on the same PC. Fe, NO_3, F and NO_2 had high factor loadings on the second PC (Table 3).

The elements assorted by each PC have been analysed individually to know the trends in their spatial variation. The PC 1 elements Ca, Cl, K, Na, Mg, PO_4 and SiO_3 showed clear variations in their total load (kg/year) in water at each station, with the load being the highest at Kumbidi, the lowermost station (Figure 5).

In the case of PC 2 elements Al, Fe and F, the total annual load was high at Amparampalayam, the uppermost station (Figure 6, Table 4). Regarding the concentration (in mg) of each element, among the stations variations are

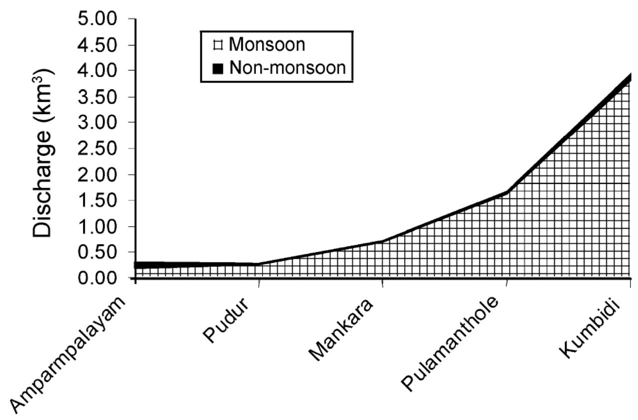
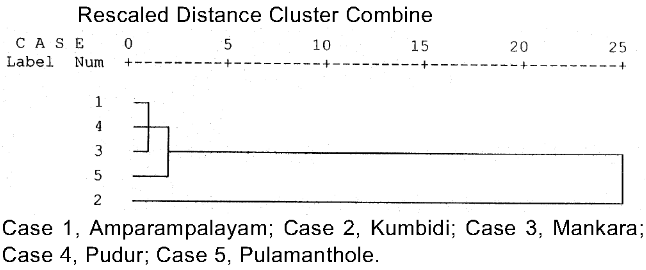


Figure 3. Influence of monsoon on river discharge at various stations.



Case 1, Amparampalayam; Case 2, Kumbidi; Case 3, Mankara; Case 4, Pudur; Case 5, Pulamanthole.

Figure 4. Dendrogram showing average linkage between stations.

Table 3. Factor loadings on the principal components for various water-quality parameters of the river Bharathapuzha (extraction method: principal component analysis; rotation method: varimax with Kaiser normalization. A rotation converged in five iterations)

	Principal components		
Parameter	PC 1	PC 2	PC 3
Al	–0.02	0.44	–0.06
Ca	0.97	–0.01	0.09
Fe	–0.01	0.77	0.12
Cl	0.96	–0.03	0.02
CO_3	0.03	0.02	0.81
F	0.01	0.60	0.07
HCO_3	0.20	–0.01	0.00
K	0.95	0.02	0.07
Na	0.96	0.05	0.05
NH_4	0.07	0.02	0.80
NO_2	–0.02	0.54	–0.18
NO_3	0.00	0.74	0.44
PO_4	0.85	–0.08	–0.06
SiO_3	0.85	–0.01	0.02
SO_4	0.45	0.00	0.07
Mg	0.90	0.01	0.02

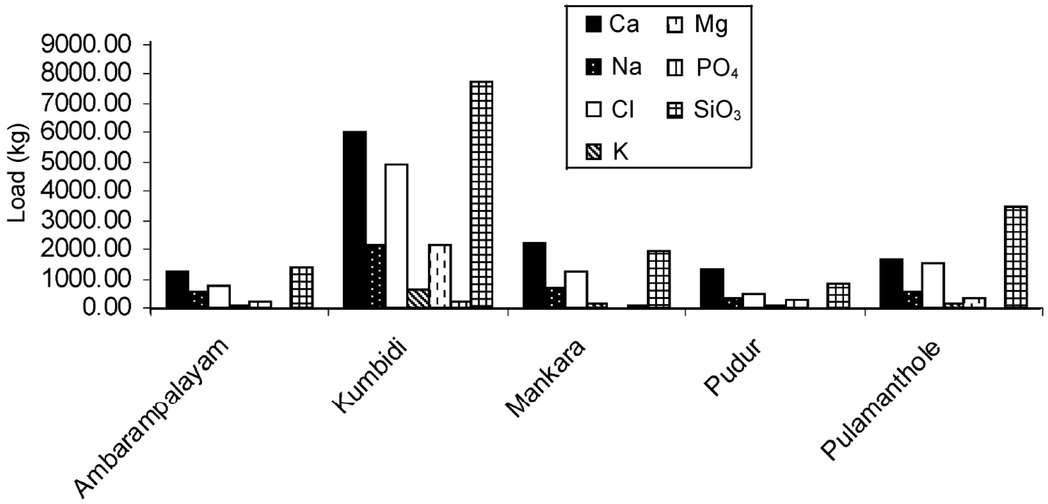


Figure 5. Spatial variation in PC 1 elements.

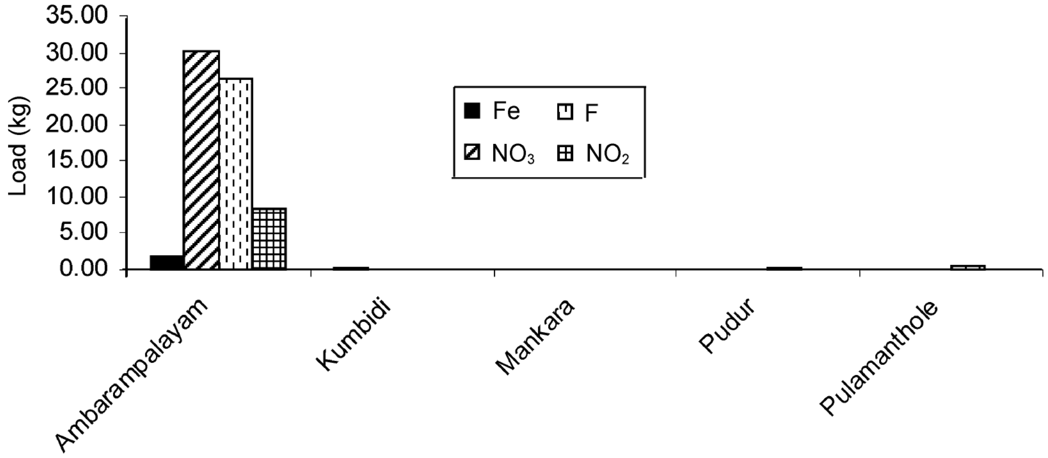


Figure 6. Spatial variation among PC 2 elements.

Table 4. Observed range in element concentration (mg) at different locations with average values (in bracket)

Element	Amparampalayam	Pudur	Mankara	Pulamanthole	Kumbidi
Ca	16–108.8 (46.43)	0–94.4 (45.14)	0–81.6 (33.35)	0–19.2 (10.63)	0–49.6 (18.81)
Cl	0–73.84 (16.53)	0–46.8 (19.29)	0–49.7 (18.72)	0–31.2 (10.30)	0–33.4 (13.21)
K	0–9.36 (2.76)	0.39–3.51 (2.15)	1.17–5.07 (2.30)	0.39–9.16 (1.28)	0.39–5.07 (1.59)
Na	0–70.84 (17.99)	1.38–40.02 (14.31)	5.06–30.36 (11.99)	0–47.39 (7.52)	2.53–19.09 (7.94)
Mg	0.05–35.55 (9.71)	4.3–31.72 (9.78)	0–60.72 (1.81)	0.96–7.68 (2.13)	0.96–11.04 (4.16)
PO_4	0–2.6 (0.05)	0.04–5.55 (0.45)	0–8.73 (0.53)	0–1.45 (0.24)	0–0.97 (0.28)
SiO_3	20.7–104.4 (44.00)	0.69–68.31 (22.06)	18.1–121.4 (26.23)	8.09–59.34 (19.83)	10.07–68.31 (22.07)
Al	0–79.47 (1.95)	0	0	0	0
Fe	0–0.2047 (0.07)	0	0	0	0–0.144 (0.0032)

obvious (Table 4), although there are considerable overlaps in the concentrations ranges.

Fluoride-rich rocks such as flurospar (CaF_2), cryolite (Na_3AlFPO_6), fluorapatite ($Ca_5(PO_4)_3F$) may contribute to the fluoride levels. Upstream area of this station is known to be prone to flurosis. The early portions of the command area of the Parambikulam–Aliyar irrigation project, an inter-state project, is of contention regarding water-sharing between Kerala and Tamil Nadu[41]. The range of chemical parameters in the downstream water profile is modified by the diluting and concentrating effects of tributary inflows[14], or due to the specific physico-chemical characteristics of an element or a group that determine their persistence in the water column. For example,

Table 5. Average annual element loading (kg) at different stations

Element	Amparampalayam	Pudur	Mankara	Pulamanthole	Kumbidi
Ca	1098.69	3276.74	2227.52	4420.01	11331.81
Cl	1205.61	2421.87	1251.91	1401.47	4902.77
K	118.88	50.15	127.68	125.76	817.94
Na	698.72	376.59	700.30	488.67	5032.15
PO_4	2.01	18.65	42.60	33.88	224.29
SiO_3	1213.93	805.55	1964.72	3208.63	13482.54
Mg^{2+}	401.53	258.87	30.57	320.53	2986.05
Fe	5.23	0	0	0	0.2300
F	40.78	0	0	0	0
NO_2	8.49	0	0	0	0
NO_3	43.54	0	0	0	0
CO_3	29.14	68.87	22.86	0	11.46
NH_4	3.27	0.07	0	0	3.83

reactive elements like Fe are oxidized at a faster rate during their course down and probably are settled. Similarly, highly conservative elements like aluminium do not move down fast and for longer distance along the flow.

The higher annual load (Table 5) in elements, especially Ca and Mg basically arises from the ancient crystalline basement rocks of the Western Ghats. But it is also possible that effluents containing the residues from soaps and detergents[10] cause local enrichment of the elements. Presence of PO_4, on the other hand, is possibly from the agriculture run-off and also due to other anthropogenic activities like excessive mining[24]. The high annual load in Cl, Na and Mg is perhaps due to the salt-water incursion from the sea during the time of lean flow in the river. Nitrate and nitrite nitrogen also may be present due to intensive fertilizer use in agriculture. Being the lowermost location, the water flesh out to the sea at Kumbidi holds sand and sediments in higher concentration[37]. In the case of SiO_3, Na and K, the increase in annual load is likely due to the association of these elements with clay[19].

Summary

The Bharathapuzha river basin is the second longest southwest-flowing river of Kerala. This article examines baseline information on water quality and water discharge in view of the characteristics of the sub-basins. The average discharge of the river basin was 3.94 km^3 per year at the lowermost station, Kumbidi. The study identified distinct spatial variation in water chemistry. Spatial variations in the water discharge, water quality and elemental load can be due to changes in land use, especially reduction in forest cover in the catchments and due to irrigation projects.

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