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Water quality variations as linked to landuse pattern: A case study in Chalakudy river basin, Kerala

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Linkage between landuse pattern and water quality is an emerging field of multidisciplinary research. Change in landuse practices, particularly urbanization and intensive agriculture lead to water quality deterioration. The present study in Chalakudy river basin in Kerala based on an analysis of 27 water samples spread over five landuse types and monitored during four seasons, substantiated this argument. Samples under urban landuse showed poor water quality throughout the year. Correlation analysis of various parameters indicated seasonality in physico-chemical characteristics of river water, which was linked to fluctuations of drainage discharge and changes in landuse pattern.

Keywords: Chalakudy river basin, landuse pattern, physico-chemical characteristics, water quality.

SPATIAL variation in river water quality has been reported in various catchment studies and most of the researches focused on hydrological pathways and biogeochemistry linked to vegetative canopy cover, soil and rock types and discharge[1]. Problems arising out of water quality deterioration are as severe as those related to water availability. It is reported that about 70% of India's surface water resources is already contaminated[2]. The condition in Kerala is equally alarming and water in various stretches of many rivers in the state is not potable[3].

Apart from climate-induced changes which are long-term and therefore slow, direct anthropogenic modification of landcover such as agriculture, aforestation, mining, urbanization, industrialization, and intervention on hydrological regimes like irrigation and damming have resulted in marked changes in water quality[4]. Several studies were attempted to address the linkage among landuse practices, water quality, sediment geochemistry, nutrient loading and drainage discharge[5–7]. However micro-level studies covering landuse change, water quality and its seasonal variation are few[8]. The present study in Chalakudy river basin is one such attempt to assess water quality in different seasons and link the spatial and seasonal variations of water quality to landuse variations. This is important, especially when investigating diffused non point source pollution[8].

The Chalakudy river basin with an area of 1525 km^2, is a tributary of the Periyar, the largest river in Kerala. There are six reservoirs impounded in this basin. The present study is limited to the stretch from the Poringalkuttu reservoir to the confluence of the Chalakudy river with the Periyar (Figure 1). The length of this stretch is 80 km, with a catchment area of 583 km^2. Relief varies from 20 m at the river mouth to 1000 m in the northeastern part of the catchment. Dominant rock types are charnockite and biotite gneiss, with recent sediments in the western part and along the river. Geomorphologically, this stretch is characterized by floodplain, transitional plain, low rolling terrain, moderately undulating terrain, highly undulating terrain and hilly area. Average annual rainfall in this area is around 3300 mm, varying from a little over 3000 mm in Chalakudy town to 3700 mm in Poringalkuttu. Seasonal variation of temperature is within 5°C. Total average annual drainage discharge (1980–2000) is 1421.81 million m^3 near Chalakudy town, as reported by the Irrigation Department, Government of Kerala.

Current landuse data (2002) were extracted by scanning IRS-1D PAN (P 099-R 066, 58 B/7 SE and SW dt. 12 January 2002) and IRS-1D L3 (P 099-R 066, 58 B/7 dt. 12 January 2002, FCC-merged) images supplemented by extensive field investigation. Topographical maps (1 : 50,000 scale) provided information about past landuse (1966–67). Table 1 presents landuse pattern during these two time periods and the changing trend. Forest and forest plantations, and settlement with mixed tree crops dominate landuse in this basin. This area also experiences widespread landuse changes. Paddy fields have reduced considerably. The area under agglomerated settlement has recorded the highest growth of +75%, which is the emerging trend in the state.

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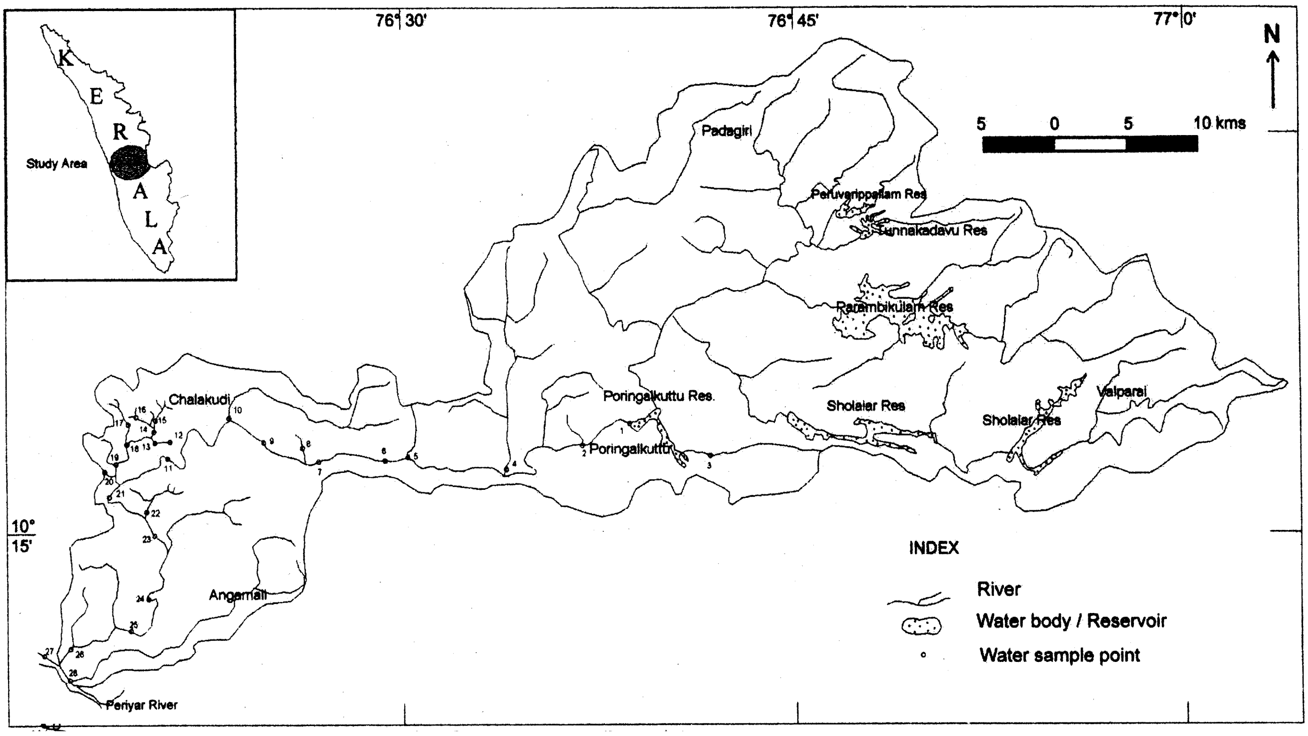

Figure 1. Chalakudi river basin and location of surface water sampling points.

Table 1. Landuse in the study area

	1966–67		2002		
Landuse category	Area	%	Area	%	Change (%) (1966–67 to 2002)
Forest and related plantations (F) (S. N-1, 2 and 4)	288.00	49.40	278.00	47.70	–3.50
Rubber and other plantations (P) (S.N–3, 5 and 6)	14.00	2.40	22.00	3.80	+57.10
Settlement with mixed tree crops (SMT) (S.N-7–11, 17 and 21–28)	176.00	30.20	244.00	41.90	+38.60
Agglomerated settlement/Urban settlement (US) (S.N-12 and 13)	4.00	0.70	7.00	1.20	+75.00
Paddy land (R) (S.N-15, 16, 18–20)	101.00	17.30	32.00	5.40	–68.30
Total area	583.00	100.00	583.00	100.00	–

S.N-1,2,3 …, Sample numbers referred in Figure 1. Sample number 14 not considered.

Altogether 27 surface water samples were collected from the main river and major tributaries during August 2001, November 2001, March 2002 and June 2002. These samples were grouped according to the major landuse categories covering forest (three samples), plantation (three samples), settlement with mixed tree crops (SMT; 14 samples), urban/agglomerated settlement (US; two samples), and paddy field (five samples). Water samples were analysed in the Chemical Science Laboratory of CESS, Thiruvananthapuram following standard American Public Health Association procedures. The discussion here will be limited to selected physico-chemical parameters like pH, DO, Cl, NO_3-N, PO_4-P, Ca, Mg and TH (total hardness). Other parameters like Na, K, SO_4, etc. which are essential for determining water quality were not considered in this study as the main objective of this communication is to demonstrate variations of water quality as linked to landuse and not water quality per se. Spatial and temporal variations of the selected elements will bring out the impact of landuse on water quality.

Analytical results of surface water samples (Table 2) indicated that river water was mildly acidic with pH

Table 2. Physico-chemical characteristics (selected) of surface water samples under different landuse types

Parameter	Landuse		Aug. 2001	Nov. 2001	March 02	June 02	Average of all observation
pH	Forest	A	6.60	6.62	6.49	6.31	6.50
		SD	0.34	0.02	0.11	0.36	0.27
	Plantation	A	6.23	6.60	6.47	6.57	6.49
		SD	0.12	0.09	0.18	0.43	0.29
	SMT	A	6.42	6.57	6.31	6.30	6.40
		SD	0.35	0.39	0.27	0.44	0.38
	US	A	6.09	6.56	6.60	6.16	6.33
		SD	0.14	0.16	0.03	0.07	0.25
	Paddy	A	6.24	6.57	6.21	6.41	6.37
		SD	0.21	0.16	0.04	0.22	0.23
DO (mg/l)	Forest	A	8.88	8.51	7.61	7.36	7.62
		SD	0.00	0.24	0.44	0.57	0.73
	Plantation	A	9.56	8.38	8.95	8.23	8.46
		SD	0.22	0.70	4.78	0.53	2.59
	SMT	A	7.57	7.17	6.36	6.17	6.73
		SD	0.73	0.78	1.24	1.06	1.14
	US	A	0.89	1.23	4.03	1.25	1.73
		SD	0.00	0.47	0.96	0.29	1.27
	Paddy	A	6.54	6.33	6.39	4.59	5.91
		SD	0.67	1.06	0.18	1.59	1.35
Cl (mg/l)	Forest	A	2.02	12.41	20.19	26.60	16.51
		SD	0.02	3.38	1.68	1.88	8.89
	Plantation	A	2.02	15.17	23.75	33.25	20.05
		SD	0.02	1.95	4.44	13.56	13.17
	SMT	A	2.03	16.89	33.04	26.60	20.97
		SD	0.51	4.29	23.34	2.97	16.27
	US	A	10.14	61.36	53.45	54.53	44.09
		SD	7.59	32.32	28.51	13.17	30.61
	Paddy	A	2.23	23.17	23.75	27.13	18.55
		SD	0.40	4.22	3.36	3.91	10.77
NO_3-N (mg/l)	Forest	A	0.42	0.15	0.21	0.88	0.42
		SD	0.34	0.20	0.04	0.40	0.41
	Plantation	A	0.97	0.04	0.43	0.56	0.46
		SD	0.82	0.03	0.05	0.22	0.48
	SMT	A	1.12	0.57	0.44	1.07	0.77
		SD	1.06	0.47	0.27	0.31	0.63
	US	A	4.16	3.69	2.42	4.14	3.77
		SD	1.95	2.86	0	0.51	1.96
	Paddy	A	1.39	0.71	0.37	1.09	0.93
		SD	1.81	0.58	0.07	0.23	1.07
PO_4-P (mg/l)	Forest	A	0.27	0.19	0.28	0.23	0.24
		SD	0.02	0.02	0.03	0.08	0.06
	Plantation	A	0.22	0.24	0.41	0.31	0.30
		SD	0.03	0.05	0.12	0.04	0.10
	SMT	A	0.26	0.19	0.49	0.29	0.31
		SD	0.07	0.05	0.08	0.05	0.13
	US	A	0.67	0.60	2.66	0.45	0.87
		SD	0.19	0.06	0	0.08	0.75
	Paddy	A	0.18	0.17	0.38	0.22	0.22
		SD	0.04	0.04	0.13	0.06	0.10
Ca (mg/l)	Forest	A	2.41	3.47	10.00	3.21	4.99
		SD	0.81	1.00	0.00	1.31	3.23
	Plantation	A	2.41	2.13	12.00	2.67	5.02
		SD	0.81	0.38	5.89	0.76	5.30
	SMT	A	4.61	4.68	43.67	11.23	17.08
		SD	0.96	2.38	45.49	20.84	30.93
	US	A	14.43	13.23	70.00	20.04	23.63
		SD	0	2.01	0	0.80	19.17
	Paddy	A	4.81	4.33	11.33	7.05	6.39
		SD	1.43	0.64	0.94	1.64	2.76

(*contd…*)

Table 2. (*Contd…*)

Parameter	Landuse		Aug. 2001	Nov. 2001	March 02	June 02	Average of all observation
Mg (mg/l)	Forest	A	4.85	1.30	0.75	2.35	2.21
		SD	3.86	0.83	0.26	2.48	2.68
	Plantation	A	1.46	0.73	0.98	5.83	2.65
		SD	0.49	0.24	0.49	1.59	2.47
	SMT	A	1.87	2.17	1.84	1.98	1.98
		SD	0.75	2.11	2.01	0.98	1.61
	US	A	4.37	5.59	2.43	3.89	4.30
		SD	1.46	3.16	0	0	2.12
	Paddy	A	1.62	0.78	0.65	1.26	1.06
		SD	0.46	0.39	0.23	1.35	0.89
TH (mg/l)	Forest	A	26.00	10.00	12.00	17.33	15.45
		SD	14.00	1.63	1.63	8.23	9.38
	Plantation	A	12.00	7.33	14.67	30.67	16.55
		SD	0	1.89	8.06	8.22	10.92
	SMT	A	18.25	16.00	49.33	21.00	26.86
		SD	3.38	5.10	48.07	3.32	28.90
	US	A	46.00	43.00	80.00	66.00	55.71
		SD	2.00	5.00	0	2.00	14.04
	Paddy	A	22.00	16.40	19.00	20.00	18.56
		SD	12.26	3.20	0.00	6.20	8.00

A, Mean; SD, Standard deviation.

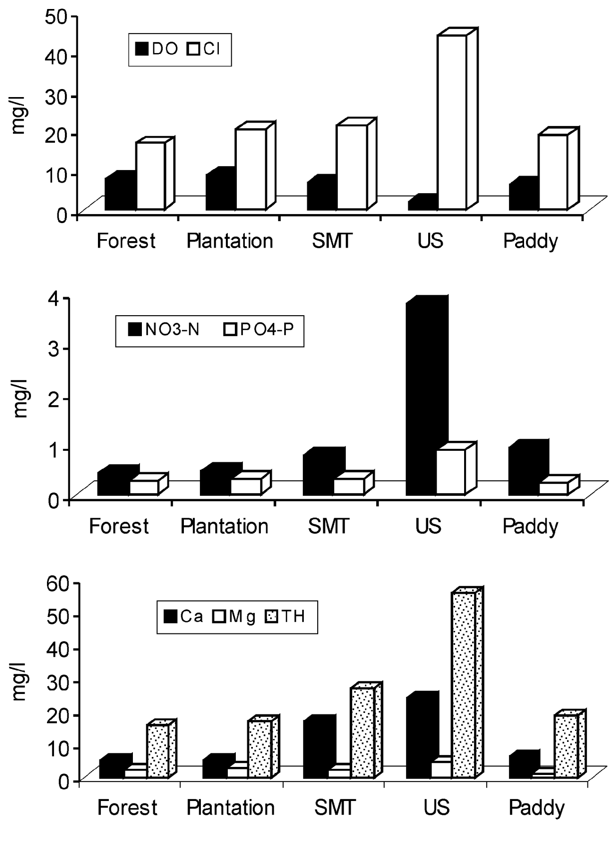

Figure 2. Physico-chemical characteristics (selected) of surface water samples under different landuse types.

value varying from 6 to 6.6. However, these are average data. Considering individual sample data, the trend is a little different. During August, pH value went down to 5.93 in one of the sample sites under urban landuse, whereas the highest value (6.95) was recorded in a sample site under the category SMT. Except one station, in all others pH value was more than 6. In November, pH value ranged from 5.45 to 7.02, and both these sample sites were under SMT. Barring these two, all other sites had pH value ranging between 6 and 7. All the sampling sites recorded pH value more than 6 during March. In June, pH varied from 5.77 to 7.09. This variation was high compared to other months, which is further corroborated by the fact that considering all sampling stations together, the standard deviation of pH values during this month was the highest (0.38) compared to the other three months of August (0.31), November (0.28) and March (0.24). The least variability in March (with standard deviation of 0.24) can be attributed to limited stream discharge and no over-land flow. Catchment parameters did not contribute much during this dry period. Standard deviations worked out for each landuse category separately (Table 2) had shown low variability in March. In the case of urban area, the highest standard deviation was during November. It may be summarized that river water experiences variations in pH over the seasons and under different landuse categories albeit limited.

TH of natural water depends on the presence of calcium and magnesium salts. Mean values covering all the seasons showed that hardness was high for the samples under urban landuse and low under plantation (Table 2, Figure 2). Due to very low flow in the river segment adjoining urban areas during March, the hardness value was very high. High average value (55.71) and low standard deviation (14.04) recorded under the category of urban landuse indicated that urbanization affected water quality and there was little dilution effect over the seasons. Spatial distribution indicated that hardness increased towards the mouth of the Chalakudy river where it joins the Periyar river, which is influenced by brackish water as the Periyar outfall to the sea is just around 15 km from the Chalakudy–Periyar confluence point.

In the case of DO, higher values were recorded under forest and plantation, whereas it depleted significantly in the urban area (Table 2). During March, when river water flow was low (Table 3) and in some places there was no water in the river, the average DO values in the case of urban area (3.07) are slightly higher compared to other seasons. However, compared to the other four landuse categories, the values were lower (Figure 2). Standard deviation of DO values was low for all the landuse categories during August and generally high during March. Seasonal variation of DO is related to temperature and biological activities[9]. Temperature rises during March, with a maximum of 33.45°C (Table 3), and due to reduction in drainage discharge the river water level is low and is easily heated up. When DO value depletes below 2 mg/l, as is recorded in the urban area, survival of fish population is doubtful. Disaggregated data on fish catch are not available at the present instance; however, it has been reported from other studies that concentrations below 5 mg/l may adversely affect the functioning and survival of biological communities and below 2 mg/l, may lead to the death of most fish[9]. Local enquiry indicated decrease and sometimes non-availability of certain fishes in the river segment adjoining the urban area. Water quality deterioration is one of the factors cited by the fishermen (K. H. Amitha Bachan, unpublished).

Chloride enters into the surface water from natural source like atmospheric deposition of oceanic aerosols and weathering of rock salts. Anthropogenic sources are industrial domestic sewage effluents, and run-off from agricultural fields through fertilizers. Urban area recorded the highest value for all four months and average of all observations (Table 2, Figure 2). Standard deviation was also high under the category of urban landuse. Pristine freshwater has a value less than 10 mg/l[9]. The entire river stretch flowing through different landuse types shows good freshwater quality only during August due to the influence of monsoon. Standard deviation values were also low during this month, and urban category value was more than 10 mg/l. The possible source of chloride is sewage discharge and agricultural run-off.

Nitrate (NO_3-N) in surface waters is an important topic of research[10]. Igneous rocks, land drainage, plant and animal debris are the natural sources of nitrate to surface water. Seasonal variation of nitrate is mostly caused by plant growth and decay. Mean value covering all four months varied from 0.42 mg/l under forest cover to 3.8 mg/l under urban landuse (Table 2; Figure 2). Seasonal variations indicated low values during March under all landuse categories. Standard deviation values were also low during this month. Nitrate values were generally high during June and August, coinciding with the monsoon, when there was luxurious plant growth and abundance of decayed vegetative matter. Elevated values under urban landuse (Figure 2) were due to direct sewage disposal in the water body. So far as paddy fields are concerned, application of nitrogenous fertilizer and decay of straw perhaps contributed to high nitrate concentration during monsoon months. The build-up of dry deposition and dead plant material in a dry spell may mean that over-land flow during monsoon will have a high solute concentration[10].

There are studies indicating positive relationship between concentration of NO_3-N and increase in drainage discharge[9,10]. Although Figure 3 depicting NO_3-N concentration and distance from the reservoir (an indirect measure of discharge) shows a positive trend, the scatter plot and weak correlation coefficient value perhaps manifested contribution of local influence, mainly landuse.

Phosphorus, an essential nutrient for living organisms, occurs in water bodies as both dissolved and particulate

Table 3. Average drainage discharge (1980–2000) and average temperature (1983–88)

Month	Discharge (in million m^3)	Temp. (max. °C)	Temp. (min. °C)
January	35.48	31.41	19.90
February	26.42	32.68	20.92
March	28.11	33.45	22.55
April	27.53	32.26	23.47
May	30.92	32.10	24.34
June	196.48	28.33	23.54
July	382.28	27.40	23.54
August	318.72	28.33	23.43
September	159.55	29.60	25.14
October	112.47	29.78	22.74
November	65.24	29.49	21.16
December	38.61	31.29	21.83
Total	1421.81		

Source: Irrigation Department, Govt of Kerala.

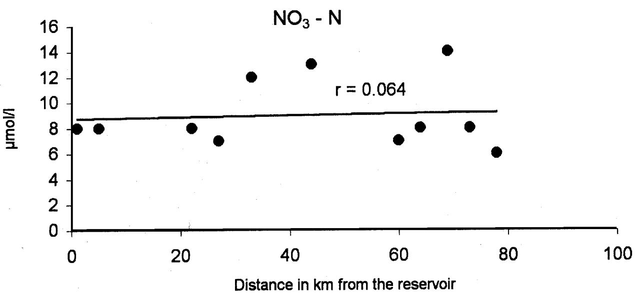

Figure 3. Scatter plot showing distribution of NO_3-N and distance from the reservoir.

Table 4. Correlation coefficient of selected physico-chemical parameters

Parameter	pH	DO	NO_3-N	PO_4-P	Chloride	TH	Ca	Mg	TSS	TDS
March 2002										
pH	1.00									
DO	0.27	1.00								
NO_3-N	0.15	–0.24	1.00							
PO_4-P	0.11	–0.36	0.84	1.00						
Chloride	–0.33	–0.20	0.15	0.42	1.00					
TH	–0.34	–0.26	0.09	0.39	0.95	1.00				
Ca	–0.37	0.22	0.09	0.37	0.97	0.99	1.00			
Mg	0.11	–0.45	–0.01	0.25	0.62	0.71	0.60	1.00		
TSS	0.20	–0.28	0.86	0.95	0.30	0.22	0.21	0.12	1.00	
TDS	–0.13	–0.36	0.49	0.72	0.90	0.85	0.85	0.50	0.62	1.00
June 2002										
pH	1.00									
DO	0.24	1.00								
NO_3-N	–0.20	–0.60	1.00							
PO_4-P	–0.11	–0.02	0.53	1.00						
Chloride	–0.20	–0.45	0.72	0.51	1.00					
TH	–0.17	–0.56	0.80	0.39	0.74	1.00				
Ca	–0.28	–0.17	0.23	0.29	0.23	0.26	1.00			
Mg	–0.03	–0.01	0.06	–0.05	0.24	0.59	–0.09	1.00		
TSS	0.41	–0.17	0.08	–0.11	–0.12	0.02	–0.09	–0.14	1.00	
TDS	–0.19	–0.67	0.96	0.54	0.81	0.84	0.25	0.09	0.06	1.00

species. It controls primary productivity. Natural sources are mainly weathering of phosphorus-bearing rocks and decomposed organic matter. PO_4-P in natural surface water mostly ranges[9] between 0.005 and 0.020 mg/l. According to this standard, PO_4-P values of all samples in the Chalakudy river were high in all seasons (Table 2). Use of phosphate as fertilizer perhaps contributed in this context, as the basin was predominantly agricultural and in Kerala, application of fertilizers in tree crops is a common practice. However, the most elevated value recorded under urban settlement could be possibly due to sewage discharge (Table 2, Figure 2). Values were high during March for all landuse categories. Standard deviation of the values under the category of forest is low, indicating low variability among samples within the forest area.

Correlation coefficients (r) of selected chemical parameters have been computed for March 2002 and June 2002, representing the dry period and the monsoon season respectively (Table 4). Seasonal variations were observed in r values. During March 2002, correlation coefficients were high between PO_4-P and NO_3-N ($r = 0.84$), PO_4-P and TSS (0.95), NO_3-N and TSS (0.86), Cl and Ca (0.97), Cl and TH (0.95), Cl and TDS (0.90), TH and Ca (0.99), and TH and Mg (0.71). Correlation of NO_3-N with other parameters like TSS and PO_4-P changes with season. In June, NO_3-N recorded the highest correlation value with TDS (0.96), followed by TH (0.80). The correlation coefficient of PO_4-P with TSS and TDS, although high in March, comes down in June 2002, and it was weak negative between PO_4-P and TSS. Similar variations could be found for other elements also. This substantiates the argument that water quality changes with the seasons and interaction of various parameters also changes. Outbreak of monsoon, change in cultivation pattern over the seasons, and application of fertilizer and its seasonal variation have all contributed. TH mainly depends upon Ca and Mg, but there are seasonal variations as evident from the Table 4. Correlation coefficient value between TH and Ca reduces from 0.99 in March to 0.26 in June. This manifests the role of other catchment parameters in TH of river water.

The results presented in this study indicate that variations in water quality were seasonal and linked to landuse practices. Urban area showed significant deterioration in water quality. Even monsoon dilution was not always effective. Lack of proper sewage system in the urban centre is a major factor. It may be noted here that a drain from the Chalakudy market directly leads to the river. In 2002–03, average fertilizer use in Kerala was 69 kg/ha, constituted by 29 kg N, 14 kg P and 26 kg K[11]. The study area dominated by intensive agriculture uses high dosage of fertilizer. Further, low rainfall and six dams in the catchment of the Chalakudy river restrict freshwater flow during dry season. Sediments and nutrients are trapped in these reservoirs. This adds to the overall deteriorating condition of river ecology.

This study has brought out that there is definite relationship between landuse and water quality. Anthropogenic activities are the main contributors to water quality deterioration. Therefore, measures to improve water quality need to address issues of landuse management. It is expected that the findings in this study will be helpful in this context.

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Erratum

Avian brain nomenclature change

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Figures 1 and 3 in the above article have inadvertently got interchanged. The captions, however, remain the same. The error is regretted.

–Editors