Ecohydrology of Lotic Systems in Uttara Kannada, Central Western Ghats, India

**T.V. Ramachandra, M.D. Subash Chandran, N.V. Joshi,
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Abstract The Western Ghats is the primary catchment for most of the rivers in peninsular India. Pristine forests in this region are rich in biodiversity but are under environmental stress due to unplanned developmental activities. This has given rise to concerns about land use/land cover changes with the realization that the land processes influence the climate. Rapid and unscientific land-use changes undermine the hydrological conditions, and deteriorate all the components in the hydrological regime. The developmental programs, based on ad-hocdecisions, are posing serious challenges to the conservation of fragile ecosystems. Considerable changes in the structure and composition of land use and land cover in the region have been very obvious during the last four decades. Pressure on land for agriculture, vulnerability of degraded ecosystems, the vagaries of high intensity rainfall and consequent occurrences of accelerated erosion and landslides, lack of integrated and coordinated land use planning become some of the reasons for rapid depletion of natural resource base. These changes have adversely affected the hydrological regime of river basins, resulting in diminished river/stream flows. This necessitates conservation of ecosystems in order to sustain their biodiversity, hydrology and ecology. In this situation, for resolving present problems and to avoid any future crisis, a comprehensive assessment of land use changes, its spatial distribution and its impact on hydrological regime were carried out. Accordingly, appropriate remedial methods have been explored for the sustainable utilization of the land and water resources in the catchment. The current research, focusing on five rivers located in the central Western Ghats, monitors water quality along with that of diatoms, land use in the catchment and threats faced by these ecosystems.

Keywords Western Ghats · Lotic ecosystems · Water quality · Diatoms

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1 Introduction

Freshwater ecosystems are grouped into lotic and lentic systems, that is, systems comprising of flowing or standing water. There are many varieties of plant and animal communities in these ecosystems which have adapted to the physical conditions associated with them. Environmental pollution, mainly pertaining to water, has gained public interest (Niemi et al. 1990) in recent times. Not only the developed countries have been affected by environmental problems, but also the developing nations suffer the impact of pollution (Listori and World-wide Bank 1990) due to unplanned developmental activities. Surface waters are vulnerable to pollution due to their proximity to pollutants on land which get dispersed off as polluted runoff and wastewaters and also due to the sustained inflow of untreated sewage. Quality of the surface waters are altered by the natural processes such as precipitation, erosion, and weathering as well as from the anthropogenic influences such as agricultural activities, urbanization, industrialization and intensive-exploitation of water resources (Jarvie et al. 1998). These impacts reduce both water quality (Sweeting 1996) and biological diversity of aquatic ecosystems (Maddock 1999).

Rivers play a major role in the assimilation or in carrying off the municipal and industrial wastewater and run-off from agricultural land. The surface run-off is a seasonal phenomenon, which is largely influenced by the climate prevailing in the basin. Seasonal variations in precipitation, surface run-off, interflow, groundwater flow and water inflows/outflows have a strong effect on the river discharge and subsequently on the concentration of nutrients/pollutants in the river water (Vega et al. 1998). Rivers are the main inland water resources for domestic, industrial and irrigation purposes and it is imperative to prevent and control river pollution. This necessitates regular monitoring to have reliable information on quality of water for effective management. In view of the spatial and temporal variations in hydrochemistry of rivers, regular monitoring programs are required for reliable estimates of water quality and conservation of riverine biodiversity. An integrated aquatic ecosystem management requires sound understanding of physical, chemical and biological aspects. An attempt is made in the present study to determine the water quality status through diatoms as bio-indicators in the rivers of central Western Ghats.

The Western Ghats of India, one of the global biodiversity hotspots, is a chain of mountains on the Western Coast with about 1,600 km long and about 100 km wide stretch (between 8°N and 21°N). The region has varied forest types from tropical evergreen to deciduous to high altitude sholas. It is also an important watershed for the peninsular India with as many as 37 west flowing rivers, three major east flowing rivers and innumerable tributaries. In this paper, the water quality along with diatoms, land use in the catchment and threats faced by these ecosystems are evaluated based on the study of five rivers in central Western Ghats. Aim of this work is to understand the ecohydrology of west flowing rivers in the central Western Ghats. The work involved exploring the current water quality status of five rivers of the Uttara Kannada District, Karnataka, assessment of the seasonality of diatoms and application of diatoms in bio-monitoring in Western Ghats, understanding the impact of catchment land-use and land-cover on water quality and diatom community in streams, identification of the stretches with major water pollution and provide recommendation for mitigation and conservation of rivers of Uttara Kannada.

2 Lotic Ecosystems of Central Western Ghats: An Overview on the Study Area

Rivers of the central Western Ghats are unique in their geomorphology, due to the presence of 'river capture' in most of the rivers. When the Indian plate moved away from the Gondwanaland, peninsular portion experienced an eastward tilt, which changed the pattern of drainage in many rivers. In many cases, like Sharavathi and Kali rivers in Uttara Kannada (Fig. 1), the western faulting led to 'river capture' and diversion of the easterly drainage to the west (Radhakrishna 1991; Kamath 1985). Five rivers are chosen for the present study. Brief descriptions on them are presented herein.

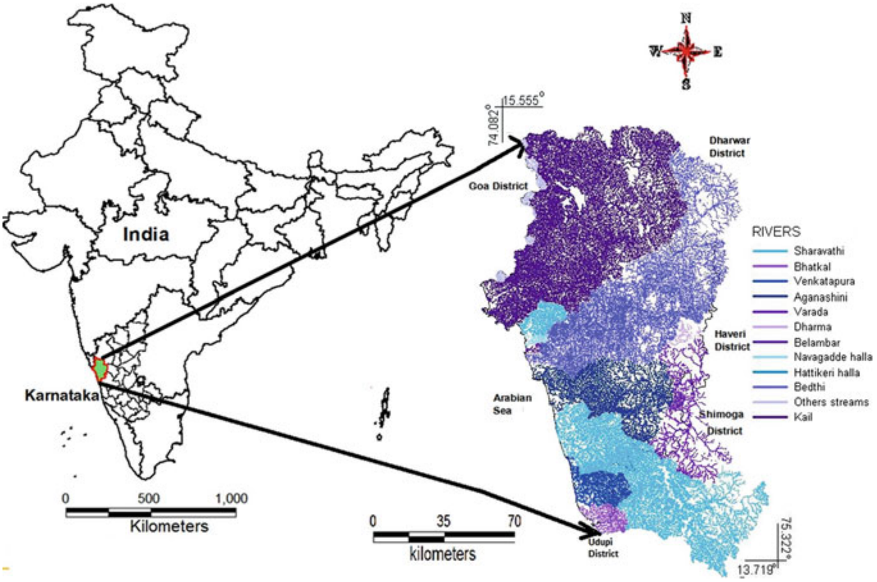


Fig. 1 Study region—Uttara Kannada district with rivers (*Source* Energy and Wetlands Research Group, CES, Indian Institute of Science)

2.1 Kali River

The Kali River (Fig. 2) flows for a length of 184 km. Previously, it originated near the village Diggi in Supataluk, as Karihole. After the construction of the dam near Supa, the entire region is now submerged in the reservoir. Pandri and Ujli are the two main tributaries of this river in the North and the stream Tattihalla also joins near Haliyal. The Kaneri and the Vaki are its two main tributaries that join at Dandeli and Anshi Tiger Reserve respectively. Later near Kadra, Thananala joins the main river. In all, the catchment area of the river is about 5,179 km^2 and the annual river discharge is estimated to be 6,537 million cu. m (Bhat 2002). There are four major dam projects on this river—the Supa reservoir near the headwaters, the Bommanhalli reservoir near the Dandeli Wildlife Sanctuary, the Kodasalli dam near Ganeshgudi and finally, one at Kadra (which is the part of the Kaiga project).

2.2 Bedthi River

The River Bedthi River (Fig. 3) originates near Hubli taluk. The river, has a total length of 152 km with a catchment area of 3,902 km^2. It discharges 4,925 million cu. m of water annually.

2.3 Aghanashini River

The Aghanashini River (Fig. 4) originates at Manjguni near Sirsi. After winding westerly course of about 70 km, it debauches into the sea about 10 km south of Bedthi. The river has two sources—a tributary called Bakurhole, rising at Manjguni, about 25 km west of Sirsi and Donihalla, which is close to Sirsi. These two streams meet at Mutthalli about 16 km south of Sirsi. Under the name Donihalla, it flows for about 25 km south of Sirsi westwards to Sahyadri's west face and at Heggarne in Siddapur, it falls off a height of about 116 m as the Lushington (or the Unchalli) falls. Further down 6 km from Bilgi near Hemanbail, it flows down again as the Burdejog. It finally meets the sea at Uppinpatna. The Aghanashini covers a catchment area of 2,146 km^2. It has an annual discharge of 966 million cu. m.

2.4 Sharavathi River

The 128 km long Sharavathi River (Fig. 5) originates at Ambutirtha in Tirthahallitaluk of Shimoga District. After a northerly course of about 64 km from Sagar, it forms the southeastern border of the Uttara Kannada District for about 13 km and flows a further

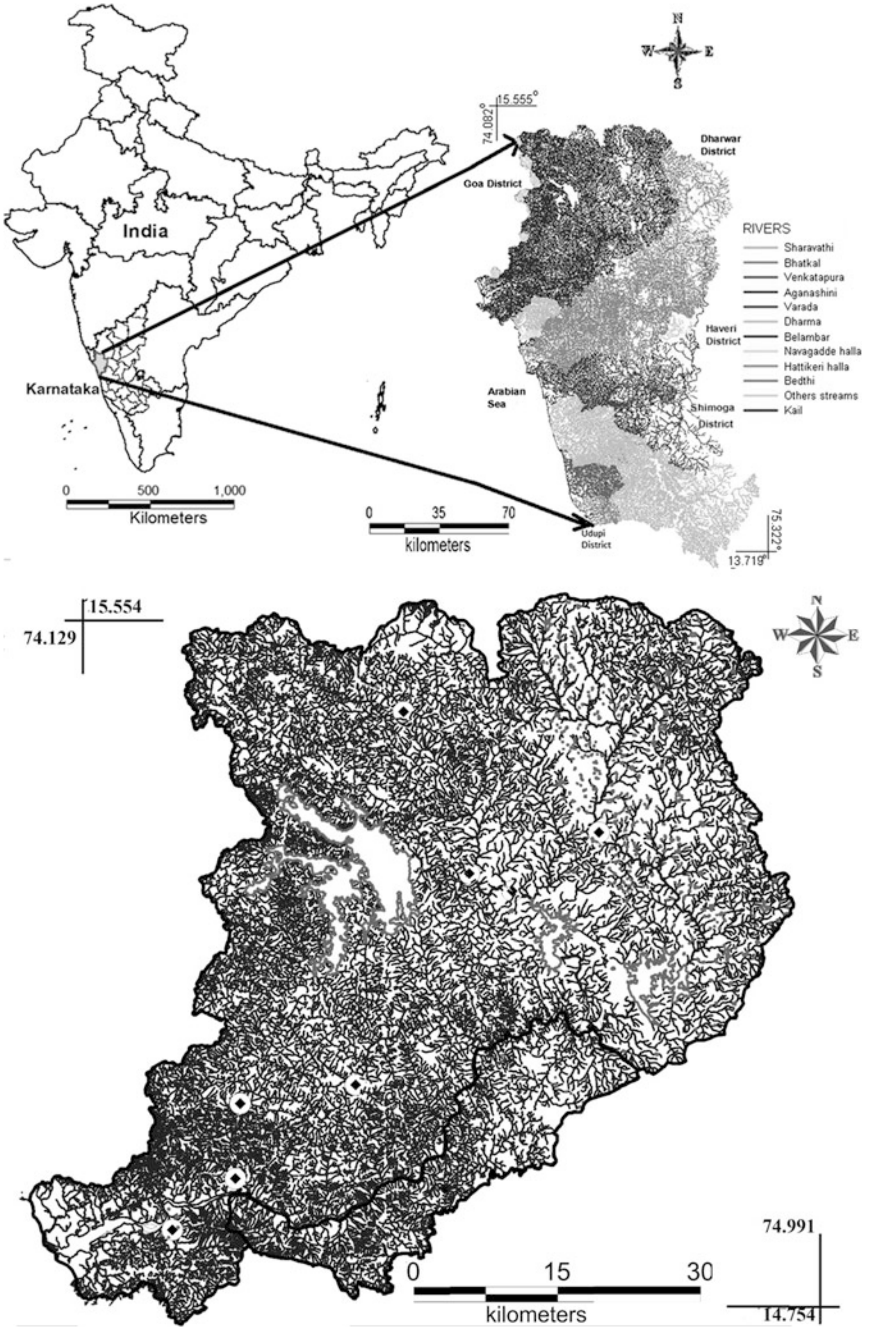


Fig. 2 River Kali with sampling sites

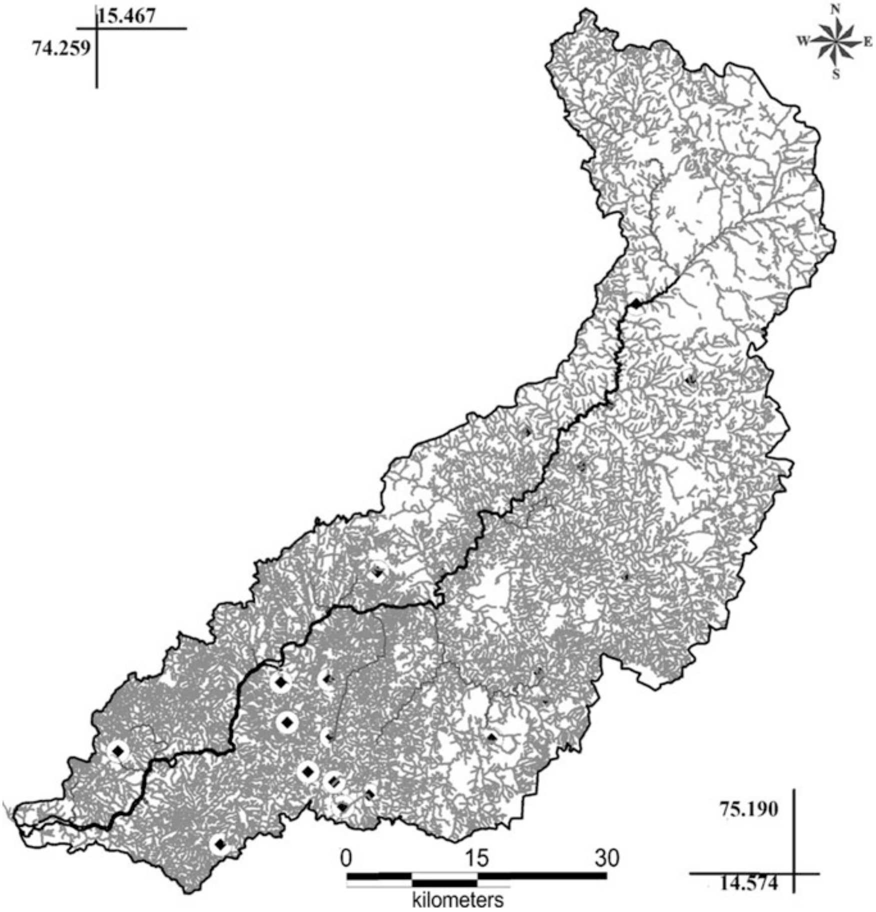


Fig. 3 River Bedthi with sampling sites

32 km to join the sea at Honnavar. Soon after touching the Uttara Kannada border the river falls off the western face of the Ghats in Jog falls at a height of 252 m into a pool 117 m deep. About 30 km west, it reaches Gersoppa. The Sharavathi has a catchment area of 2,209 km^2 and an annual discharge of 4,545 million cu.m.

2.5 Venkatapura River

The Venkatapura River (Fig. 6) originates in Western Ghats and confluence into Arabian Sea after a course of 45 km near Venkatapura with a catchment of 335 km^2. The river basin is divided into sub basins namely Chitihalla, KatagarNala, BastiHalla, Kitrehole and Venkatapura based on major tributaries.

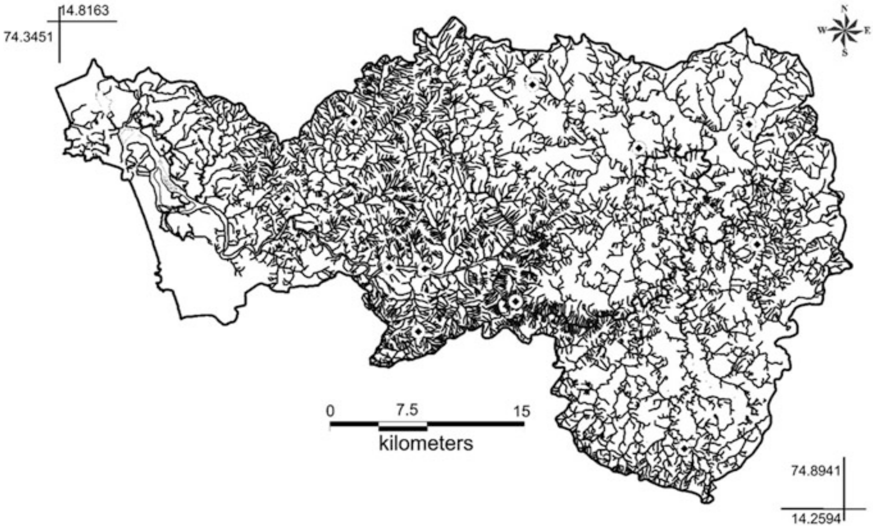


Fig. 4 River Aghanashini with sampling sites

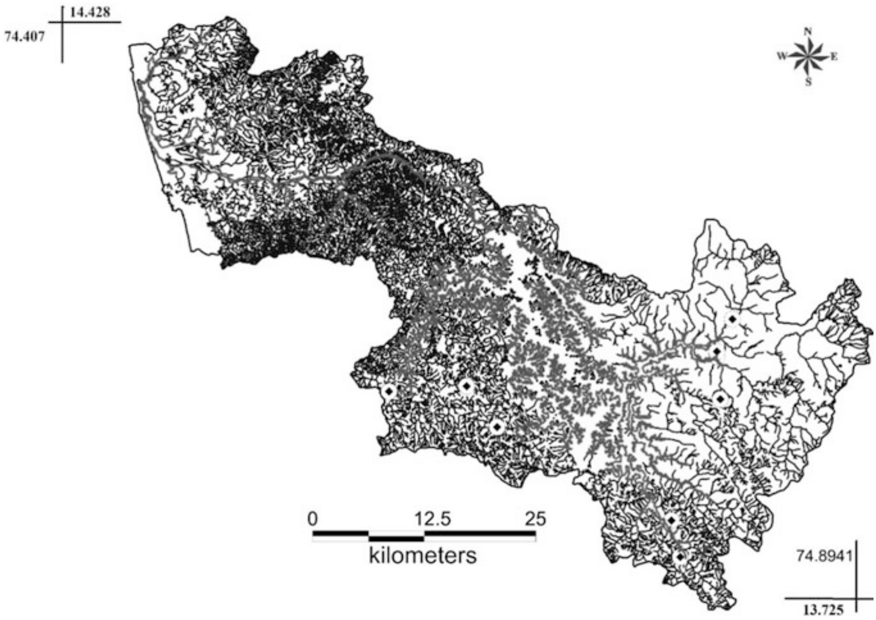


Fig. 5 River Sharavathi with sampling sites

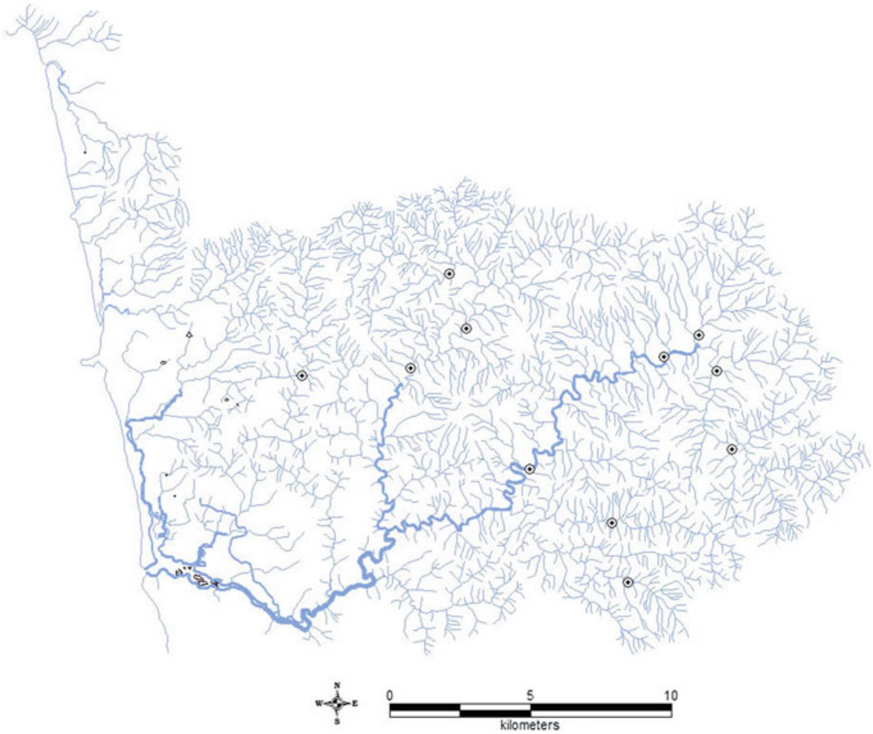


Fig. 6 Venkatapura River with sampling sites

3 Materials and Methods

3.1 Water Quality Monitoring

Water samples were collected at each sampling locations (Table 1) from each source in clean polythene containers of 2.5 L capacity. The sample containers were labeled with a unique code and date of collection. pH, water temperature, Total Dissolved Solids, Salinity and Nitrates were recorded immediately after collection using EXTECH COMBO electrode and Orion Ion Selective Electrode. Other parameters namely, chloride, hardness, magnesium, calcium, sodium, potassium, fluoride, sulphate, phosphates, and coliform bacteria were analyzed in lab. All the analyses were carried out as per the procedures provided in Standard Methods for the examination of water and wastewater (APHA 1998). Details of the methods of water quality determination are presented in the Table 2.

Table 1 Details of the sampling sites (river basin-wise—marked in Figs. 2, 3, 4, 5, and 6)

SITES	CODE	LAT	LON	SITES	CODE	LAT	LON
Aghanashini river basin (ARB)				*Kali river basin (KRB)*			
Sonda	A1	74.4834	14.4868	Beegar	K1	74.5818	14.9163
Nellimadke	A10	74.8431	14.5289	Astolli	K10	74.5383	15.4289
Neralamane	A11	74.8439	14.4554	Kervada	K2	74.6368	15.2454
Balur	A12	74.8098	14.4853	Mavlangi	K3	74.5923	15.2561
Baillalli	A13	74.7920	14.3013	Tatwala	K4	74.7466	15.0879
Hulidevarakodlu	A2	74.6643	14.4040	Sakathi	K5	74.3378	14.9185
Donehole	A3	74.5878	14.4330	Naithihole	K6	74.2593	14.8543
Deevalli	A4	74.5584	14.4332	Kesrolli	K7	74.7412	15.3037
Ullurmatha	A5	74.5823	14.3844	Kaneri	K8	74.4676	15.0247
Yanahole	A6	74.5355	14.5344	Badapoli	K9	74.3560	15.0144
Jalagadde	A7	74.6127	14.5480				
Kurse	A8	74.6900	14.5595				
Sappurthi	A9	74.7562	14.5234				
Bedthi river basin (BRB)				*Sharavathi river basin (SRB)*			
Mathigadda	B1	74.5926	14.6730	Nandiholé	S1	75.1245	14.0418
Vajgadde	B10	74.6154	14.6213	Haridravathi	S2	75.1084	14.0209
Nycti. Site	B11	74.6120	14.6390	Mavinaholé	S3	75.1055	13.9735
Angadibail	B12	74.5332	14.6067	Sharavathi	S4	75.0804	13.8532
Daanandhi	B13	74.8667	14.7358	Hilkunji	S5	75.0896	13.7730
Hemmadi	B14	74.8586	14.7510	Nagodiholé	S6	74.8839	13.9269
Attiveri	B15	75.0357	15.0759	Hurliholé	S7	74.8428	13.9786
Yerebail	B16	74.9395	15.0470	Yenneholé	S8	74.7268	13.9650
Gunjavathi	B17	74.9140	14.9921				
Chitgeri	B18	74.9834	14.8557	*Venkatapura river basin (VRB)*			
Karadrolli	B19	74.8356	14.9918	Badabhag	V1	75.6293	14.0588
Kammani	B2	74.5958	14.7132	Bachochodi	V10	74.6907	14.0901
Dabguli	B20	74.6572	14.8508	Kelanur	V11	74.6959	14.0653
Ramanguli	B21	74.6054	14.1238	Undalakatle	V2	74.5900	14.0910
Kalghatghi	B22	74.9785	15.1586	Midal	V3	74.5543	14.0888
Manchiker	B23	74.7861	14.8910	Arkala	V4	74.6563	14.0415
Apageri	B3	74.5840	14.6389	Galibyle	V5	74.6085	14.1038
Hasehalla	B4	74.5840	14.7551	Nagoli	V6	74.6735	14.0946
Kaleswara	B5	74.6095	14.7587	Ondalasu	V7	74.6028	14.1213
Andhalli	B6	74.8016	14.6701	Hegganamakki	V8	74.6848	14.1018
Makkigadde	B7	74.4299	14.7095	Kurandura	V9	74.6616	14.0227
Kelaginkeri	B8	74.5926	14.6730				
Devanahalli	B9	74.6635	14.6281				
Kurandura	V9	74.6616	14.0227				

Table 2 Methods used for analysing water samples

Parameters	Units	Methods	Section no. APHA 1998
pH	–	Electrode method	4500-H^+ B
Water temperature	°C		2550 B
Salinity	ppm		2520 B
Total dissolved solids	ppm		2540 B
Electrical conductivity	µS		2510 B
Dissolved oxygen	mg/L	Iodometric method	4500-O B
Alkalinity	mg/L	HCl titrimetric method	2320 B
Chlorides	mg/L	Argentometric method	4500-Cl^- B
Total hardness	mg/L	EDTA titrimetric method	2340 C
Calcium hardness	mg/L	EDTA titrimetric method	3500-Ca B
Magnesium hardness	mg/L	Calculation method	3500-Mg B
Sodium	mg/L	Flame emission photometric method	3500-Na B
Potassium	mg/L	Flame emission photometric method	3500-K B
Fluorides	mg/L	SPADNS method	4500-F- D
Nitrates	mg/L	Nitrate electrode method and phenol disulphonic acid method	4500-NO3- D
Sulphates	mg/L	Turbidimetric method	4500-SO_4^{2-} E
Phosphates	mg/L	Stannous chloride method	4500-P D

3.2 *Diatom Collection, Preparation and Enumeration*

Figure 7 illustrates the habitat of diatoms—diatom colonies on stones, sand, etc. At each site, three to five stones were randomly selected across the stream and diatoms were scraped off the exposed surface of the stones using a tooth brush. Fresh samples were carefully checked to assure that majority of the diatom frustules were alive prior to acid combustion. A hot HCl and $KMnO_4$ method was used to clean frustules of organic materials. The cleaned diatom samples were dried on 18 × 18 mm cover slips and mounted with Pleurax. A total of 400 frustules per sample were enumerated and identified using compound light microscope (Lawrence and Mayo LM-52-series, with 1,000 X magnification) following the methods described by Taylor et al. (2005) and Karthick et al. (2010). Diatoms were identified at species level according to Gandhi (1957a, b, c, 1958a b, 1959a, b, c, 1960a, b, c), Krammer and Lange-Bertalot (1986–1991) and Taylor 2004; Taylor et al. (2007a, b).

Fig. 7 Diatoms on stone in streams

3.3 *Land Use Land Cover (LULC) Analysis*

The remote sensing data were processed to quantify the land use of respective basins broadly into 6 classes—forest and vegetation; agriculture and cultivated area; open scrub and barren; water bodies; built-up; and others (includes categories like rocky outcrop, etc.). The multi-spectral data of Indian Remote Sensing (IRS) LISS-III with a spatial resolution of 23.5 m were analyzed using IDRISI Andes (Eastman 2006; http://www.clarklabs.org) and GRASS (http://ces.iisc.ernet.in/grass). Land use analysis involved (a) generation of False Colour Composite (FCC) of remote sensing data (bands—green, red and NIR). This helped in locating heterogeneous patches in the landscape (b) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15 % of the study area and uniformly distributed over the entire study area, (c) loading these training polygons co-ordinates into pre-calibrated GPS, (d) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, (e) supplementing this information with Google Earth (http://www.googleearth.com) (f) 60 % of the training data has been used for classification, while the balance was used for validation or accuracy assessment. Based on these signatures, corresponding to various land features, supervised image classification was carried out using Gaussian Maximum Likelihood Classifier (GMLC) to the final six categories.

3.4 Data Analysis

Compiled data were tested for normality before performing statistical analyses. Statistical analyses comprised Kruskal-Wallis test (H), Principal Component Analysis (PCA) and Non-Metric Multi Dimensional Scaling (NMDS). All the tests were performed using the R-software (R Development Core Team 2006). Box plots were used to visually summarize the data. The line in the box indicates the median value of the data. If the median line within the box is not equidistant from the edges of the box, then the data are skewed. "Gridding" is the operation of spatial interpolation of scattered 2D data points onto a regular grid. Gridding allows the production of a map showing a continuous spatial estimate. The spatial coverage of the map is generated automatically as a square covering the data points. Non-metric multidimensional scaling is based on Bray-Curtis distance matrix was performed for classifying the sites across river basins. In NMDS, data points are placed in 2 or 3 dimensional coordinates system preserving ranked differences.

The non-parametric Kruskal-Wallis test was used to assess whether species richness, species diversity and turnover across water quality regimes were significantly different. Temporal variation in diatom assemblages in each site was analyzed by NMDS using absolute abundance data. NMDS is an ordination method well suited to data that are non-normal or are arbitrary or discontinuous and for ecological data containing numerous zero values (Minchin 1987; McCune and Grace 2002). Results were visualized showing the most similar samples closer together in ordination space (Gotelli and Ellison 2004). A final stress value, typically between 0 and 15, was evaluated as a measure of fitted distances against the ordination distance, providing an estimation of the goodness-of-fit in multivariate space. Changes in species composition or percentage turnover (T) were used to indicate community persistence. T was calculated as $T = (G + L)/(S1 + S2)$ times 100 where G and L are the number of taxa gained and lost between months respectively, and S1 and S2 are the number of taxa present in successive sampling months (Diamond and May 1977; Brewin et al. 2000; Soininen and Eloranta 2004). The relationship between the local population persistence, the local abundance in terms of relative abundances, and the regional occupancy were examined using correlation analysis (Soininen and Heino 2005). For the species distribution model, the species were classified as core species as species that occurred in over 90 % of sites, and satellite species as species that occurred in fewer than 10 % of sites (McGeoch and Gaston 2002; Soininen and Heino 2005). Local occupancy of each diatom species was calculated by their percentage of occurrence at each site across the seasons. Seasonal diatom community was related to the water quality parameters using multiple linear regressions. Finally, water quality variables were used in PCA to elucidate the spatial water quality variation.

4 Results and Discussion

4.1 PH

The pH of river water is the measure of negative logarithm of hydrogen ion concentration that indicates how acidic or basic the water is on a scale of 0–14. Most of the peninsular rivers fall between 6.5 and 8.5 on this scale with 7.0 being neutral. The optimum pH for river water is around 7.4. Water's pH can be altered by industrial and agricultural runoff. Vajgadde at BRB (Bedthi River basin) has recorded low pH of 6.9 and Kalghatgi from the same river has recorded highest pH of 8.27. Low ranges of pH are observed in the forested streams and high alkaline pH are observed in sites contaminated with agricultural and urban runoff (Figs. 8 and 9). A pH of 8.0 should be sufficient to support most river life with the possible

Fig. 8 pH across river basins

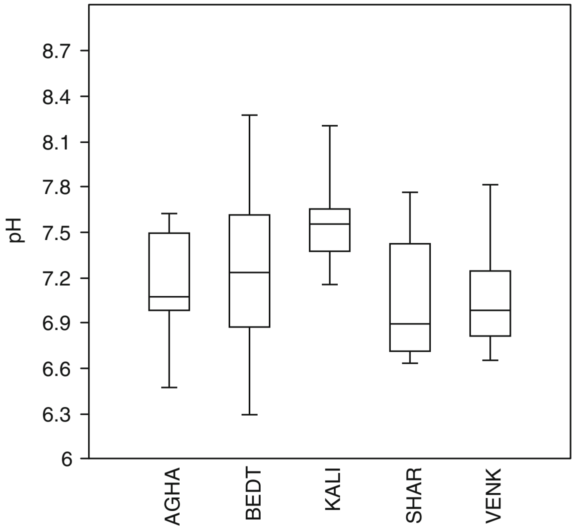
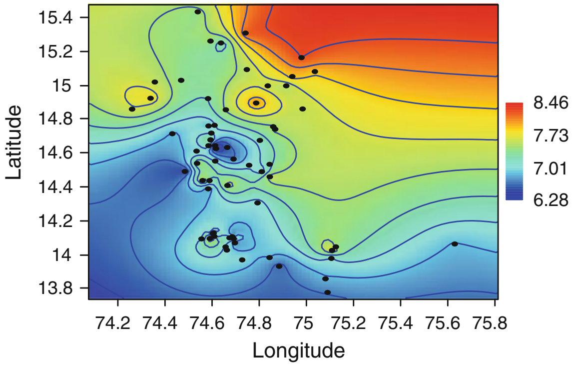


Fig. 9 Spatial representation of pH across sites



exception of snails, clams, and mussels, which usually prefer a slightly higher pH. The average pH in the study was 6.9, a value that is only sufficiently basic for bacteria, carp, suckers, catfish, and insects. BRB (Bedthi River basin) and KRB (Kali River basin) record most of the alkaline nature, whereas ARB (Aghnashini River basin), SRB (Sharavathi River basin) and VRB (Venkatapura River basin) sites record neutral to near acidic nature.

4.2 Electrical Conductivity and Total Dissolved Solids

Pure water does not conduct electricity. Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cat ions (ions that carry a positive charge). Organic compounds such as oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate in it; an oil spill would lower the conductivity.

Low level of electrical conductivity was observed at Vajgadde at BRB (22.5 µS/cm) and highest value was recorded from Kalghatghi of the BRB (1038.95 µS/cm), as illustrated in the Fig. 10. Sites of BRB showed high levels of variation when compared to the SRB and VRB. KRB sites recorded comparatively higher conductivity and

Fig. 10 Electrical conductivity across river basins

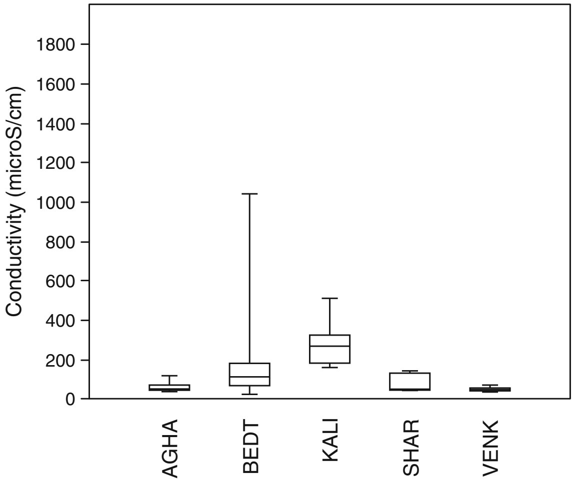
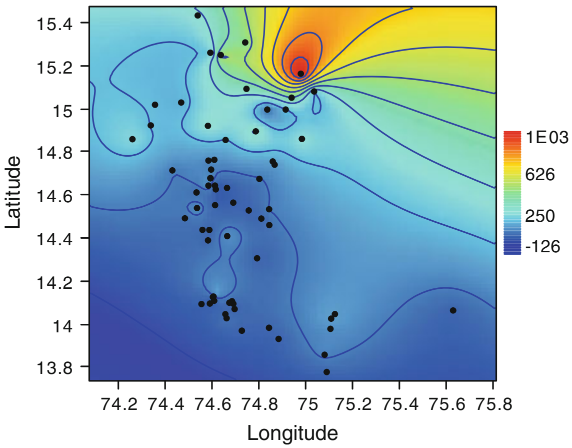


Fig. 11 Spatial representation of electrical conductivity across sites



total dissolved solids, perhaps due to the accelerated erosion associated with the conversion of natural vegetation into monoculture plantations in its catchment area in the north part of the river basin (Fig. 11).

4.3 Dissolved Oxygen

The atmosphere is a major source of dissolved oxygen in river water. Waves and tumbling water mix atmospheric oxygen with river water. Oxygen is also produced by rooted aquatic plants and algae as a product of photosynthesis. An adequate supply of dissolved oxygen (DO) is essential for the survival of aquatic organisms. A deficiency of DO in is a sign of an unhealthy river. There are a variety of factors affecting the levels of dissolved oxygen.

In the present study, lowest dissolved oxygen levels were observed in Kervada (3.67 mg/L) located in the KRB. This site is located adjacent to the effluent discharge point of a Paper mill (Fig. 12). The paper mill effluent is characterized with high levels of organic content, which might consume most of the oxygen for its degradation with the help of bacteria. Bacteria which decompose plant material and animal waste consume dissolved oxygen, and decrease the quantity available to support life. Ironically, it is life in the form of plants and algae that grow uncontrolled due to fertilizer that leads to the masses of decaying plant matter. This site is also infested with marsh crocodiles (*Crocodylus palustris*), which prevails as a major threat to the humans and livestock in the surroundings. Crocodiles are attracted to this particular place due to availability of the solid organic contents present the paper mill effluent. Sites at SRB recorded saturated levels of dissolved oxygen in the streams and all other sites recorded with high variation. Apart from the organic pollution other reason for low levels of dissolved oxygen is lack of mixing in water. Small to medium sized check dams are constructed in the middle

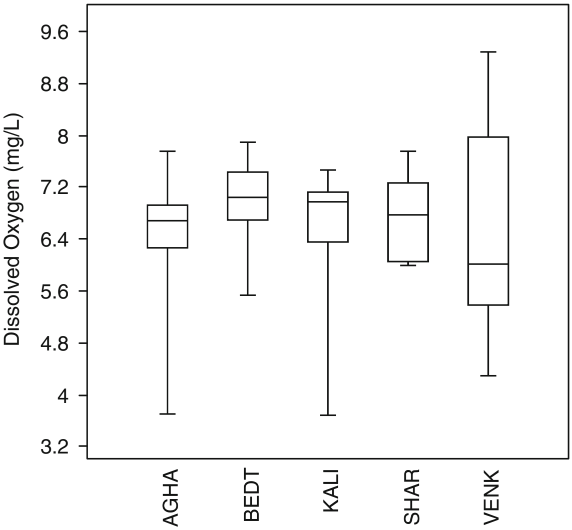


Fig. 12 Dissolved Oxygen levels across river basins

reaches of all the rivers, might have converted the lotic system into lentic system wherein diffusion of atmospheric oxygen into stored water is highly restricted due to the stagnant conditions. Thus, many factors namely organic pollution, active consumption by bacteria, algae and exotic plants and reduced influx due to damming have all contributed towards low levels of dissolved oxygen.

4.4 Nutrients

Unlike temperature and dissolved oxygen, the presence of nitrates usually does not have a direct effect on aquatic insects or fish. However, excess levels of nitrates in water can create conditions that make it difficult for aquatic insects or fish to survive. Nitrate-nitrogen is important because it is biologically available and is the most abundant form of nitrogen in Central Western Ghats streams. Like phosphorus, nitrate can stimulate excessive and undesirable levels of algal growth in water bodies leading to eutrophication. Nitrates come to the streams mainly from the runoff from the agriculture farms and eroded sediments. Runoff from the agriculture farms carries huge amount of fertilizer residues. Among the studied river basins, the KRB and BRB recorded high levels of nitrates from its upstream region (Fig. 13). Both KRB and BRB possess intense agriculture and limited surface water bodies in their upstream regions which leads to high levels of nitrates.

Along with the nitrates, phosphate also plays an important role in the river hydrobiology. Phosphorus is an important nutrient for plant growth. Excess phosphorus in the river is a concern because it can stimulate the growth of algae. Excessive algae growth, death, and decay can severely deplete the oxygen supply in

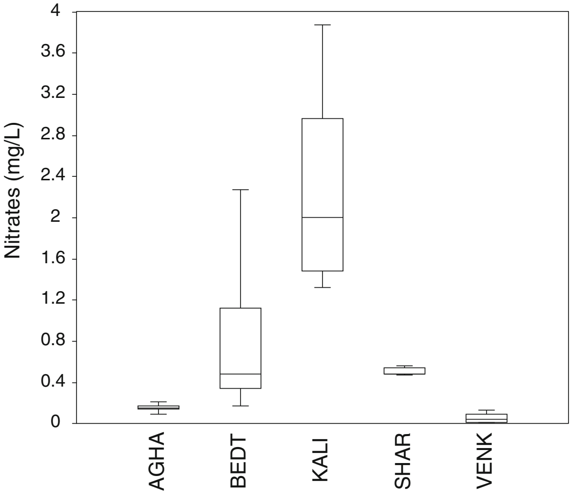


Fig. 13 Nitrate across River Basins

the river, endangering fish and other forms of aquatic life. Urban runoff is the major source for phosphates in the streams. Among the studied basins, BRB receives considerable amount of urban sewage from Hubli city. The impact of high levels of phosphates leads to algal blooms in many reaches of the Bedthi River. Manchikeri site located in between Sirsi and Yellapur has a check dam for pumping water for drinking water supply. Recently another check dam was constructed near the Manchikeri Bridge to store water for Yellapur drinking water supply. Though check dam stores water to support drinking water supply, owing to the intensive agricultural and other activities in the upstream regions, check dam also plays as a reservoir for pollutants and reduces the chances of the accumulated pollutants diffusing away. Stagnated water with heavy nutrient content leads to algal bloom. Preliminary investigations suggest that the algal bloom was created by algal genus *Microcystis,* a blue-green algae (also referred to as Cyanobacteria). It is a common bloom-forming algae found primarily in nutrient enriched river and lake waters. This genus is colonial, which means that single cells can join together in groups which tend to float on the water surface. Colony sizes will vary from a few to hundreds of cells. Any large algal bloom has the potential to result in fish kills by depleting the water of oxygen. The dead algal cells sink down and consume huge amount of oxygen for their decomposition. In such situations, there may not be enough oxygen remaining in the water to support fish in the vicinity. Furthermore, as these large blooms die and sink to the bottom, they commonly release chemicals that can produce a foul odor and musty taste. Some strains of *Microcystis* may produce toxins that have been reported to result in health problems to animals that drink the water, and minor skin irritation and gastrointestinal discomfort in humans that come in contact with toxic blooms. Uncontrolled growth of single species of algae will also lead to death of aquatic invertebrates and fishes due to unavailability of food, which in turn affects the aquatic food chain.

4.5 Lotic Ecosystems: Intra Basin Variations in Quality

Principal component analysis reveals that the BRB contains sites with pristine to heavily polluted waters. Most of the sites in northern part of BRB stand out separately in ordination space due to their very high amount of ions and nutrients. Sites in the SRB, KRB and ARB seem to fall in the same quality of water, whereas the VRB stands out separately with very pristine water quality status (Figs. 14 and 15). NMDS plot of the water quality variables shows that ionic and physical parameters have the same origin, where as nutrients arise from different source (Fig. 15).

4.6 Seasonality of Benthic Diatoms and Water Quality

The water chemistry data along the Bedthi River showed high annual variation across sites. The parameters which showed significant difference among the groups are pH, conductivity, chlorides, hardness, calcium, magnesium, sodium and potassium. All these parameters were found to be high in HPAS, moderate in MPPS and very low in LPFS (Table 3). Irrespective of the pollution status, dissolved

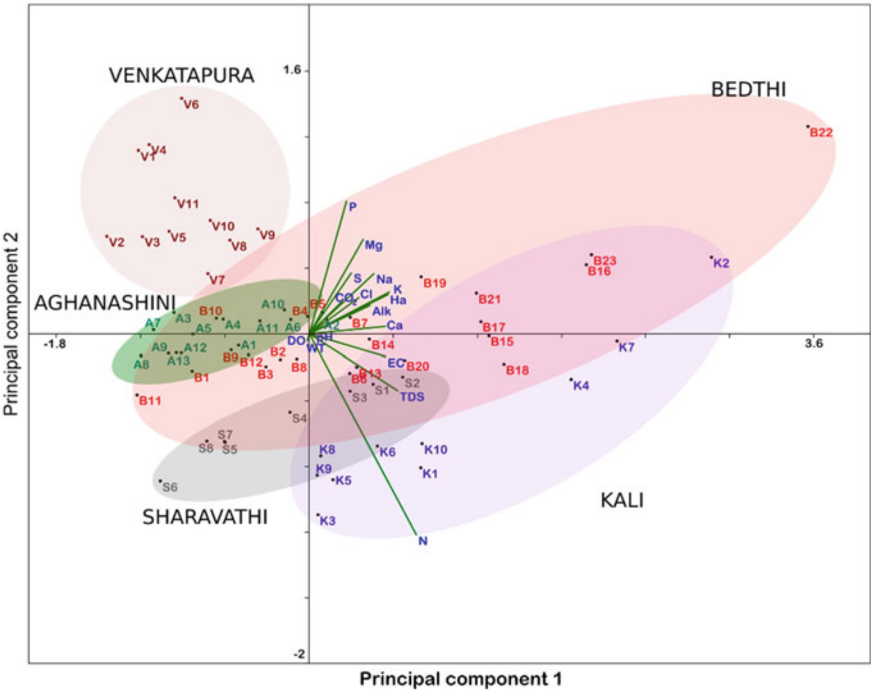


Fig. 14 PCA plot for water quality variables across the River Basins

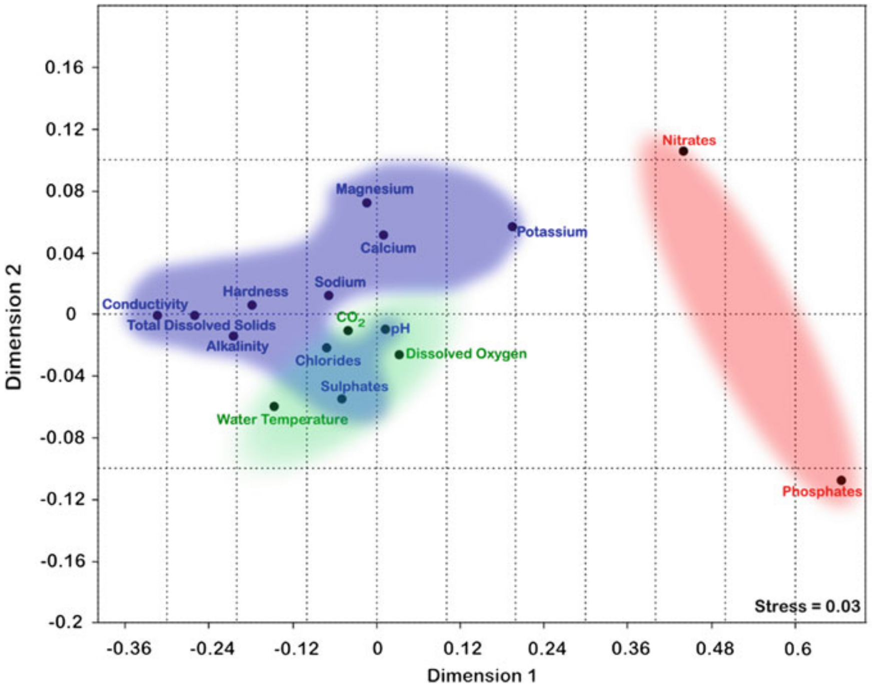


Fig. 15 NMDS plot of water quality variables across River Basins

Table 3 Species richness and diversity across space and time at BRB sites

Months	LPFS		HPAS		MPPS	
	KAM	HAS	KAL	MAN	AND	DAN
Jan	14 (1.10)	10 (1.04)	7 (1.58)	-L-	4 (0.81)	14 (2.27)
Feb	10 (1.58)	6 (1.10)	7 (1.65)	9 (1.63)	4 (1.04)	19 (2.34)
Mar	4 (1.25)	6 (0.85)	8 (1.73)	14 (1.90)	6 (0.95)	-D-
Apr	7 (1.47)	7 (0.67)	9 (1.65)	1 (0)	8 (0.93)	-D-
May	11 (1.40)	4 (0.47)	3 (0.92)	8 (1.34)	11 (1.76)	-D-
Jun	9 (1.16)	3 (0.15)	4 (1.02)	-M-	3 (0.98)	5 (1.14)
Jul	4 (0.77)	-M-	1 (0)	-M-	6 (1.19)	7 (1.46)
Aug	-M-	-M-	-M-	-M-	5 (0.79)	5 (1.35)
Sep	1 (0)	-M-	1 (0)	-M-	2 (0.69)	9 (1.67)
Oct	4 (0.78)	5 (0.77)	5 (1.34)	5 (1.15)	9 (1.29)	9 (1.35)
Nov	4 (0.82)	4 (0.94)	6 (1.54)	-L-	-L-	4 (0.84)
Dec	4 (0.87)	-L-	8 (1.76)	16 (2.02)	2 (0.69)	10 (1.39)

oxygen (DO) levels across water quality regimes were roughly similar with mean DO levels (Mean ± S.D) of 7.51 ± 1.67, 7.08 ± 2.21, 6.43 ± 2.91. However, anoxic DO level of 0.86 mgL^{-1} was observed in one sample from the HPAS (KAL). PCA results indicated that water quality differed markedly among sampling sites and across seasons (Fig. 14) with the first component explaining 84.6 % of the total variation. Three distinct clusters were observed along a pollution gradient. Sample scores from HPAS (KAL and MAN) were positioned to the right along PCA axis 1, and were characterized by higher conductivity, phosphates, nitrates, alkalinity, hardness, calcium, sodium and potassium levels. MPPS (AND, DAN) were positioned along the PCA axis 2. In contrast, samples from the LPFS (HAS, KAM) were located to the left along the PCA axis 1, and were characterized by higher DO and low levels of ions and nutrients. Water chemistry parameters namely, the pH, carbon dioxide, alkalinity, nitrates, sulphates were positively loaded while dissolved oxygen was negatively loaded with principal axes. These results indicate that the water chemistry between these sites was strongly different throughout the year. Stream water chemistry differed between the three groups of sites (Fig. 16). Clusters illustrated in Fig. 17 reveal distinct grouping based on the ion and nutrient concentrations in the respective sampling sites across the river basins.

One hundred and three species of diatoms were recorded from all the six sites during the study period, with a flora typical of oligotrophic to eutrophic conditions. Among the taxa recorded, the *Achnanthidium minutissimum* (KÜtz) Czarn., *Gomphonema gandhii* Karthick and Kociolek, *G. difformum* Karthick and Kociolek, *Nitzschia palea* (KÜtz) W. Sm., *Nitzschia frustulum* (KÜtz) Grun., *Cymbella* sp. and *Navicula* sp. *Achnanthidium minutissimum*, *Gomphonema gandhii* and *G. difformum*, were present throughout the study period in LPFS and MPPS, while *Nitzschia palea* and *Nitzschia frustulum* were dominant in HPAS. In contrast, *Cymbella* sp. was the only diatom present at the MAN site during the month of April. The samples from headwater oligotrophic streams (often with low pH and conductivity) were characterized by the occurrence of *Gomphonema gandhii*, *Achnanthidium minutissimum and Gomphonema difformum*. Assemblages from eutrophic streams (HPAS) were characterized by dominance of *Nitzschia palea*, *N. frustulum and* occasionally with *Cyclotella meneghiniana*.

The species richness was highest at three sites; KAM, DAN and MAN, even though each one inherited different water chemistry regimes. All the six sites were characterized with very low species richness during the monsoon season (Table 3). In all the sites during the entire study period, the diversity (H′) ranged between the highest 2.34 in DAN during the month of February to lowest of 0 in KAM and KAL during the monsoon months. Kruskal–Wallis results showed that the species diversity across three water chemistry regimes were significantly different (Kruskal–Wallis, H = 6.97; p = 0.03).

Species abundances across season suggested trends within community composition in ordination space (Fig. 18). In sites KAM and KAL, the communities of post monsoon season aggregated in ordination space. However, this trend was not recognized in HAS, DAN, MAN and AND sites. In LPFS (KAM and HAS) and MPPS (AND and DAN), the diatom assemblages were identical for pre-monsoon,

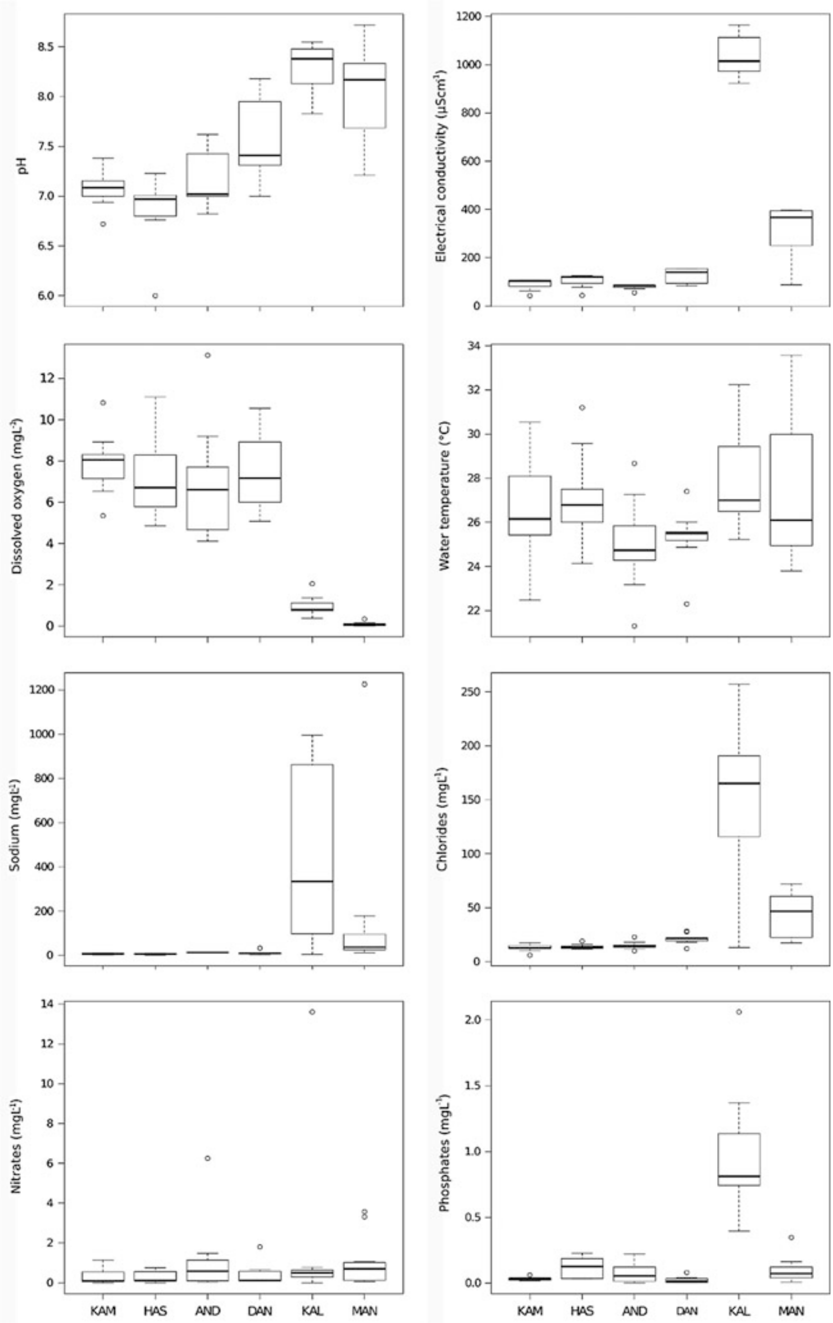


Fig. 16 Water chemistry at sampled sites during the study period at BRB

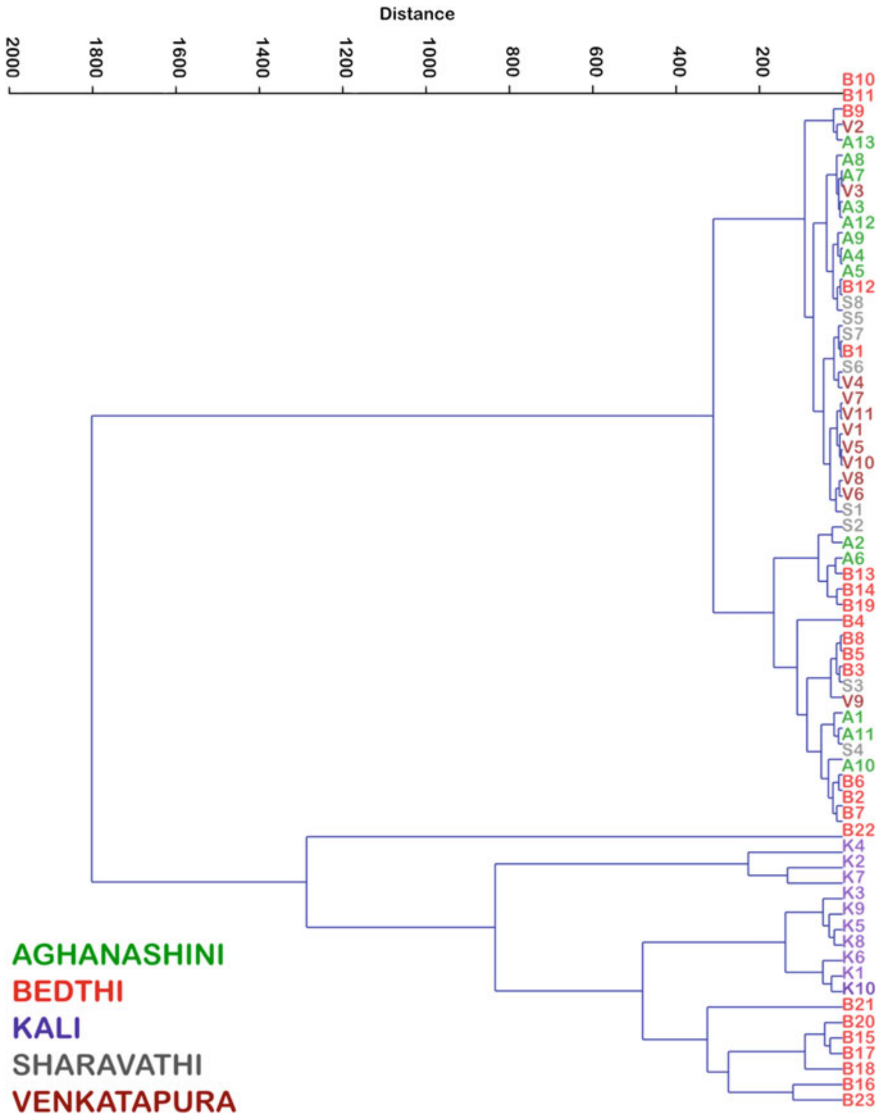
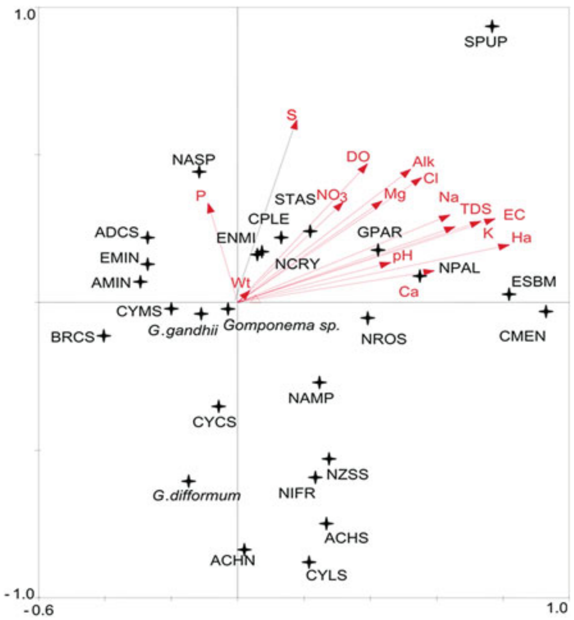


Fig. 17 Cluster analysis of sampling sites across river basins based on water quality

monsoon and post-monsoon seasons respectively, whereas the assemblages in HPAS (KAL and MAN) were not identical across seasons. Though there are trends on community composition, a strong relation with the seasonally dynamic environmental variables could also be envisaged. The difference in the species richness among sites were not significant (Kruskal–Wallis H = 6.07; p = 0.29). Species richness from highest to lowest within water quality regimes, followed the order: LPFS > MPPS > HPAS. Overall, species richness was lowest during the monsoon

Fig. 18 CCA bi-plot of water chemistry variables and dominant species assemblages



months in all the sites. Changes in species composition or percentage turnover (T) did not follow any trend irrespective of site water chemistry. The highest mean turnover (94.44 % ± 11.11) was observed in MAN, indicating the lowest persistence (Table 3), followed by DAN (79.08 ± 14.47), HAS (70.46 ± 27.64) and AND (64.77 ± 23.71). The mean species turnover was less than 50 % in KAL (47.96 ± 38.1) and KAM (44.03 ± 20.85). Interestingly, KAL showed a wide range of turnover with a minimum of 9 % during the post monsoon and a maximum turnover of 100 % during the monsoon months. In LPFS sites 25 % of the species were persistent across seasons and in MPPS sites 30 % of the species were persistent. However in the HPAS sites, a minimum persistence of 7.14 % was observed for KAL and 80 % persistence in MAN. The differences in turnover were significant across sites (Kruskal–Wallis H = 17.52; p = 0.0036).

Percentage occupancy showed a significant relationship with local maximum species abundance (r = 0.49; P = <0.0001) and local mean species abundance (r = 0.37; P = <0.0001). This positive correlation was slightly stronger for the local maximum abundance. However, it was highly significant for both the local abundance measures. Species that occurred locally with more frequency also tended to be abundant across the sites. The species–occupancy frequency distribution (Fig. 18) followed a "satellite-mode" (Hanski 1982) of species distribution, where a high proportion of species occurred at a small number of sites. Sixty three species occurred at only one site, twenty two species occurred in two sites, eleven species occurred in three sites; five species occurred in four sites, three species occurred in five sites and none of the species occurred in all the six sites.

4.7 Diatom Based Biomonitoring

A total of 140 diatom taxa were identified across sites, 61 of them reaching a relative abundance of over 5 % in at least one site. Appendix 1 provides the checklist of diatoms. The species compositions were dominated by *Gomphonema gandhii* Karthick and Kociolek, *Achnanthidium minutissimum* Kützing, *Achnanthidium* sp., *Gomphonema* sp., *Gomphonema parvulum* Kützing, *Nitzschia palea* (Kützing) W.Smith, *Nitzschia frustulum* (Kützing) Grunow var. *frustulum*, *Navicula* sp., *Navicula cryptocephala* Kützing, *Cyclostephanos* sp., *Cymbella* sp., *Eolimna subminuscula* (Manguin) Moser Lange-Bertalot and Metzeltin, *Sellaphora pupula* (Kützing) Mereschkowksy, *Eunotia minor* (Kützing) Grunow in Van Heurck, *Nitzschia amphibian* Grunow f. *amphibia*, *Cyclotella meneghiniana* Kützing, *Gomphonema difformum* Karthick and Kociolek, *Navicula rostellata*Kützing, *Cocconeis placentula* Ehrenberg var. *euglypta* (Ehr.) Grunow, *Brachysira* sp., *Stauroneis* sp., *Encyonema minutum* (Hilse in Rabh.) D.G. Mann, *Cyclotella* sp. and *Nitzschia* sp. The species composition contains cosmopolitan to possible Western Ghats endemic species. In general, species from oligotrophy to highly eutrophic condition were observed. The current study also documents some of the species for the first time in Western Ghats and many new species descriptions are underway. Waters were circumneutral throughout the study area (Table 4), with certain tendency towards alkalinity in the streams drained from agriculture and urban catchment. The highest ionic and nutrient values correspond to the agriculture catchment dominated streams, particularly in the leeward side of the mountains. Oxygenation was generally close to saturation; the lowest values are due to wastewater water inflows in few localities. The most oligotrophic sites were located in mountain watercourses, while downstream sites were generally more polluted, becoming eutrophic in condition. The detailed water chemistry variables are presented in Table 5.

The results of correlation performed between diatom indices and water chemistry variables are presented in the Table 6. It is observed that significant correlations, albeit at varying degrees exist between most of the diatom indices and water chemistry variables. Diatom indices IPS, EPI and SID showed correlation with more number of water chemistry variables when compared to the other indices. TDI and IPS are negatively correlated with pH, EC, TDS, alkalinity, calcium, magnesium,

Table 4 Summary of the canonical correspondence analysis for the stream sites from central Western Ghats

Variables	Axis order			
	1	2	3	4
Eigen value	0.275	0.193	0.162	0.119
Species-environment correlations	0.815	0.755	0.890	0.754
Cumulative percentage variance of species data	10.0	17.0	22.9	27.2
Cumulative percentage variance of species-environment relation	25.8	43.8	59	70.1

Table 5 Waterchemistry variables in 45 sites of CWG streams

Variables	Mean	Std. dev	Median	Min	Max
pH	7.22	0.49	7.14	6.03	8.16
WT (°C)	25.31	2.70	25.07	19.00	33.00
EC (μScm^{-1})	160.55	207.10	107.67	41.55	1164.67
TDS (mg L^{-1})	122.24	204.98	60.30	20.88	1299.67
Alkalinity (mg L^{-1})	54.55	50.32	30.00	6.81	180.00
Chlorides (mg L^{-1})	32.39	40.40	22.72	5.90	220.24
Hardness (mg L^{-1})	51.26	71.05	28.00	10.00	348.00
Calcium (mg L^{-1})	13.88	16.14	8.02	1.60	78.56
Magnesium (mg L^{-1})	16.35	16.73	9.36	1.17	65.95
DO (mg L^{-1})	6.96	1.68	7.23	2.93	10.87
Phosphates (mg L^{-1})	0.36	0.56	0.04	0.00	2.30
Nitrates (mg L^{-1})	0.74	1.10	0.13	0.03	4.30
Sulphates (mg L^{-1})	25.73	20.84	16.87	0.00	74.10
Sodium (mg L^{-1})	25.77	72.18	9.09	4.11	370.00
Potassium (mg L^{-1})	6.33	15.72	1.30	0.19	75.00

sodium and potassium. Percent pollution tolerant diatoms were positively correlated with most of the ionic variables. None of the indices were correlated with water temperature. No correlation of temperature with any of the indices observed that may be due to differing temperature regime in tropical when compared to temperate streams. Similar observation was recorded by Taylor et al. (2007a) from South African rivers. The first four axes of CCA explain 70.1 % variance of species-environment relation and the ordination plot reveals two distinct clusters of species.

Among the species observed in this study, two species were possibly endemic to Western Ghats (*G. gandhii*, *G. difformum* and few other species that are yet to be identified). In few sites, these species were very dominant (>80 % of the total assemblages). The remaining dominant taxa were cosmopolitan and well documented in international literature (Krammer and Lange Bertalot 1986–1991). It is important to note that the indices that were developed and tested in European rivers, lack Western Ghats endemic taxa. Most sites were oligo-mesotrophic and only a few of the streams were eutrophic. The differences in the water quality of these rivers were reflected in the values for the diatom indices, by the relative abundances of indicators of trophic/saprobic stage and by different types of diatom community.

The correlations obtained in the present study are comparable to those demonstrated by Taylor et al. (2007b) in South Africa and by Kwandrans et al. (1998), Prygiel and Coste (1993) and Prygiel et al. (1999) in Europe. Significant correlations emphasize that diatom indices can be used to reflect changes in general water quality (Table 6). Canonical correspondence analysis (Fig. 18) demonstrates that certain widely distributed taxa have similar ecological characteristics in widely separated geographic areas. Species commonly associated with poor water quality in Europe e.g., *Eolimna subminuscula* Lange-Bertalot, *Nitzschia palea* (Kützing)

Table 6 Pearson correlation coefficients between measured water chemistry variables and diatom index scores in 45 sites of CWG streams

INDICES	pH	WT	EC	TDS	Alk	Cl	Ha	Ca	Mg	Na	K
SLA	−0.33*	–	−0.59**	−0.52**	−0.49**	–	−0.62**	−0.43**	–	−0.51**	−0.58**
DESCY	−0.32*	–	−0.54**	−0.46**	−0.41**	–	−0.65**	−0.47**	–	−0.49**	−0.52**
IDSE/5	−0.32*	–	−0.60**	−0.50**	−0.46**	–	−0.63**	−0.45**	–	−0.55**	−0.60**
SHE	–	–	−0.52**	−0.38**	−0.38*	–	−0.56**	−0.41**	–	−0.43**	−0.56**
WAT	–	–	–	–	–	–	−0.36*	–	–	−0.34*	−0.44**
TDI	−0.32*	–	−0.64**	−0.54**	−0.46**	–	−0.69**	−0.53**	−0.30*	−0.52**	−0.58**
%PT	0.36*	–	0.68**	0.62**	0.35*	0.43**	0.66**	0.50**	0.41**	0.65**	0.58**
GENERE	–	–	−0.49**	−0.39**	−0.30*	–	−0.54**	−0.41**	–	−0.41**	−0.41**
CEE	–	–	–	–	–	–	−0.36*	–	–	–	−0.40**
IPS	−0.36*	–	−0.68**	−0.59**	−0.42**	–	−0.66**	−0.46**	−0.31*	−0.56**	−0.58**
IBD	–		−0.56**	−0.43**	−0.34*	–	−0.61**	−0.46**	–	−0.46**	−0.51**
IDAP	–	–	−0.51**	−0.38*	−0.38*	–	−0.56**	−0.40**	–	−0.44**	−0.53**
EPI-D	−0.33*	–	−0.58**	−0.51**	−0.41**	−0.31*	−0.59**	−0.44**	–	−0.53**	−0.55**
DI_CH	–	–	−0.54**	−0.43**	−0.45**	–	−0.58**	−0.39**	–	−0.41**	−0.53**
IDP	–	–	−0.48**	−0.35*	−0.39**	–	−0.58**	−0.42**	–	−0.43**	−0.49**
SID	−0.36*	–	−0.50**	−0.45**	−0.40**	−0.38**	−0.47**	−0.37*	–	−0.43**	−0.46**
TID	–	–	−0.53**	−0.43**	−0.47**	–	−0.59**	−0.41**	–	−0.40**	−0.48**
Evenness	–	–	0.39**	0.40**		–	0.41**	–	–	–	–

WT Water temperature, *EC* Electric conductivity, *TDS* Total dissolved solids, *ALK* Alkalinity, *Cl* Chlorides, *Ha* Total hardness, *Ca* Calcium hardness, *Mg* Magnesium hardness, *Na* Sodium, *K* Potassium. *Diatom Indices SLA* Sládeček's index, *DESCY* Descy's pollution metric, *SHE* Steinberg and schiefele trophic metric, *WAT* Watanabe index, *TDI* Tropical diatom index, *GENRE* Generic diatom index, *CEE* Comission for economical community Index, *IPS* Specific pollution sensitivity metric, *IBD* Biological diatom index, *IDAP* Indice diatomique artois picardie, *EPI-D* Eutrophication/pollution index, *IDP* Pampean diatom index, *%PT* Percentage tolerant

$^*p<0.1$ and $^{**}p<0.05$

W. Smith, *Sellaphora pupula* (Kützing) Mereschkowksy, *Gomphonema parvulum* (Kützing) ordinate on the right side of the CCA together with elevated levels of ionic and nutrients. Taxa typical of cleaner, less polluted waters ordinate on the left side of the diagram e.g., *Gomphonema difformum* Karthick and Kociolek. However, *Gomphonema gandhii* Karthick and Kociolek seems to have a wider ecological tolerance when compared to its morphologically related species. *Achananthidium minutissimum* group from Western Ghats streams contains morphologically three distinct taxa with wide ecological preferences. Despite the reevaluation of this genus multiple times (Lange-Bertalot and Krammer 1989; Krammer and Lange-Bertalot 1986–1991; Potapova and Hamilton 2007) there are still major gaps in taxonomy and ecology apart from non-inclusion of specimens from tropical rivers. Similar problem holds good for some of the other genus like *Gomphonema*. This analysis had demonstrated that the widely distributed species encountered in the streams of Western Ghats are not only morphologically identical, but also have similar environmental tolerances. *G. gandhii* and *G. difformum* are few among the dominant taxa in this data set but are not included in any of the index calculations. Their omission in the index calculations could result in an under or overestimation of the index scores. Taylor et al. (2007b) cautioned about the associated problems with the usage of European indices in South African rivers. However, the data provided in the present study suggest that European diatom indices can be used in India provided indices address the issues concerned with ecology of endemic species. Hence, the list of taxa included in the indices needs to be adapted according to the study region by providing more importance to the local endemic flora which encourages taxonomic and ecological studies in tropics. The structure of benthic diatom communities and the use of diatom indices yield good results in water quality monitoring in India. However, the occurrence of possible endemic species necessitates a diatom index unique to India.

4.8 LULC Analysis

LULC showed considerable variability among catchments, with forest/vegetation land cover as a dominant class (mean = 64.36 %, range = 0.13–95.45 %), followed by agriculture/cultivation area (mean = 24.27 % range = 2.55–63.63 %), among the 24 catchments. LULC analysis shows that natural vegetation is poor towards the leeward side of the mountains (eastern region), due to the intense anthropogenic activities. This region has more of agriculture, open scrub/barren land, and built-up area. In the entire study region, the class forest/vegetation covers predominantly moist deciduous type, with small isolated patches of semi-evergreen vegetation in the eastern region and the western region (windward side) with rugged hilly terrain and heavier rainfall ($\sim$5,000 mm) having characteristic evergreen to semi-evergreen forests. The detailed LULC for each catchment is given in the Table 7 and the land cover images are given in the Fig. 19. The dendrogram of sites based on LULC obtained by Ward's method is shown in the Fig. 20. Three well differentiated clusters

Table 7 Percentage LULC classes for each catchment in the study area

	Forest/ vegetation	Agriculture/ cultivation	Open scrub/ barren land	Water bodies	Built up	Others
CHI	52.5	34.24	10.9	1.18	0.14	1.04
MEL	83.58	10.88	0.57	2.84	1.52	0.61
KEL	85.83	8.19	1.4	3.03	0.92	0.62
BEE	90.41	2.55	0.16	5.11	1.16	0.61
ANG	81.54	12.67	1.38	0.08	0.18	4.14
MAK	95.45	3.02	0.38	0.01	0.13	1.01
HUR	52.84	28.62	11.89	3.91	0.1	2.64
MAV	48.85	36.26	10.79	2.94	0.43	0.73
YEN	56.15	24.49	10.47	5.61	0.16	3.12
BAI	70.85	23.49	0.99	0.58	0.2	3.89
DEE	64.34	28.64	3.62	0.51	0.2	2.69
YAN	90.83	6.52	0.56	0.02	0.08	1.98
SAP	42.8	50.61	4.5	0.97	0.31	0.81
BAD	88.36	7.29	0.24	0.11	0.06	3.94
NAI	67.43	17.89	3.65	1.03	0.44	9.58
SAK	80.08	14.94	0.26	0.92	0.24	3.58
AND	68.1	24.87	3.36	0.93	0.98	1.77
DAA	86.29	10.84	0.58	1.26	0.41	0.63
HAS	88.6	5.77	0.42	3.96	0.88	0.37
KAM	88.8	5.31	0.6	4.01	0.89	0.39
MAN	23.46	50.42	20.69	0.67	0.52	4.25
KAL	0.53	59.6	30.22	0.02	0.84	8.79
SAN	0.13	63.63	31.48	0.02	0.16	4.59
GUN	36.82	51.72	10.52	0.52	0.35	0.07

can be seen, with forest cover decreasing and agriculture/cultivable land cover increasing from top to bottom. The third cluster from top includes sites SAN, KAL, MAN, SAP and GUN, which are characterized with intensive agricultural activities (>50 %). The group located in the center of the dendrogram is characterized by more forest cover (>50 %) with moderate amount of agricultural land. The topmost group is dominated by forest land cover of more than 80 %.

4.9 Relationship of LULC with Water Chemistry and Diatom Assemblages

A PCA bi-plot of water quality variables and LULC for all sample sites is given in Fig. 21. The two-dimensional bi-plot describes 65 % of the variation in data, where 52 % displayed on the first axis and 13 % is displayed on the second axis. Among

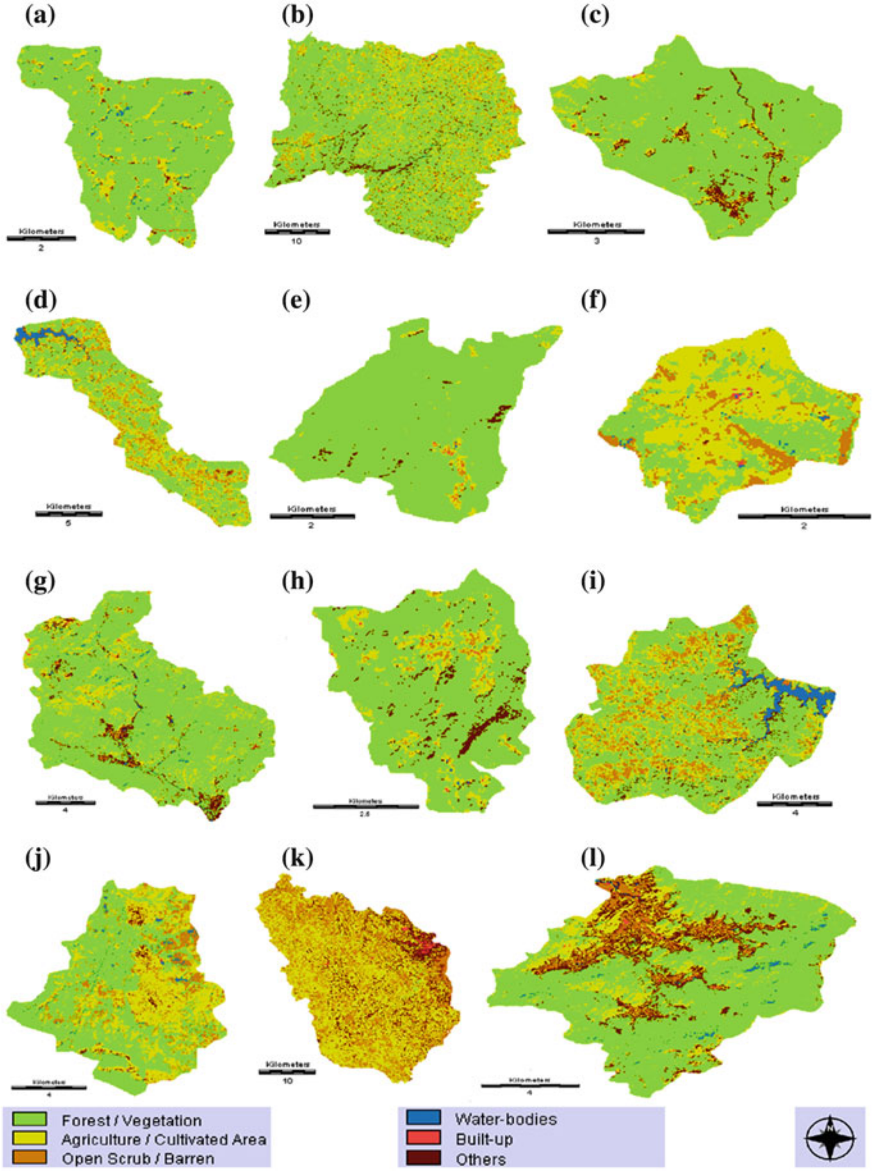


Fig. 19 Land use of study catchments in central Western Ghats.**a** Daanandhi,**b** Deevalli, **c** Badapoli, **d** Mavinahole, **e** Makkegadde, **f** Gunjavathi, **g** Sakathihalla, **h** Angadibail, **i** Hurlihole, **j** Chitgeri, **k** Kalghatghi, *l* Naithihole land use of study catchments in central Western Ghats. **m** Beegar, **n** Andhalli, **o** Yennehole, **p** Kammani, **q** Sangadevarakoppa, **r** Machikere, **s** Melinakeri, **t** Yanahole, **u** Sapurthi, **v** Bailalli, **w** Kelaginakere, **x** Hasehalla

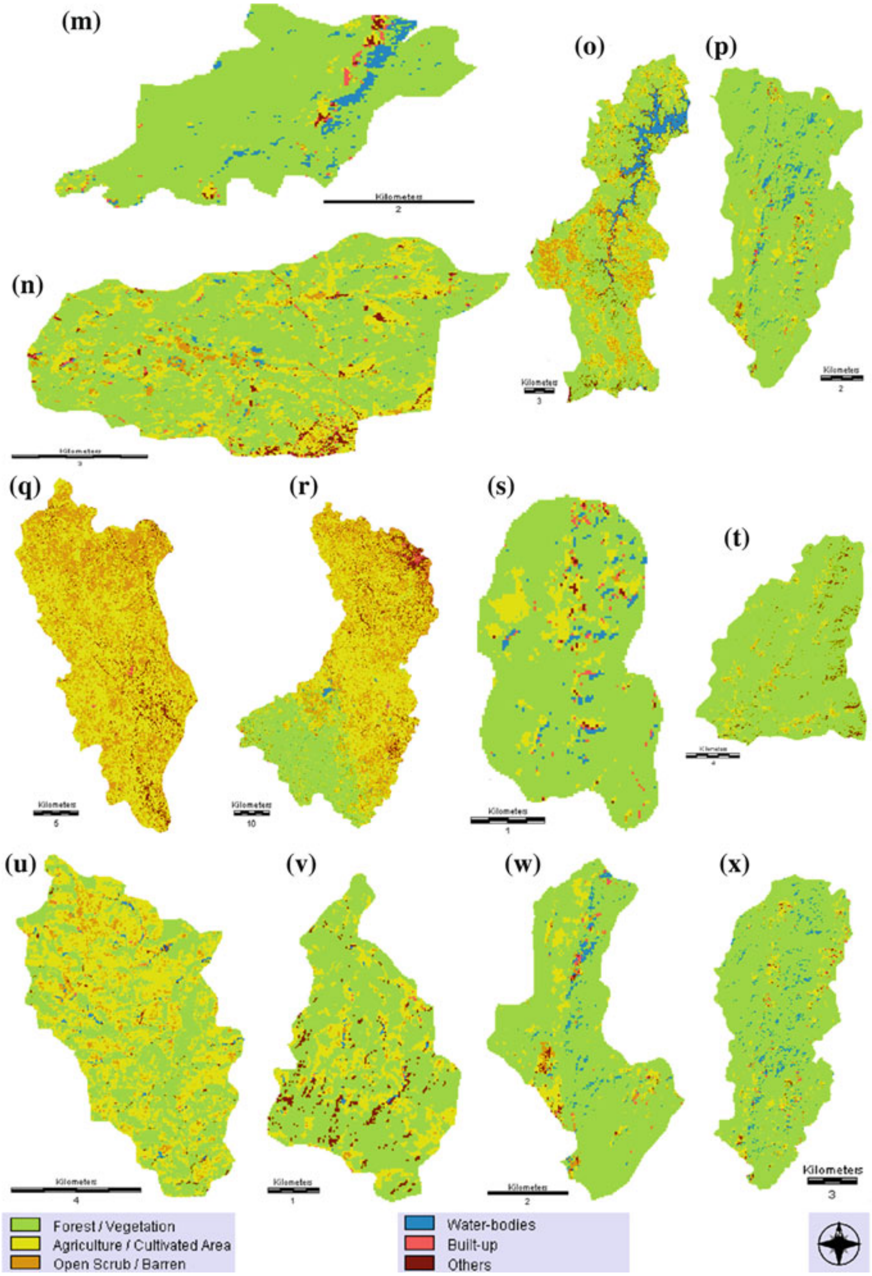


Fig. 19 (continued)

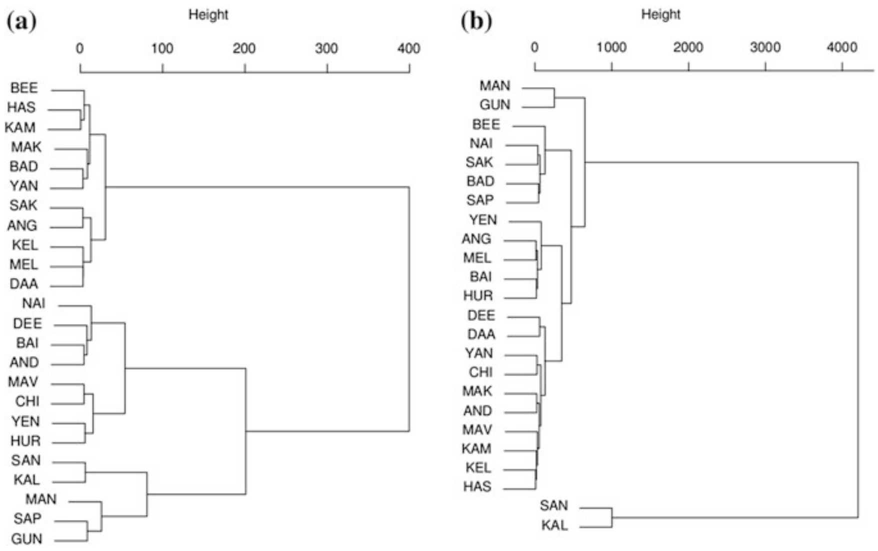
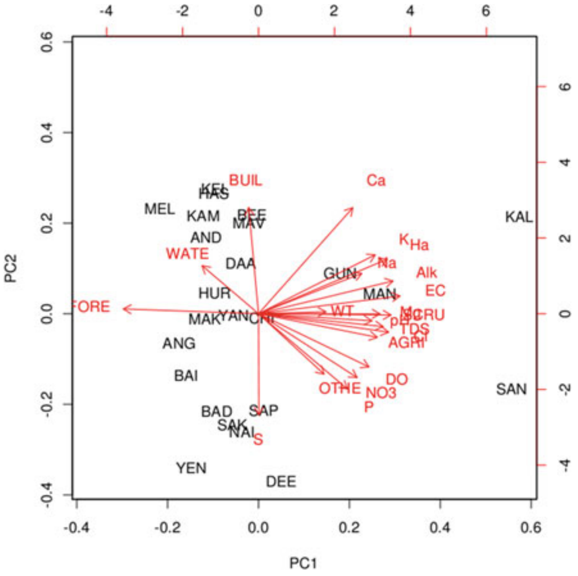


Fig. 20 Dendrogram of the cluster analysis based on **a** LULC and **b** water quality in the 24 sampling sites of the central Western Ghats

Fig. 21 PCA bi-plots of water chemistry and LULC variables in study sites in central Western Ghats Streams



water chemistry variables, ionic variables were positively correlated with first axis and among the LULC variables percentage agriculture and scrub land cover were positively related to the first axis. Sites with more than 50 % of agriculture land cover were separated from other sites on the PC2 axis indicating trends in water quality may be related to land use. Agriculture dominated sites were placed due to the higher conductivity, ionic and nitrates levels relative to the forest dominated sites, which are characterized by low ionic and nutrient in nature.

Correlation between percentage agricultural land cover with water chemistry variables and diatom autecological indices revealed the role of landscape (Hegde et al. 1994). Previous studies reported agricultural expansion as one of the major driver for deforestation (Menon and Bawa 1998) in Western Ghats and thereby determine the environmental condition of streams and diatom assemblages (Fig. 22). The gradient of percentage agriculture land cover were positively correlated with water chemistry variables like electrical conductivity (r = 0.67), total dissolved solids (r = 0.62), nitrates (r = 0.60) and pH (r = 0.52). Gradient of percentage agriculture land cover were positively correlated with percentage pollution tolerant diatoms (r = 0.65, Fig. 23). Relation between the diatom

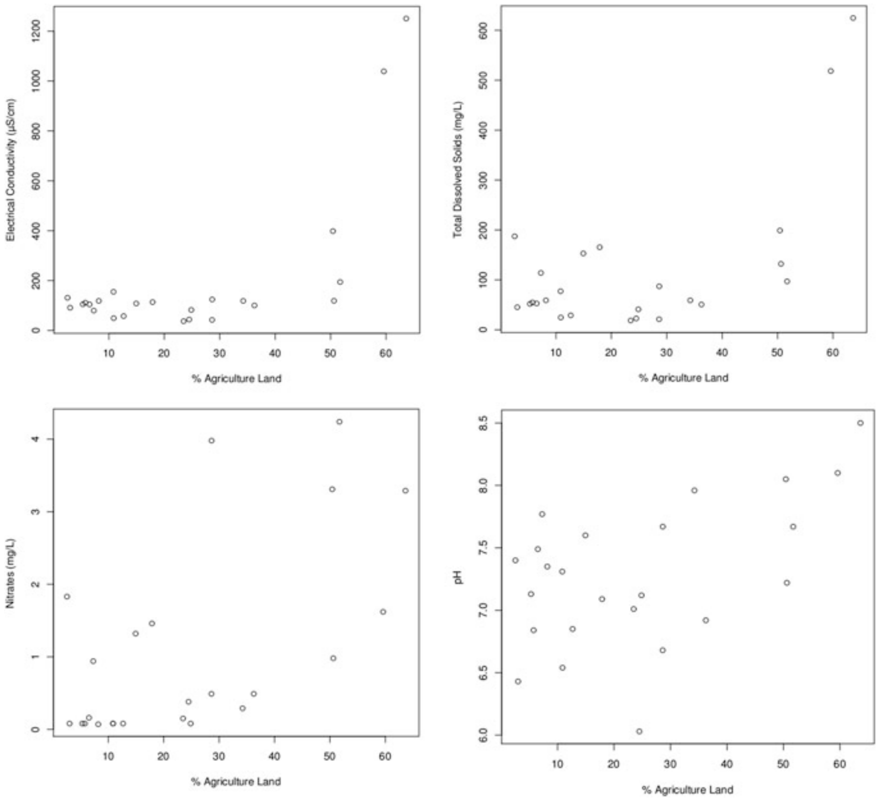


Fig. 22 Changes in water quality variables along a gradient of percentage agricultural land cover in central Western Ghats

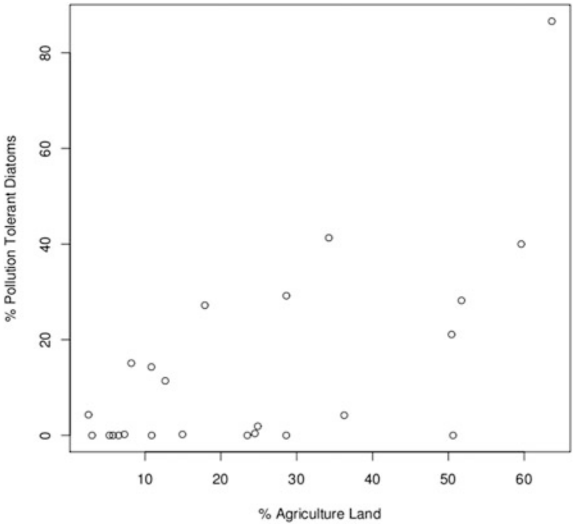


Fig. 23 Pollution tolerant diatoms with gradient of agricultural land cover (%) in central Western Ghats

autecological indices with land cover and water chemistry variables are given in Tables 7 and 8 respectively. Most of the diatom autecological parameters were positively correlated with forest/vegetative cover and negatively correlated with agriculture/cultivable and scrub land cover. All the diatom indices were normalized to a range of 0–20, where <9 indicates bad water quality, 9–12 indicates poor water quality, 12–15 indicates moderate water quality, 15–17 indicates good quality and >17 indicates high quality. The present study shows that within a similar eco-region, the diversity and community composition of diatoms changes with LULC pattern. Among all the 24 catchments, most of the catchments were dominated by forest/vegetation land cover. However, forest cover in the leeward side catchment was very low owing to anthropogenic activities. Hydro power projects commenced in the study area since 1960s seem to have lost.

The streams draining the catchments with agriculture and scrub land cover were characterized with ionic and nutrient rich waters, which highlight that the water chemistry variables are driven by the composition of land cover. Many studies have reported that urban and agricultural land use play a primary role in degrading water quality in adjacent aquatic systems by altering the soil surface conditions, increasing the impervious area and generating pollution (Tong and Chen 2002; White and Greer 2006). The results suggest better water quality tendencies in watersheds having less urbanization with more natural vegetation region. Percent agriculture in the catchment ranged from 2 to 63 % with an average of 24.27 %.

Table 8 Water chemistry variables of the sampling sites in central Western Ghats

Water chemistry variables (units)	Mean ± S.D	Range
pH	7.28 ± 0.58	6.03–8.50
Water temperature (°C)	26.09 ± 2.52	22.10–35.43
Electrical conductivity (µScm^{-1})	199.00 ± 301.44	37.17–250.67
Total dissolved solids (mg L^{-1})	120.26 ± 149.68	18.67–624.67
Alkalinity (mg L^{-1})	70.44 ± 111.46	12.00–421.07
Chlorides (mgL^{-1})	35.25 ± 62.36	4.99–255.92
Hardness (mg L^{-1})	69.49 ± 96.94	12.00–376.00
Calcium (mg L^{-1})	14.76 ± 17.33	1.60–84.97
Magnesium (mg L^{-1})	15.72 ± 18.58	1.17–71.01
Dissolved oxygen (mg L^{-1})	7.58 ± 1.77	4.81–11.52
Phosphates (mg L^{-1})	0.18 ± 0.36	0.01–1.30
Sulphates (mg L^{-1})	19.94 ± 18.07	2.91–67.91
Sodium (mg L^{-1})	52.92 ± 201.09	1.05–996.03
Potassium (mg L^{-1})	11.01 ± 35.01	0.41–168.33
Nitrates (mg L^{-1})	1.06 ± 1.33	0.07–4.24

Thus the sites selected for the present study covered a good range of the land-use gradient and hence the inferences drawn from the statistic may not have been influenced by skewed sampling. An aggregated measure of LULC such as percentage agriculture in catchments may only represent the potential of LULC effects on streams. Percentage agriculture lands in catchments were positively correlated with the ionic and nutrient variables. Studies have shown that the percentage of agriculture at watershed scale is a primary predictor for nitrogen and phosphorus (Ahearn et al. 2005).

Diatom community structure in streams of the central Western Ghats was found to be strongly related to the land use practices as could be observed elsewhere (Stevenson et al. 2009; Walsh and Wepner 2009). The nutritional changes in the streams triggered by the LULC changes stands as a determining factor in structuring the diatom species composition. Effects of nutrient are commonly identified as one of the most important determinants of diatom species composition in lentic and lotic ecosystems (Pan and Stevenson 1996). However, the diatom species composition at CWG streams were controlled more by the ionic variables than the nutrient concentration. More of pollution tolerant species were seen in the streams in agriculture dominated catchments. Blinn (1993, 1995) found that higher salinities ($\geq$35 mScm^{-1}) tend to override other water quality parameters in structuring diatom communities in salt lakes. Agriculture dominated sites represented high pH, TDS and nutrient loads, (Figs. 22 and 23) which is also supported by positive correlation between percentage of agriculture land with percentage of pollution tolerant diatoms (Fig. 23).

5 Conclusions

- The results indicate that (a) the water quality regimes show seasonal variations, (b) diatom species assemblages change accordingly in all the water quality regimes, due to seasonal water quality conditions and (c) the species distribution across the sites followed the satellite-mode due to the specific ecological niches of the diatoms.
- This study concludes that the environmental quality of the Western Ghats streams can be monitored by biomonitoring ventures and compared to other water monitoring programs. This study also suggests that the diatom community in this region is rich with possible endemic taxa; hence considerable amount of importance has to be given for the taxonomy of the lesser-known species before commencing the biomonitoring programs.
- The analyses and results provided insights into the linkages between land use practices and water quality in the streams and the relative sensitivity of water quality variables to alterations in land use. The relationships between the diatom indices and water chemistry variables relation showed the impact of land use on the stream ecosystem.
- It has been evident that the causes and sources of water pollution in the five river basins are due to agricultural land use, anthropogenic activities and industrialization. The major occupation in the study area is agriculture, which is main source of increase in nitrates and ionic components in streams. Domestic and industrial sewage discharges into the rivers are responsible for the observed high concentration of electrical conductivity, total dissolved solids, total hardness and other ionic components. Proper treatment of effluent from the industrial processes to the acceptable levels and discouraging stagnation of water through small dams are the two major recommendations to minimize the damages on the river ecosystem in the central Western Ghats. Table 9 lists the threats and remedial measures.

Table 9 Threats and mitigation measures

River basin	Region	Problem	Remedial measures
Kali	Dandeli	Paper mill effluent	Enforce effluent treatment by the industry (implementation of the control of water pollution, Polluter pays principle)
Kali	Ramnagar	Non-point source pollution in streams and rivers from Agriculture fields	Avoiding intense use of chemical fertilizers and pesticides
Kali	Honkon (Brackish)	Mechanized sand mining	Stopping of sand mining in certain ecologically sensitive region and regulated sand mining in selected localities
Bedthi	Sangdevarkoppa	Non-point source pollution	Avoiding intense use of chemical fertilizers and pesticides
Bedthi	Kalghatghi	Urban domestic sewage, non-point source pollution	Implementation of sewage treatment plant in Hubli town. Sewage should be treated before letting into the river
Bedthi	Kalghatghi	Solid Waste Disposal in River	Setting up Solid waste disposal facility in outskirts of Hubli town
	Manchikeri	Urban domestic sewage, non-point source pollution	Implementation of sewage treatment plant in Hubli town. Sewage should be treated before letting into the river
Sharavathi	Gerusoppa and downstream	Mechanized sand mining	Stopping of sand mining in certain ecologically sensitive region and regulated sand mining in selected localities

Acknowledgment We are grateful to the NRDMS division, the Ministry of Science and Technology (DST), Government of India, The Ministry of Environment and Forests (MoEF), Government of India and Indian Institute of Science for the financial and infrastructure support.

Appendix

Appendix 1 Checklist of epilithic diatoms of Rivers of Uttara Kannada, Karnataka

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Achnanthes sp. J.B.M. Bory de St. Vincent		+			
Achnanthes minutissima Kützing*v. minutissima* Kützing (*Achnanthidium*)	+	+	+	+	+
Achnanthes sp.		+			
Achnanthidium sp.	+	+	+	+	+
Actinocyclus sp.	+				
Amphora montana Krasske	+				
Amphora pediculus (Kützing) Grunow	+				+
Amphora species		+			
Aulacoseira ambigua (Grunow) Simonsen	+	+		+	
Aulacoseira granulata (Ehr.) Simonsen		+			
Aulacoseira granulata (Ehr.) Simonsenmorphotype *curvata*		+			
Bacillaria paradoxa Gmelin	+				
Brachysira neoexilis Lange-Bertalot	+	+	+	+	+
Brachysira sp.	+	+	+	+	+
Brachysirawygaschii Lange-Bertalot	+		+	+	+
Brassierea sp Hein and Winsborough		+			
Caloneis bacillum (Grunow) Cleve	+	+		+	
Caloneis hyalina Hustedt	+				
Caloneis silicula (Ehr.) Cleve	+	+			+
Caloneis species		+			
Cocconeis placentula Ehrenberg *var.euglypta* (Ehr.) Grunow	+	+	+		+
Craticula sp A. Grunow		+			
Craticulaacco modiformis Lange-Bertalot		+			

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Craticula molestiformis (Hustedt) Lange-Bertalot		+			
Craticula submolesta (Hust.) Lange-Bertalot	+	+			+
Craticula vixnegligenda Lange-Bertalot		+			
Cyclostephanos sp F.E. Round		+			
Cyclostephanos species	+	+			+
Cyclotella sp F.T. Kützingex A de Brébisson		+			
Cyclotella meneghiniana Kützing	+	+			
Cyclotella ocellata Pantocsek		+			
Cyclotella species		+			
Cymbella kolbei Hustedt var. *kolbei*	+	+		+	+
Cymbella species	+	+	+	+	+
Cymbella tumida (Brebisson) van Heurck	+	+			
Cymbopleura (Krammer) Krammer					+
Cymbopleura sp.	+			+	+
Diadesmis contenta (Grunow ex V. Heurck) Mann	+	+			+
Diploneis elliptica (Kützing) Cleve		(+)			
Diploneis oblongella (Naegeli) Cleve-Euler		(+)			
Diploneis ovalis (Hilse) Cleve		+			
Diploneis subovalis Cleve	+	+			+
Encyonema mesianum (Cholnoky) D.G. Mann	+				+
Encyonema minutum (Hilse in Rabh.) D.G. Mann	+	+			+
Encyonema species	+				+
Entomoneis alata Ehrenberg		+			
Eolimna subminuscula (Manguin) Moser Lange-Bertalot and Metzeltin	+	+			

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Eunotia sp C.G. Ehrenberg		+			
Eunotiabi lunaris (Ehr.) Mills var. *bilunaris*					+
Eunotia incisa Gregoryvar. *incisa*	+	+			
Eunotia minor (Kützing*)* Grunow	+	+	+	+	+
Eunotia rhomboidea Hustedt	+		+	+	+
Eunotia sp.	+	+		+	
Fallaciainsociabilis (Krasske) D.G. Mann		+			
Fallacia pygmaea (Kützing) Stickle and Mann sp. *pygmaea* Lange-Bertalot	+	+			
Fallaciatenera (Hustedt) Mann in Round		+			
Fragilaria biceps (Kützing) Lange-Bertalot	+	+	+	+	+
Fragilaria species		+			
Fragilaria ulna (Nitzsch.) Lange-Bertalotvar. *ulna*	+	+	+	+	+
Fragilari aungeriana Grunow	+				
Frustulia saxonica Rabenhorst				+	
Frustulia species	+			+	+
Geissleriadecussis (Ostrup) Lange-Bertalot and Metzeltin		+			
Gomphonema acuminatum Ehrenberg	+				
Gomphonema difformum Karthick and Kociolek		+	+	+	
Gomphonemadi minutum Karthick and Kociolek	+	+	+		
Gomphonema gandhii Karthick and Kociolek	+	+	+	+	+
Gomphonema parvulum (Kützing) Kützingvar. *parvulum f. parvulum*	+	+	+	+	+
Gomphonema pseudo augur Lange-Bertalot		+			
Gomphonema species	+	+	+	+	+
Gyrosigma acuminatum (Kützing) Rabenhorst	+	+			

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Gyrosigma scalproides (Rabenhorst) Cleve	+				
Gyrosigma species		+			
Hantzschia distincte punctata Hustedt in Schmidt et al.				+	
Hippodontaavittata (Cholnoky) Lange-Bert. Metzeltin and Witkowski	+				+
Luticola species	+	+			
Luticola species (*aff. mutica*)	+				
Navicula species		+			
Navicula antonii Lange-Bertalot		+		+	
Navicula cincta (Ehr.) Ralfs in Pritchard	+				
Navicula cryptocephala Kützing	+	+	+	+	+
Navicula cryptotenella Lange-Bertalot	+				
Navicula elginensis (Gregory) Ralfs in Pritchard					+
Navicula erifuga Lange-Bertalot	+	+			
Navicula gracilis Ehrenberg	+			+	
Navicula hustedtii Krasske					
Navicula hustedtii Krasskevar. *obtusa* Hustedt	+			+	
Navicula leptostriata Jorgensen	+	+	+	+	+
Navicula peregrina (Ehr.) Kützing	+				
Navicula reinhardtii (Grunow) Grunow in Cl. and Möller				+	
Navicula riediana Lange-Bertalot and Rumrich	+			+	+
Navicula rostellata Kützing	+	+		+	+
Navicula sp.	+	+	+	+	+
Navicula symmetrica Patrick	+	+	+	+	+
Navicula viridula (*Kützing*) Ehrenberg	+				
Navigiolum species.					
Neidium affine (Ehrenberg) Pfitzer	+				+

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Nitzschia sp. A.H. Hassall		+			
Nitzschia amphibia Grunowf. *amphibia*	+	+			+
Nitzschia clausii Hantzsch	+	+		+	+
Nitzschia compressa (J.W. Bailey) Boyer		+			
Nitzschia dissipata (Kützing) *Grunowvar.media* (Hantzsch.) Grunow				+	
Nitzschia fonticola Grunow in Cleve et Möller	+	+			
Nitzschia frustulum (Kützing) Grunow var. *frustulum*	+	+			
Nitzschia gracilis Hantzsch				+	
Nitzschia linearis (Agardh) W.M. Smith var. *linearis*					
Nitzschia nana Grunow in Van Heurck	+				
Nitzschia obtusa W.M. Smith var. *kurzii* (Rabenhorst) Grunow	+	+		+	+
Nitzschia palea (Kützing) W. Smith	+	+		+	+
Nitzschia reversa W. Smith	+	+		+	+
Nitzschia sigma (Kützing) W.M. Smith		+		+	+
Nitzschia species	+	+			+
Nitzschia umbonata (Ehrenberg) Lange-Bertalot		+			
Pinnularia acrospheria W.M. Smith var. *acrospheria*		+			+
Pinnularia brebissonii (Kütz.) Rabenhorst var. *brebissonii*	+	+		+	
Pinnularia divergens W.M. Smith. var. *undulata* (M. Perag. and Herib.) Hustedt				+	
Pinnularia gibba Ehrenberg				+	
Pinnularia species		+		+	+
Placoneis sp.	+	+		+	
Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot	+	+	+	+	+

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Planothidium rostratum (Oestrup) Round and Bukhtiyarova	+	+			+
Planothidium sp. Round and Bukhtiyarova		+	+	+	
Pleurosigma salinarum (Grunow) Cleve and Grunow	+				
Pseudostaurosira brevistriata (Grun. in Van Heurck) Williams and Round		+			
Rhopalodia gibba (Ehr.) O.Mullervar.gibba					+
Rhopalodia operculata (Agardh) Hakansson	+				+
Sellaphora species	+	+			
Sellaphora americana (Ehrenberg) D.G. Mann	+			+	+
Sellaphora laevissima (Kützing) D.G. Mann				+	
Sellaphora nyassensis (O. Muller) D.G. Mann	+	+			
Sellaphora pupula (Kützing) Mereschkowksy	+	+		+	+
Seminavis sp. D.G. Mann		+			
Seminavis species		+			
Skeletonema species					
Stauroneis species	+	+			+
Surirella angusta Kützing	+	+		+	+
Surirella species	+	+		+	+
Synedra sp.		+			
Tryblionella calida (grunow in Cl. and Grun.) D.G. Mann	+	+			
Tryblionella levidensis W.M. Smith		+			
Total	83	95	22	51	55
Total number of taxa reported from all river basins	140				

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