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Spatial variability of water quality in the upstream Bhadra river, tributary of river Tungabhadra, in the Western Ghats of India: Application of multivariate statistical techniques

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Water quality of river water examined at 23 stations in the upstream of Bhadra River basin from Kudrekmukh National Park (KNP) to Bhadra Wildlife Sanctuary (BWS) in India. Spatial cluster analysis performed on 23 sampling stations revealed three clusters depending on the similarities in the water quality variables that could delineate the number of sampling stations required for optimal sampling. Sample cluster analysis classified the 24 environmental variables in the data set into seven clusters depending on the similarities in the water quality variables. Principal component analysis of water produced 7 components, which accounted for 88.15 % of total variance. Factor analysis was performed on principal components extracted seven variance factors (VFs) after rotation with all VFs having eigenvectors of high (> 0.70) and moderate (> 0.50) loadings. The VF 1 accounted for 37.93 % of total variance with 9 eigenvectors (loading > 0.70) such as conductivity, total alkalinity, total hardness, Ca, Mg, Na, K, chloride and silicate. On total eigenvectors generated on 24 water quality data sets of river water were classified into four types *viz.* safe (normal), low polluted, medium polluted and highly polluted waters with corresponding total eigenvectors of < 0.50, > 0.50 - < 1.00, > 1.00 - < 1.50 and > 1.50, respectively. Total factor score produced for 23 sampling stations revealed a total of five types of sampling stations with safe, low, medium, high and very high levels of pollution with corresponding total factor scores of less than zero (< 0.0), > 0.0 - < 1.50), (> 1.50 - < 3.00), (> 3.00 - < 4.50) and (> 4.50), respectively.

[Keywords: Cluster analysis, Correlation analysis, Factor analysis, Karnataka, Lotic water body, Principal component analysis, Western Ghats]

Introduction

Freshwater is one of the limited resources on our planet. Water with high concentration of some substances adversely affects the quality of biota in the given water body at a given time. Spatial variability of water quality in inland lotic water bodies particularly in rivers is directly affected by various activities, both natural and anthropogenic, operating in the river basin and is becoming increasingly affected by anthropogenic activities. The traditional way of examination of river water quality is a univariate statistical technique, which considers only two variables at a given time[1]. The interpretation of different samples or variables could be undertaken at a time using multivariate statistical methods[2,3]. Multivariate statistical methods have been extensively used in geological and ecological studies in the sixties, seventies and eighties in the last century[4-6] and these techniques are now widely used in various scientific fields. A good amount of information is available on the utilisation of multivariate statistical methods in assessing water quality of rivers from different geographical regions of the world[7-15] including India[16-22]. Application of Cluster analysis (CA), Principal component analysis (PCA) and Factor analysis (FA) is useful to understand the patterns of variation of environmental variables of water in the river basin[23-25]. Further, there is a dearth of information on the water quality of Bhadra River in the Western Ghats.

Material and Methods

Study area

The river Bhadra rises at 'Gangamula' on the Varaha Parvata Mountain in the Aroli-Gangamula region at an elevation of about 1198 m above MSL in the *Sahyadri* range of the Western Ghats of India. The river Bhadra flows eastwards initially and then turns north east. Total length of river Bhadra is 138 km and sub montane in character. The geology of river Bhadra is said to be Precambrian archean of Dharwar schist. The belt of this rock consists of granite, limestone, dolomite, chlorite schist and thick beds of magnetite quartzite. The upper reaches of the Bhadra river basin has deposits of iron ore which is banded magnetite quartzite. The river Bhadra receives water from many tributaries, streams, rivulets and small perennial water flow shoal forests and the water flow in the main river is riffle, swirling and intermittent pools. The river bed largely consists of granite rocks, cobbles and pebble stones and only at pools the river bottom consists of sand and silt. The river basin receives assured rain fall every year of about 400 to 700 cm during monsoon season, June to August. The KNP is located in the upper reaches of Bhadra River. The Kudremukha iron Ore Company Limited (KIOCL), carried out its open cast mining since 1976, is located in the KNP area. The Apex Court of India in its Judgement dated 30.10.2002 had directed the KIOCL to wind up its mining activity by December 2005 and accordingly the mining operation and allied activities has been closed. A dam (Lakya dam) has been built at Lakya village to store the silt and clay of tailings of open cast mining of KIOCL. The BWS is located in the downstream Bhadra River. A dam has been built across the Bhadra River at Lakkavally mainly for irrigation purpose and hydro power is also produced to some extent.

A total of 23 water sample collection sites for determination of quality of water from river Bhadra were fixed starting from the river origin to the backwaters of Bhadra dam including its major tributaries, streams and rivulets. The sampling station 1 (Bhagavathi) on the Bhadra River near the Kadmbi Waterfalls located in the KNP area and exposed to the natural tropical evergreen wet forest environment. The sampling stations at Lakya and Malleshwara on the Bhadra River are located adjacent to mining and allied activities of KIOCL and are exposed to anthropogenic activities. The sampling stations at Siregola and Khodi, exposed to the natural tropical evergreen wet forest environment, located on the Bhadra river and the sampling stations at Muthodi near Honnahalla and Madla near Hipla village on Sowmyavahini stream, exposed to natural tropical dry deciduous forest environment, in the BWS. The rest of the sampling stations Nellibedu, Kalasa, Balehole, Magundi upstream, Magundi downstream, Balehonnur and Khandya on Bhadra river and Balagalu and Samse on Somavahini stream, Balehole on Balehole stream, Kundur and Huligere on Huligehalla stream, Arenur and Khdabagere on Anebiddahalla stream, Kolela on Kolele stream and Kallikoppa on Bakri stream are associated with agricultural activities and human settlements. A total of 12 stations are selected on main Bhadra river and 11 stations in tributaries on both left (3 stations) and right (8 stations) banks of the Bhadra to include heterogeneous agro-climatic conditions in the river basin. The river basin has been subjected to anthropogenic activities including farming such as extensive coffee plantations, tea gardens, paddy field and arecanut and coconut plantations. The Sowmyavahini River (stations 21-22) drains into the backwaters of Bhadra reservoir near Hebbe whereas the river Bahakri stream (station 23) directly discharges into the Bhadra reservoir near N. R. Pura.

Sample and sampling procedures

River water was collected from 23 sampling stations located in the upstream of Bhadra River basin from KNP to BWS during summer period (31.03.2001 – 03.04.2001). The sampling stations and their co-ordinates are presented in Figure 1 and Table 1. Air temperature (AT), water temperature (WT) and sediment temperature (ST) were measured at the time of sampling using mercury thermometer at the collection site *per se*. Water sample was collected by filling a white plastic container from just under the

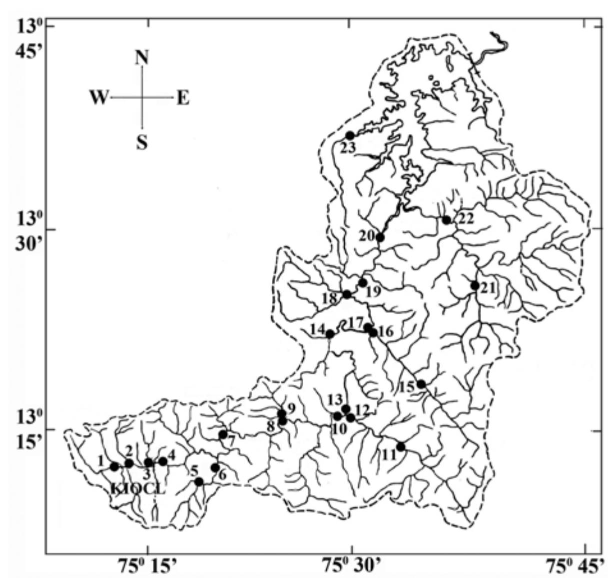

Fig. 1 — Location of sampling stations for collection of water sample in the Bhadra river basin in the Western Ghats

Table 1 — Location of sampling stations for collection of water sample from the upstream Bhadra river basin in the Western Ghats, Karnataka

Station No.	Name of the place	Name of the river	Code	Coordinates
1	Bhagavathi	Bhadra	Kwf 01 B	13.215 N; 75.18 E
2	Lakya	Bhadra	Lak 02 B	13.212 N; 75.24 E
3	Malleshwara	Bhadra	Mal 03 B	13.213 N; 75.39 E
4	Nellibedu	Bhadra	Nel 04 B	13.206 N; 75.28 E
5	Balagalu	Somavahini	Bag 05 Sm	13.187 N; 75.32 E
6	Samse	Somavahini	Sam 06 Sm	13.188 N; 75.33 E
7	Kalsa	Bhadra	Kal 07 B	13.251 N; 75.35 E
8	Balehole	Bhadra	Bal 08 B	13.265 N; 75.42 E
9	Balehole	Balehole	Bal 09 Bs	13.269 N; 75.42 E
10	Magundi	Bhadra	Mag 10 B	13.274 N; 75.47 E
11	Kundur	Huligehalla	Kun 11 H	13.226 N; 75.55 E
12	Huligere	Huligehalla	Hul 12 H	13.270 N; 75.49 E
13	Magundi	Bhadra	Mag 13 B	13.278 N; 75.48 E
14	Balehonnur	Bhadra	Bah 14 B	13.358 N; 75.47 E
15	Arenur	Anebiddahalla	Are 15 A	13.272 N; 75.61 E
16	Kadabagere	Anebiddahalla	Kad 16 A	13.371 N; 75.53 E
17	Khandya	Bhadra	Kha 17 B	13.380 N; 75.52 E
18	Kolale	Kolele	Kol 18 K	13.421 N; 75.49 E
19	Siregola	Bhadra	Sir 19 B	13.413 N; 75.51 E
20	Khodi	Bhadra	Kho 20 B	13.478 N; 75.53 E
21	Muthodi	Sowmyavahini	Mut 21 Sw	13.419 N; 75.54 E
22	Hipla	Sowmyavahini	Hip 22 Sw	13.511 N; 75.61 E
23	Kallikoppa	Bakri	Kal 23 Bk	13.619 N; 75.49 E

water surface. The samples were kept under refrigerated condition and transported to the laboratory for analysis. Estimation of biological oxygen demand (BOD) of water, separate samples were collected in BOD bottles, kept in refrigerated conditions, transported to the laboratory for incubation and analysis. For estimation of dissolved oxygen (DO) the water sample was collected, fixed with Winkler's reagent in the field *per se* and analyzed as early as possible with-in 5 hrs. The AT, WT, and ST are expressed in degree centigrade.

Analytical methods

The DO of river water estimated following the Winkler's procedure[26]. The electrical conductivity (EC) of river water was determined using water analysis kit (SYSTRONICS 371; ISO 9001: 2008 Co. Ahmedabad). The hydrogen ion concentration (pH) and turbidity were determined by pH metro and Nephlometer, respectively. The total solids (TS), dissolved solids (DS), suspended solids (SS), BOD, total hardness (TH), total alkalinity, chloride, florid, calcium (Ca) and magnesium (Mg) of water were estimated[26-27]. The amounts of sodium (Na) and potassium (K) in river water samples were determined (Spray and burning method) employing a photometer (SYSTRONICS 127, ISO 9001: 2008 Co., Ahmedabad). The concentrations of sulphate (SO_4) by turbidometric method, inorganic phosphate (PO_4) by stannous chloride method, nitrate (NO_3) by brucine method, silicate by molybdosilicate method and iron (Fe) by Phenanthroline method of river water were determined[26]. The values of EC and turbidity are expressed in ųScm^{-1} and NTU, respectively. The results of analysis of TS, DS, SS, DO, BOD, total hardness, total alkalinity, chloride, Ca, Mg, Na, K, NO_3, PO_4, SO_4, silicate, fluoride and Fe are expressed in mg/l.

Statistical procedures

All statistical and mathematical computations were done using IBM SPSS 24 software and Microsoft Office Excel 2010. CA, PCA and FA were carried out using field and laboratory data standardized through z-scale transformation to avoid error due to large variations in data ambit and to render the data dimensionless.

Cluster analysis – Hierarchical agglomerative CA performed on the normalized data set of environmental parameters using Ward's method with

Squared Euclidean distance as a measure of similarity for spatial CA. The CA uses the ANOVA method to determine the distances between clusters while attempting to minimize the sum of squares of any two clusters that can be formed at each step. Hierarchical agglomerative CA was performed using Between Group Linkage method with the Pearson correlation coefficient as the measure of similarity for variable (sample) CA. The CA was applied to the water quality data set for variables and also to sampling stations to generate variable (sample) and spatial (station), respectively, dendrograms[11,28,29].

Principal component analysis – Principal component analysis extracts the eigenvalues and eigenvectors from the correlation matrix of original variables. The principal components are the uncorrelated (orthogonal) variables that are obtained by multiplying the original correlated variables with the eigenvector which is the list of coefficients (loadings or weightings). In the present study, the data on variables was subjected to PCA to find the number of components that can adequately explain the observed correlations among the observed variables and to delineate the pattern recognition that attempts to explain the variance of a large set of inter-correlated variables and transforms them into a smaller set of independent (uncorrelated) variables (principal components). Principal components include a linear combination of observable variables[30].

Factor analysis – The procedure is the same as described above up to the extraction of eigenvalues and eigenvectors from the correlation matrix of original variables. The data on variables was then further subjected to FA which extracts the new group of variables, known as variance factors (VF's), by rotating the axis defined by PCA. Thus FA further reduces the contribution of less significant variables obtained from PCA. The unobservable, hypothetical and latent parameters are also included in VFs. Data was subjected to varimax rotation to generate VFs for variables and factor scores for stations[5,31-32].

Results and Discussion

The observations on average and measures of variation (SD) of the climatic factors and water quality variables and their minimum and maximum values observed at sampling stations in the course of study is shown in Table 2. The minimum values of AT, WT, ST, TS, SS, EC, turbidity, total hardness, Ca, Na, K, NO_3 and PO_4 and maximum values of DO content of water were noticed at the sampling site located in the KNP area of Bhadra River and Sowmyavahini stream in the BWS where natural environment prevails. Further, the minimum values in

Table 2 — Average, standard deviation, minimum and maximum values of climatic and water quality parameters in the Bhadra river basin during summer season

Parameters	Code	Mean	SD	Observations and sampling stations			
				Minimum	Station	Maximum	Station
Air temperature	AT	31.20	3.78	24.00	21	38.50	19
Water temperature	WT	29.22	2.53	21.00	21	33.00	11
Sediment temperature	ST	29.00	2.63	21.00	21	32.00	6, 17
Total solids	TS	90.22	68.86	20.00	20	350.00	23
Suspend solids	SS	46.09	62.29	10.00	3, 9, 16, 20	320.00	23
Dissolved Solids	DS	44.13	34.92	10.00	3, 7	120.00	15, 20, 21
pH	pH	7.55	0.25	7.04	16	8.09	23
Conductivity	EC	95.83	36.47	37.00	1	175.00	15
Turbidity	Tur	5.30	4.07	1.10	1	16.00	23
Alkalinity	Alk	65.65	24.92	30.00	1, 3	120.00	12
Dissolved oxygen	DO	7.19	0.72	5.98	15	8.46	4
BOD	BOD	1.81	0.96	0.17	17	3.57	8
Total hardness	TH	26.74	10.25	8.00	1	44.00	11, 12
Calcium	Ca	7.35	2.28	3.21	1	11.62	21
Magnesium	Mg	4.72	2.00	1.12	3	8.19	11, 12
Sodium	Na	22.23	13.75	8.05	1	65.75	15
Potassium	K	0.69	0.37	0.16	1	1.64	15
Chloride	Chl	10.85	4.31	7.10	3	22.72	15
Fluoride	Flu	2.97	0.90	2.04	2	6.12	20
Silicate	Sil	222.35	143.49	62.00	2	518.00	23
Iron	Fe	0.72	0.78	0.06	2	3.71	16
Sulphate	SO_4	2.69	3.16	0.20	16, 20	12.20	2
Nitrate	NO_3	0.56	0.74	0.14	4, 5, 11, 14, 21	2.88	8
Phosphate	PO_4	1.76	3.87	0.15	1	17.75	23

DO, SS, alkalinity, Mg, chloride, fluoride, silicate and Fe concentrations and the maximum value in SO_4 concentration were noticed at station 2 and station 3 located on the Bhadra River in the area of mining and allied activities where anthropogenic activities due to mining and allied activities are more. The DO content of water was high at station 4 (Nellibedu) located on the Bhadra river immediately after the area of mining and allied activities. The maximum values of temperature (AT, WT, ST), solids (TS, SS, DS), pH, EC, turbidity, total alkalinity, total hardness, Ca, Mg, Na, K, chloride, silicate, Fe, NO_3, fluoride and PO_4 concentrations and low values of DO and BOD contents were noticed at the sampling sites located in the middle and downstream of the Bhadra river basin in the Western Ghats where farming and human settlements are common.

Correlation analysis

The correlation matrix of climatic factors and water quality variables is presented in Supplementary Table (Table S1). The observation on BOD, SO_4, fluoride and NO_3 concentrations of river water did not show any significant correlation with other parameters observed during the study period indicating that these variables are not affected by other variables and are derived from different sources. The positive correlations observed among conductivity, alkalinity, total hardness, Ca, Mg, Na, K, chloride and silicate which could be due to mineral composition of the water derived from natural sources in the river basin. High concentration of ionic minerals in stream water is due to surface runoff from agricultural fields and also due to increased quantity of Ca, Mg, Na, K, bicarbonates, etc., in streams and rivulets. The data on NO_3 of river water did not show any significant correlations with other parameters observed indicating that this nutrient is derived from the application of fertilisers and manures and also from effluents of small towns and villages situated on the banks of the river.

Cluster analysis

Cluster analysis reveals the intrinsic structure of a data set without making *a priori* assumptions about the data to classify the objects of the system into categories or clusters based on their nearness or similarity[7]. Hierarchical clustering is the most common approach, where clusters are formed sequentially by starting with the most similar pair of objects and forming higher clusters in a step-by-step fashion. A dendrogram showing clusters for climatic and water quality parameter is presented in Figure 2. In the present study the observation on hierarchical cluster analysis with average linkage between groups produced two major groups of climatic and water quality parameters, *viz*., the first group included clusters 1 to 6 and the second group included cluster 7 which is quite different from rest of the clusters. The hierarchical cluster analysis has produced a total of 7 distinct clusters which are interconnected to each other in the present study. The cluster 7 included the variables such as air, water and sediment temperatures and emerged as a distinct indicating dissimilar from rest of the variables. Cluster 1, comprising variables having high similarity with one another (total hardness, Mg, EC, Ca, alkalinity, Na, K, chloride, silicate) forming group with cluster 2 which was comprised of Fe and turbidity in a step up manner. These two clusters are forming group in a step up manner with cluster 3 which in turn, contains two clusters with SS, PO_4 and TS and pH, forming group with cluster 4. The cluster 4 having two variables namely DS and fluoride and forming group with cluster 5 (DO, SO_4, BOD) and cluster 6 which contains a lone variable, NO_3, which is not similar, although better similar with cluster 5, than with any variables. Cluster 7 with longest branch with similar variables and is entirely different from rest of the clusters.

The Euclidian distance usually gives similarities between two samples, and a 'distance' can be represented by the difference between analytical

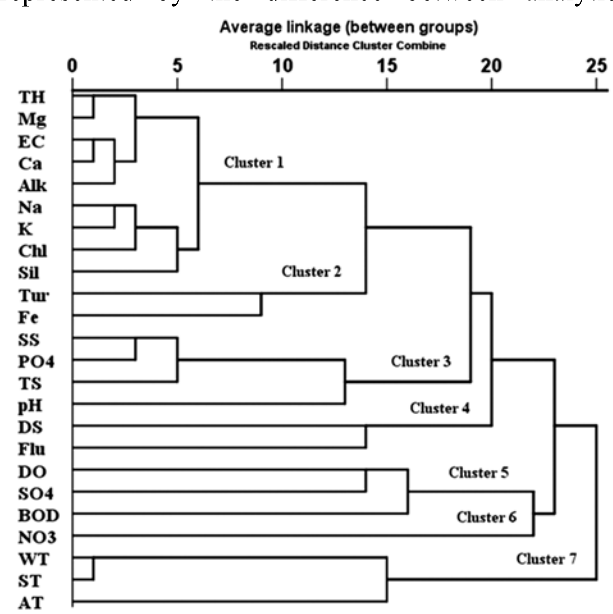

Fig. 2 — Dendrogram showing the clusters of climatic and water quality variables according to water quality characteristics of river water from the Bhadra river basin

values from both the samples[29]. In the present study spatial cluster analysis presented in Figure 3 revealed a dendrogram in which all 23 sampling stations in the river basin were grouped in to three distinct clusters. Cluster 1 consisted of 9 stations with 6 sampling stations on main Bhadra river at Balehole, Magundi downstream, Balehonnur, Khandya, Siregola and Khodi and 3 sampling stations on the tributaries at Balehole on Balehole stream and at Muthodi and Hipla on Sowmyavahini stream. Cluster 2 consisted of 8 stations with 6 sampling stations on main Bhadra River at Bhagavathi, Lakya, Malleshwara, Nellibedu, Kalasa and Magundi upstream and 2 sampling stations on the Somavahini stream at Balagalu and Samse. Cluster 3 consisted of 6 sampling stations at Kundur and Huligere on Huligehalla stream, Arenur and Kadabagere on Anebiddahalla stream, Kolale on Kolele stream and Kallikoppa on Bakri stream.

The stations in the above three clusters had same environmental features and natural backgrounds that were affected by identical origin. Cluster 1 is represented by stations located in the lower reaches from Magundi downstream to Khodi in the Bhadra river basin in the Western Ghats with similar natural backgrounds of agricultural practice such as coffee plantations and tropical dry deciduous forests in the catchment area of Sowmyavahini stream and some pockets of tropical evergreen forests around Siregola in the BWS. Even though sampling stations at Station 8 on Bhadra River and Station 9 on Balehole stream are located in the upper reaches they were constituted in cluster 1 which could be due to local anthropogenic activities at Balehole village and agricultural activities in the upland area of Balehole stream up to Basarikatte village. Cluster 2, represented by stations located in the upper stream reaches, from Ganagamoola to Magundi upstream, of Bhadra river basin in the Western Ghats with similar natural backgrounds of tropical evergreen forests and grassland in and around KNP and on the right bank of Bhadra river from Balehole to Magundi of Hemmakki stream catchment area and coffee and tea plantations from Nellibedu to Magundi. A group of 6 stations (8, 13, 14, 17, 19, 20) and another group with 6 stations (1-4, 7, 10) located on the main Bhadra River are segregated in cluster 1 and cluster 2, respectively. When the river is flowing from the upstream to downstream with riffles, swirling and intermittent pools with inputs from many tributaries, streams, rivulets and small perennial water flow from shoal forests the self-purification occurs in the main stream, as in the present case, thus indicating the operation of the concept of "solution for pollution is dilution" in the river system. In addition to the stations in these clusters, the stations located on streams such as stations 21 and 22 on the Sowmyavahini stream and Balehole stream in cluster 1 and stations 5 and 6 on the Somavahini stream are by and large exposed to similar natural background of tropical forests and anthropogenic activities such as coffee plantations, paddy cultivation and co-cultivation of other commercial plantation crops in the valleys and also on the hilly regions. Thus the clusters 1 and 2 are quite similar to one another on the cluster diagram, but both are very different from cluster 3. Cluster 3 is represented by sampling stations located on the tributaries in the downstream of the Bhadra River. The catchment areas of these streams are subjected to agricultural practices and human settlements with dry forest cover and these streams almost dry up during summer due to natural evaporation and extraction of water for agricultural purposes using motor fitted pumps.

Based on the water quality data and information generated using CA we conclude, with a caution since no data are available on monsoon and post monsoon seasons, that all in cluster 3 such as stations 11 and 12 on Huligehalla, stations 15 and 16 on Anebiddahalla stream, station 18 on Kolele stream and station 23 on Bakri stream correspond to high levels of pollution

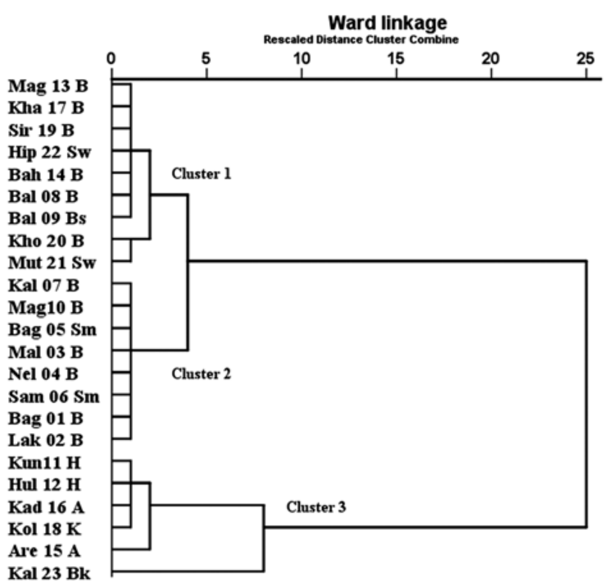

Fig. 3 — Dendrogram showing the clustering of sampling sites according to characteristics of river water in the upstream the Bhadra river basin

and station 21 on Sowmyavahini stream and station 20 on Bhadra river in cluster 1, correspond to low pollution, compared to cluster 3, in the Bhadra river of the Western Ghats. The stations 20 and 21 are segregated slightly from the rest of the stations in cluster 1. Station 20, last station on the main Bhadra River, is located in the tropical wet ever green forest area in the BWS has accumulated the pollution transported from the upstream and showing high pollution and hence segregated along with station 21 from the rest of the stations in cluster 1. Further, station 20 has similar forest background of upper reaches and receives both polluted and non-polluted water from many steams in the upstream of this station resulting dilution of pollution and self-purification along the river course in the upstream. Even with these natural processes of dilution and self-purification the pollution gets accumulated at station 20. Thus, disapproving the earlier apparent concept of "solution for pollution is dilution" and indicating the concept of "solution for pollution is not dilution" in the river system since pollution accumulates in the downstream in any one of the environmental components such as, water, as in the present case, sediment or biota and remain and/or circulate in the environmental components of the river system. Therefore, the stations 20 and 21 are similar to other clean reaches in cluster 1 (8, 13, 14, 17, 19) and cluster 2 (1 - 4, 7, 10) and dramatically different from other polluted reaches in the cluster 3. Thus, spatial CA segregated the river stretches based on the similar background and characteristic features that are influenced by similar origins of water quality variables in the river basin. The results of CA can also be used for quick appraisal of water quality that a few stations in each cluster could serve as a good spatial assessment of water quality of the entire basin[7]. Thus, it is conspicuous that CA is very much useful in assisting a dependable categorization of waters in the entire river basin and possible to design a future sampling programme in an excellent way. Further, the sampling frequency and number of stations in the monitoring area would be added or deleted, thereby reducing the resources without losing significance of the outcome[33]. Thus the pilot survey, as in the present case, CA has guided us in monitoring of water quality in river Bhadra and also in the adjoining river Tunga including the micro structure variations of small streams in these basins in the Western Ghats over the period of time[34]. A good amount of information is available on the application of cluster analysis in assessment of river water quality[7-9,14-16,24, 25,30, 35,36].

Principal component analysis

PCA reveals information on the important variables, which explain the whole data set through data reduction with a minimum loss of original information[7,16,30] and information on correlation between the most important factors contributing to the data structure[37]. Further, it permits to delineate the possible factors that impact the water systems and are accountable for the variations in water quality which thus offers a valuable tool for developing suitable action plan for constructive governance of the water resources[25]. The Scree plot generated in the present study is presented in Supplementary Figure (Fig. S1) and was used to recognise the number of principal components to be retained to understand the hidden data composition[7]. In this investigation the PCA produced a total of seven components that explained about 88.15 % of total variance in the data set of water quality variables. Eigenvalues > 1 was considered to decide the number of components that can adequately explain the observed correlations among the observed variables. The rest of the residual variance (11.85 %) is by unexplained variables. The eigenvalues and their contribution to the total variance produced a small number of components (7) which accounted for variation occurring in a much large number of variables (24). The first component accounted for 37.93 % of the total variance and was correlated (loading > 0.70) with nine eigenvectors such as conductivity, alkalinity, total hardness, Ca, Mg, Na, K, chloride and silicate. The sixth principal component accounted for 5.95 % of the total variance and was correlated with NO_3. Whereas the 2nd 3rd, 4th, 5th, and 7th principal components, although, accounted for 13.47 %, 10.62 %, 8.72 %, 6.97 % and 4.49 %, respectively, correlated (loading > 0.70) with none of the variables and these components are composed of variables with loading of < 0.70.

Factor analysis

The objective of FA refers to the application of a variety of statistical techniques whose common objective is to represent a set of variables in terms of a smaller number of hypothetical variables and to minimize the contribution of less important parameters and even further reduction of data coming from PCA by rotating the axis specified by PCA, based on well acknowledged doctrines, and establishing a fresh set of variables called VF's. In the present study the FA performed on the data obtained from PCA produced a total of seven VFs. The corresponding VFs, loadings and their explained variance are presented in Table 3. The coefficients of variance factor having criteria of loadings > 0.50 are considered for identification of eigenvectors for further exploration. The coefficients of variance factor having loadings > 0.70 as strong and > 0.50 to < 0.70 as less strong are considered as significant. Variance factor 1, which explained 32.833 % of the total variance, constituted by strong positive loadings (> 0.70) on EC (0.966), alkalinity (0.955), total hardness (0.946), Ca (0.932), Mg (0.925), Na (0.863), K (0.835), chloride (0.825) and silicate (0.769) which could be due to mineral composition of the water derived from natural forest sources in the river basin, soil weathering and surface runoff including the KIOCL mining area in the upper reaches of the river basin. The accumulation of these minerals in waters of streams and rivulets could have been contributed by surface runoff from agricultural fields. Variance factor 2, considered for 14.03 % of total variance, with strong positive loadings of TS (0.858), SS (0.945) and PO_4 (0.926) and less strong (> 0.50 to < 0.70) positive loading of pH (0.552). This variance factor represents the contribution of non-point sources of pollution from forest and agricultural lands and soil erosion due to weathering. Application of fertilizers and manure is very common in agricultural practice such as paddy cultivation, coffee and tea plantations, which are practiced in the river basin and due to runoff from these fields and also due to soil erosion in the upper reaches, have contributed more PO_4 in river water and thus the high loadings of PO_4. Variance factor 3 accounted for 10.379 % of total variance with high positive loadings on WT (0.946) and ST (0.898) and moderate loading on AT (0.657). This variance factor represents the effect of climatic conditions in the river basin such as diurnal variations. It is well known that as AT increases the WT, which also increases due to absorption of solar radiation particularly in shallow waters where water flow is less due to stagnation. The substratum under the water also gets heated up due to warm water above, particularly during summer. The sampling was carried out during daytime. The time of sampling has greater influence on AT than the WT and ST.

Table 3 — Loadings of the first seven principal components, with varimax rotation, for data set of climatic and water quality variables in the upstream Bhadra river basin in Karnataka. Description of different codes for environmental variables is given in Table 2. VF stands for variance factor.

Parameter	VF1	VF2	VF3	VF4	VF5	VF6	VF7
AT	.146	.073	.657	-.353	.188	-.135	.317
WT	-.107	-.110	.946	.085	-.095	.072	-.052
ST	-.185	-.186	.898	.164	-.074	.011	-.106
TS	.266	.858	-.184	.060	.244	.132	-.163
SS	.152	.945	-.021	.058	-.169	.118	-.004
DS	.252	.006	-.326	.014	.782	.051	-.314
pH	.015	.552	-.067	-.601	.347	.034	.015
EC	.966	.147	-.057	.119	.121	.052	-.011
Tur	.261	.401	-.115	.540	-.267	-.152	.410
Alk	.955	.120	-.039	.074	.053	-.105	.076
DO	-.319	-.003	.016	-.505	.122	.656	.177
BOD	.270	-.047	.126	.262	.065	.803	.298
TH	.946	-.031	-.140	-.137	.075	.116	.072
Ca	.932	.123	-.209	-.029	.142	.010	.015
Mg	.925	-.073	-.116	-.167	.054	.145	.085
Na	.863	.176	.132	.359	.069	-.012	-.086
K	.853	.181	.170	.406	.019	.052	-.071
Chl	.825	.246	-.060	.394	.134	.056	-.001
Flu	.180	-.069	.127	-.031	.790	-.096	.273
Sil	.769	.342	.012	.230	.026	-.167	.232
Fe	.375	.098	.129	.756	.228	-.107	.232
SO_4	.090	.216	-.124	-.276	-.247	.702	-.219
NO_3	.048	-.022	-.020	.097	.044	.129	.831
PO_4	.136	.926	-.074	.000	-.110	-.092	.102
Eigen value	7.880	3.367	2.491	2.369	1.782	1.777	1.489
% total variance	32.833	14.03	10.379	9.872	7.426	7.404	6.205
Cumulative % variance	32.833	46.86 3	57.242	67.114	74.540	81.944	88.149

Variance factor 4 accounted for 9.872 % of total variance with high positive loading on Fe (0.756) and moderate positive loading on turbidity (0.540) and moderate negative loadings on pH (-0.601) and DO (-0.505). We presumed that this variance factor represents contributions of runoff from Fe rich soil, common in the river basin, and runoff from the open cast surface mining area of KIOCL in the upstream catchment area of river Bhadra. It is well known that turbid water affects the respiration of aquatic organisms and also reduces the DO content in water. As turbidity, with high content of solids and other mineral composition, of water increases the consumption of DO also increases for degradation of organic matter and oxidation of ionic minerals and accumulation of free carbon dioxide in water which ultimately changes the pH value. The positive loadings of Fe and turbidity and negative loadings of pH and DO accounted for allochthonous

(Fe, turbidity) and autochthonous (pH, DO) inputs of this VF. Variance factor 5 accounted for 7.426 % of total variance with high loadings of DS (0.782) and fluoride (0.790) and this represents natural sources due to runoff from forests and agricultural and mining areas. High concentrations of DS were recorded at station 3 near a mining area and also at Khodi (station 20), the last sampling station, on main Bhadra River. High content of fluoride was also recorded at Khodi. It is well acknowledged that particles in water tend to absorb nutrients such as PO_4 and NO_3. The fluoride content also increases due to inflow of fluoride rich water from tributaries such as Huligehalla stream, Anebiddahalla stream and Balehole stream into the Bhadra River. Thus, high values of fluoride at Khodi in the Bhadra River. Variance factor 6 accounted for 7.426 % of total variance with high positive loadings of BOD (0.803) and SO_4 (0.702) and moderate loading of DO (0.656). This variance factor represents the organic matter in water from agricultural runoff and also from human settlements along the river banks including streams and also from a natural source (SO_4). It is well known that the demand for DO will be more in organic matter-rich water for its biodegradation. In the present study this demand is met by a natural mixing process of atmospheric oxygen. Thus, this factor contributed positive loadings of BOD, sulphate and DO. Variance factor 7 accounted for 6.205 % of total variance with high positive loadings on nitrate (0.831). This variance factor points to the sources of nutrients from agricultural runoff and municipal effluents. The river basin has been subjected to agricultural activities including extensive coffee plantations, tea gardens, paddy fields and arecanut and coconut plantations and application of fertilizers and manures to these commercial crops is common in the river basin. Thus the nutrient, PO_4, from agricultural runoff points to this variance factor. Similar studies have been conducted in various parts of the world for evaluation of water quality[9,16,23,25,38].

Total eigenvector - The data on total eigenvectors is presented in Figure 4. The data revealed four major categories of water quality variables in the upstream Bhadra river basin of the Western Ghats of Karnataka (Table 4). The variables having total eigenvector of < 0.50 such as SO_4 (0.14), DO (0.15), pH (0.3) and SS (0.46) are considered as normal variables which contribute no pollution in the river basin hence the water is normal or safe due to these variables in the river basin. The variables, having total eigenvector of > 0.50 - < 1.00, such as ST (0.51), WT (0.74), Mg (0.86), AT (0.90), PO_4 (0.90), total hardness (0.91) and Ca (0.98) are considered as low pollution causing variables in the river basin and hence the river water is slightly polluted due to these variables. The variables, having total eigenvector in the range of > 1.00 - < 1.50, such as turbidity (1.07), DS (1.09), NO_3 (1.11), alkalinity (1.13), fluoride (1.17), TS (1.22), EC (1.34) and silicate (1.44) are considered as medium pollution causing variables in the river basin hence the water indicating medium level of pollution. The variables having total eigenvector in the range of > 1.50 - < 2.00, such as Na (1.50), chloride (1.60), K (1.61), Fe (1.72) and BOD (1.78) are considered as high pollution causing variables and hence the water is highly polluted due to these variables in the river basin.

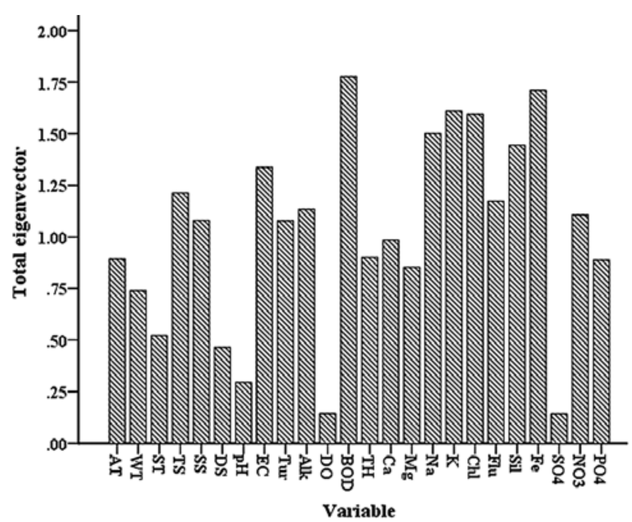

Fig. 4 — Total eigenvectors for environmental variables in the upstream Bhadra river basin

Table 4 — Classification of water pollution based on eigenvector obtained from environmental variables in the upstream Bhadra river basin in Karnataka. Description of codes for environmental variables is given in Table 2

Sl. No.	Classification/Category	Eigenvector	Environmental variables
1	Safe / Normal	< 0.50	SS, pH, DO, SO_4
2	Low pollution	> 0.50 - < 1.00	AT, WT, ST, TH, Ca, Mg, PO_4,
3	Medium pollution	> 1.00 - < 1.50	TS, DS, EC, Tur, Alk, Flu, Sil, NO_3
4	High pollution	> 1.50	BOD, Na, K, Chl, Fe

Factor score – The data on factor scores 1 and 2 for different sampling stations are presented in Supplementary Figure (Fig. S2). The observations on factor scores showed high pollution levels at stations 15, 16 in Anebiddahalla stream and stations 11 and 12 on Huligehalla streams due to factor score 1 (conductivity, alkalinity, total hardness, Ca, Mg, Na, K, chloride and silicate). The data on scores of factor 2 showed slight pollution at stations 14 (Balehonnur) and 20 (Khodi) on the Bhadra river and station 18 (Kolale) on Kolale stream, station 22 (Hipla) on Sowmyavahini stream and 23 (Kallikoppa) on Bakri stream. The data on scores of factor 3 and factor 4 for various sampling stations is presented in Supplementary Figure (Fig. S3). The data on factor score 3 showed the maximum loadings for variables such as WT, ST and AT (factor 3) at station 11 (Kundur) on Huligehalla stream and station 6 (Samse) on Somavahini stream and stations 19 (Siregola) and 20 (Khodi) on the main Bhadra river. The data on scores for factor 4 showed the maximum values at station 16 (Kadabagere) in Anebiddahalla stream, station 18 (Kolale) on Kolale stream and station 1 (Bhagavathi) on the Bhadra river indicating slight pollution due to iron, turbidity, pH and DO. In the rest of the stations the pollution is negligible due to these variables. The data on scores of factor 5 and factor 6 is presented in Supplementary Figure (Fig. S4). The score for factor 5 revealed that station 20 (Khodi) in the Bhadra river, station 21 (Muthodi) on the Sowmyavahini stream, station 8 (Balehole) on the Bhadra river, station 15 (Arenur) on the Anebiddahalla stream caused pollution due to DS and fluoride. The data on scores for factor 6 showed pollution levels at stations 3 (Lakya) and 4 (Nellibedu) on the main Bhadra river and station 5 (Balagalu) on Somavahini stream showed pollution by BOD and SO_4 which could be due to organic matter from agricultural and forest runoff and natural (sulphate) forest areas. The data on scores for factor 7 for different stations in Supplementary Figure (Fig. S5) revealed that the pollution at stations 8 (Balehole) and 19 (Siregola) on the main Bhadra river and station 16 (Kadabagere) on Anebiddahalla stream was due to NO_3. The sources of nitrogen could be non-point sources due to agricultural runoff and effluents from human settlements in the upstream of Kalasa, Semse, Balehole, Magundi, Khandya and other adjoining areas.

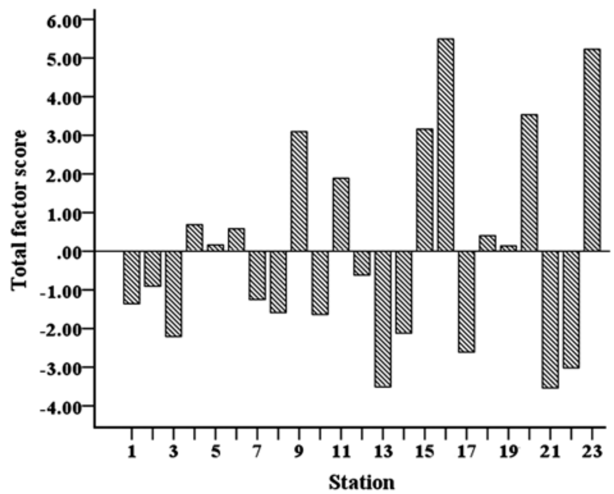

Fig. 5 — Total factor scores for sampling stations located in the upstream Bhadra river basin

Total factor score - The data on total factor score for 23 water sampling stations in the present study is presented in Figure 5 and the data revealed the negative total factor scores (less than zero) which indicated that river water is not polluted for sampling stations located in the main Bhadra river at Bhagavathi, Lakya, Malleshwara, Kalasa, Balehole, Magundi upstream, Magundi downstream, Balehonnur and Khandya and also in tributaries at Huligehalla downstream and Muthodi and Hipla on Sowmyavahini stream. The positive loadings of total factor score (> 0.0 - < 1.50) for sampling sites located in the main Bhadra river at station 4 (Nellibedu) and station 19 (Siregola) and also in tributaries at stations 5 (Balagalu) and 6 (Samse) in Somavahini stream and station 18 (Kolele) on Kolele stream indicating low pollution of water. The positive loadings of total factor score (> 1.50 - < 3.00) for sampling site at station 11 (Kundur) on Huligehalla stream indicating medium pollution of water. The positive loadings of total factor score (> 3.00 - < 4.50) for sampling station 9 (Balehole) on Balahole stream, station 15 (Arenur) on Anebiddahalla stream and station 20 (Khodi) on the main Bhadra river indicating high pollution of water. The positive loadings of total factor score (> 4.50) for sampling stations 16 (Kadabagere) on Anebiddahalla stream and station 23 (Kallikoppa) on Bakri stream indicating very high pollution of water. Higher side of factor score correspond to high influence[39] of the factor on the sample collection site. The water sampling station 1 (Bhagavathi) situated in the upstream of Bhadra River in the KNP and stations 21 (Muthodi) and 22 (Hipla) located in Sowmyavahini stream of the BWS exhibited normal water, even though some of the variables showed higher values in the data set. However, the sampling site located immediately after the area of mining and allied activities in the main Bhadra river at station 4 (Nellibedu) and sampling sites in Somavahini stream, adjacent drainage area of the mining area of KIOCL, at station 5 (Balagalu) and station 6 (Samse) showed low levels of pollution in the upstream of Bhadra river due to coffee plantations and other human activities. Further down in the main Bhadra river at stations 7 (Kalasa), 9 (Balehole), 10 (Magundi upstream) and 13 (Magundi downstream), 14 (Balehonnur) and 17 (Khandya) showed normal water, which could be due to self-purification of river due to mixing and settling processes. Further downstream, before the Bhadra reservoir, the sampling sites at stations 19 (Siregola) and 20 (Khodi) showed low and high, respectively, levels of pollution. In general the findings in the present study produced a total of five categories of sampling stations situated in the upstream Bhadra river basin which indicated that the value of total eigen score of less than zero (< 0.0) is safe (no pollution), > 0.0 - < 1.50 is low pollution, > 1.50 - < 3.00 is medium pollution, > 3.00 - < 4.50 is high pollution and > 4.50 is very high pollution. Accordingly the sampling stations on different stretches of the river basin is classified and presented in Table 5. The stations (1 - 3, 7 - 8, 10, 13 - 14, 17) located on the main Bhadra River stretch except stations 4 (Nellibedu), 19 (Siregola) and 20 (Khodi) are grouped under safe water category based on factor score of less than zero. Stations located on streams such as station 12 (Huligere) on Huligehalla stream and stations 21 (Muthodi) and 22 (Hipla) on Sowmyavahini stream are also grouped under safe water category. The stations 4 (Nellibedu) and 19 (Siregola) on the main Bhadra river and stations 5 and 6 on Somavahini stream and station 18 on Kolele stream are grouped together under low pollution category based on eigen scores of > 0.0 - < 1.50. Stations 4, 5 and 6 are located in the upper reaches of the Bhadra river basin and are situated in the adjacent (station 4) and nearby adjoining stations (5 and 6) of KIOCL mining area. Station 11 at Kundur on Huligehalla stream is grouped under medium pollution category based on eigen scores of > 1.50 - < 3.00. Stations 9 (Balehole) on Balehole stream and 15 (Arenur) in Anebiddahalla stream and station 20 (Khodi) on the Bhadra river are grouped under high pollution category based on eigen scores of > 3.00 - < 4.50. Station 16 (Kadabagere) on Anebiddahalla stream and station 23 (Kallikoppa) on Bakri stream are grouped under very high pollution category based on eigen scores of > 4.50.

Environmental variables and health of river at different stretches - The individual and/or group of water quality variables affecting the health of river at different stretches of river is depicted in Table 6. The variables such as conductivity, alkalinity, total hardness, Ca, Mg, Na, K, chloride and silicate of VF 1, accounted for 32.833 % of total variance, caused the maximum pollution either individually and/or as a group at station 15 in Anebiddahalla stream in the

Table 5 — Classification of water pollution at different sampling stations based on the factor score obtained from sampling stations in the upstream Bhadra river basin in Karnataka. Names and other details of different sampling stations are given in Table 1

Sl. No.	Classification/ Category	Factor score	Stations
1	Safe / Normal	< 0.00	1, 2, 3, 7, 8, 10, 12, 13, 14, 17, 21, 22
2	Low pollution	> 0.00 - < 1.50	4, 5, 6, 18, 19
3	Medium pollution	> 1.50 - < 3.00	11
4	High pollution	> 3.00 - < 4.50	9, 15, 20
5	Very high pollution	> 4.50	16, 23

Table 6 — Environmental variables causing water pollution, either individually and/or as a group, at different stretches (stations) in ascending order based on factor scores in the upstream Bhadra river basin in the Western Ghats during the study period. Names and other details of sampling stations are given in Table 1 and codes for environmental variables in Table 2

Sl. No.	Variance factors (VF's)	Environmental variables	Stations (pollution in ascending order based on factor scores)
1	VF1	EC, Alk, TH, Ca, Mg, Na, K, Chl, Sil	8, 9, 19, 23, 21, 16, 12, 11, 15
2	VF2	TS, SS, PO_4	14, 18, 20, 22, 23
3	VF3	AT, WT, ST	7, 18, 14, 16, 4, 15, 17, 5, 20, 6, 19, 11
4	VF4	pH, Tur, Fe	5, 13, 23, 14, 3, 1, 15, 18, 16
5	VF5	DS, Flu	6, 11, 1, 15, 9, 21, 20
6	VF6	DO, BOD, SO_4	10, 15, 16, 23, 1, 8, 6, 5, 9, 2, 4
7	VF7	NO_3	12, 11, 22, 3, 18, 7, 16, 19, 9

entire river basin during the study period. The health of the river was also affected in some of the streams such as Samse, Balaehole, Huligehalla, Anebiddahalla, Sowmyavahiniand Bakri streams by these variables. However, in the case of main Bhadra River these variables caused low level of pollution at stations Siregola and Balehole. Sampling stations (11, 12, 15) located on the streams indicated the non-point and physical sources of pollution at these sampling sites. Station 16 located in Anebiddahalla at Kadabagere and station 21 located in Sowmyavahini stream in BWS showed the maximum concentrations of Fe (3.71 mg/l) at station 16 and Ca (11.62 mg/l) at station 21. Such a high concentrations for example iron at station 16 could be due to runoff from Fe rich soils in the stream catchment area. The contribution of Ca is considered as a result of cat ion–exchange processes at soil-water interface[40] and dissolution of Ca bearing minerals[13,25]. The loading of total eigenvector (0.98) in the river basin for Ca in Figure 3 indicating low pollution levels which, perhaps could be due to the extraction of Ca from water for the growth[41] of external calcareous shell by filter feeding freshwater oysters and mussels inhabiting[42] the Bhadra river and thus, reducing the Ca content in water to some extent. The pollution level was medium (> 1.0 - < 1.5) due to alkalinity, EC and Na and high level of pollution (> 1.5) due to K and chloride in the river basin (Table 4) suggesting accumulation of pollution in Bhadra river water as the river moves downstream and such high pollution load in the downstream has been reported[43] in the urban river system. The contribution of silicate was attributed to soil erosion from natural background, agricultural runoff and anthropogenic activities, particularly mining, in the river basin.

The variables of TS, SS and PO_4 of VF 2, accounted for 14.03 % of total variance, were responsible for high pollution either individually and/or as a group at station 23 on Bakri stream in the entire river basin followed by station 22 on Sowmyavahini stream at Hipla and station 20 at Kolale on Kolele steam. The high concentration of PO_4 in this stream could be due to surface runoff from coffee plantations, soil erosion and other agricultural practices in upland areas. The suspended particles in the agricultural runoff with high concentration of PO_4 could contribute in increased river pollution. Occasionally high concentration of PO_4 in shallow or stagnant waters, as in Bakri stream, enhances the prolific growth of algae and subsequently decomposition of algae and also organic matter enhances the PO_4 content in water. Washing of cloths and bathing (detergents) also contribute to the concentration of PO_4 in water. The quantity of SS in a stream generally show upward trend in water where the pH is low, as in the present study at station 16, the autochthonous suspended particles will not undergo aggregation due to chemical reaction easily and resulting in precipitation as evidenced by high loading of SS in VF 2.

The eigenvectors such as AT, WT and ST of VF 3, accounted for 10.379 % of total variance, were responsible for high pollution either individually and/or as a group at station 11 (Kundur) on Huligehalla stream. The health's of other tributaries affected by these variables is Somavahini, Anebiddahalla and Kolale streams. The health of the river stretch of Siregola and adjoining stretch of Khodi-Koosagal, Khandya and Balehonnur in the downstream of Bhadra River and also Kalasa and Nellibedu in the upper reaches of main Bhadra River is also influenced by these variables due to warm water inflow from streams. The streams monitored (Somavahini, Huligehalla, Anebiddahalla, Kolale) and other streams/rivulets which are not monitored (Bilegal, Kachgi, Hemmaki and others) in the present study enhance the water temperature of the main Bhadra River to some extent and thereby effecting the health of the main Bhadra River during summer. The observations at stations 11 and 12 located on Huligehalla stream and stations 15 and 16 located on Anebiddhalla stream revealed low thermal pollution at stations located in the tributaries which are exposed to similar type of geographic and agro-climatic conditions, anthropogenic activities and low water flow in the middle stretch of river Bhadra.

The variables such as pH, turbidity and Fe of VF 4, accounted for 9.872 % of total variance, caused the maximum pollution, either individually and/or as a group, at station 16 in Anebiddahalla stream at Kadabagere during the study period. The streams of other stretches of the Bhadra River including Anebiddahalla (station 15), Somavahini, Kolele and Bakri streams also showed pollution due to these variables. The suspended particles with fine to coarse particles are susceptible for chemical reaction thereby precipitate and resulting in low SS in river water where pH of water is high[24]. The pH of stream water affects the coagulation reaction and diffuse reactions of suspended particles and also the vegetative growth. High growth of algae has been noticed in Bakri stream[44] and also in the Sita River[45], adjoining river basin, during summer months. High iron concentration has also been attributed to the water bodies with reducing conditions and low pH values[26]. The KIOCL has been exploring the iron ore on the right bank of river Bhadra in the upper stretch in the KNP. Perhaps, surface runoff from this surface open cast mining area might have contributed to the increased iron content in the lower stretch of main Bhadra River. High content of Fe in the downstream of main Bhadra River might have further enhanced by inflow of water with high content of iron from tributaries such as Huligehalla, Anebiddahall and Kolele streams.

The variables such as DS and fluoride of VF 5, accounted for 7.426 % of total variance, were responsible for the maximum pollution either individually and/or as a group at station 20, the last station, on main Bhadra River. This, perhaps, could be due to transfer of these variables along the river course and also inputs from tributaries in the upstream of this station. These variables also showed high concentration at station 1, the first station, due to the natural sources from the tropical evergreen forest area. Among the streams, the Sowmyavahini stream at Muthodi (station 21) showed maximum pollution due to DS and fluorides due to coffee curing units and agricultural activities in the upper reaches of the stream. These variables also caused pollution in the streams such as Somavahini, Balehole, Huligehalla and Anebiddahalla streams.

The eigenvectors such as DO, BOD and SO_4 of VF 6, accounted for 7.404 % of total variance, were responsible for high pollution, either individually and/or as a group, in the Bhadra river basin at station 4 located immediately after a mining area followed by stations 2 (Lakya), 8 (Balahole), 1 (Bhagavathi) and 10 (Magundi). Among the streams, Balehole followed by Somavahini, Bakri and Anebiddahalla streams showed high pollution due to these variables. The low water flow in the Huligehalla stream at Kundur coupled with high rates of evaporation of water due to high summer atmospheric temperature reduces the DO level in water. The bottom of Bhadra River at Nellibedu (4) is composed of small rocks, cobbles and pebble stones with swirling of water flow, enhancing the DO level in water due to mixing of atmospheric oxygen. The DO concentration in water is very important for aerobic biota since DO is used to metabolize food for sustaining life. Any changes caused in DO levels due to anthropogenic activities and also natural activities in the natural background sources will be echoed in DO content in river water. The DO levels in the downstream of has more fluctuations than in the upstream and is not as conspicuous for upstream as for downstream[24]. Sulphate is also used as fertilizer in agricultural activities but its pollution level in the present river basin is negligible as a non-point source of pollution. BOD is an important variable to highlight the aquatic pollution caused by organic matter and is an important variable to be used on and specified in evaluating pollution degree of stream[24,25]. The present river basin is located in the Western Ghats, one of the world's biodiversity hotspots, of India and is located in the remote forest and hilly region of Karnataka where the extent of municipal effluent pollution due to BOD is not high except at Balahonnur town. However nonpoint sources due to application of fertilizers and manure discharged from coffee plantations and tea gardens and also from natural forest areas and mining runoff might have caused high BOD levels in the river basin.

The variable, NO_3, of variance factor 7, accounted for 6.205 % of total variance, was responsible for pollution at various stations/stretches of the Bhadra river basin. Nitrate caused highest pollution at station 9 in Balahole stream followed by other streams such as such as Anebiddahall, Kolale and Huligehalla and Sowmyavahini streams. However, in the main Bhadra river high pollution at Siregola stretch (19) followed by Kalasa stretch (7) and KIOCL township (Malleswara village) stretch of main Bhadra River was also due to NO_3. The concentration of nitrate could be due to the application of organic manures, inorganic fertilizers, surface runoff in the upland forest and coffee plantation areas. Amongst the various sources of nitrogen found in the water body, the nitrogen released from the organic and inorganic fertilizers used in agricultural applications are the major contributors[24,25]. Application of fertilizers, manures and pesticides in commercial plantation crops such as tea, coffee, arecanut and coconut, which are abundant in the present river basin, is a common practice to enhance the growth of commercial crops and to control crop diseases in the present study area. The commercial plantations such as tea and coffee in the hilly regions of catchment of a river basin, as in the present case, contribute high levels of ammonia than in pesticides, which also applied in large quantities to control pests of these commercial plantation crops, and the oxidized products such as nitrates and nitrites coming from organic nitrogen have adverse effects on aquatic biota and even on human health[24].

In general, the variables, responsible for water pollution in the river system, showed increased concentrations along the river course from upstream to downstream stretches in the Bhadra river basin in the Western Ghats even though the dilution of river water and self-purification process are active with in the river system.

Conclusions

The data on water quality generated in the present study forms the baseline data during the mining activities of KIOCL in the KNP area and the data may help in eco-restoration activities in the Bhadra river basin. The CA was very much useful in assisting in categorization of sources, natural and anthropogenic, of water pollution types/areas in the entire river basin. Application of PCA and FA in water quality analysis revealed that the water pollution gets accumulated in the downstream stretches even though the natural processes of dilution and self-purification are operating the in the river basin. Further, it disapproved the earlier apparent concept of "solution for pollution is dilution" and indicated the concept of "solution for pollution is not dilution" in the river system. Furthermore, the application of FA has revealed the types and sources of contamination at different stretches/stations in the Bhadra river water. However, the water quality data set on spatial and temporal scales over a period of time frame is warranted to elucidate a clear cut outcome on water quality of this river basin.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscair.res.in/jinfo/ijms/IJMS_49(04)649-664_SupplData.pdf

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Conflict of Interest

The authors declare that they do not have any sort of known competing financial or personal interests that could have come to light to impact the work reported in this paper.

Author Contributions

ST conceptualized the idea of the project, funding acquisition, field work, supervision of laboratory work, interpretation of field and laboratory data, drafting, review and editing. GKS has done field work, discussion and interpretation of field survey and data. MVR has done field work and laboratory analysis. BS has assisted in data analysis.

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