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Assessment of water quality of the tropical stream Somavahini in the Bhadra Wildlife Sanctuary, Western Ghats, India

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Abstract

A total of 21 water quality variables of the stream Somavahini, a tributary of river Bhadra, in the Jagara Valley of Bhadra Wildlife Sanctuary in the Western Ghats region of Karnataka, India were monitored and assessed for a period of one year. Cluster analysis (CA) for variables and stations produced dendrograms revealing similar natural background, sources and pollution areas in the main stream and also in tributaries (Tadve, Hipla). Cluster analysis revealed that the number of sampling months could be reduced. Temporal CA produced four distinct seasons. Principal component analysis (PCA) revealed six components that explained 75.03% of total variance, and reduced the dimensionality of data from 21 to 6 components, and produced 71.43% of data reduction with only 15.76% of loss of information. Factor analysis (FA) further reduced the contribution of less significant variables obtained from PCA and Variance Factor 1 (VF 1) accounted for 14.38% of total variance. Application of PCA and FA in water quality analysis revealed that station 1 at Muthodi contributed the highest pollution followed by station 4 at Hebbe in the downstream of the main stream Somavahini. Further, it was revealed that the water from Hipla tributary was safe/normal whereas Tadve tributary water was slightly polluted. The variables such as turbidity, nitrate and iron have caused no pollution at upstream station near Muthodi and subsequently caused slight pollution in Tadve tributary and also at downstream station near Hebbe in the main stream Somavahini due to further accumulation. The water quality variables comprising water temperature, dissolved oxygen and biological oxygen demand have indicated high level of pollution in the upstream station due to anthropogenic activities and subsequently these variables indicated no pollution in tributaries and also at downstream station at Hebbe due to dilution and self-purification processes operating in the stream basin.

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Introduction

The stream Somavahini, tributary of the river Bhadra, is located on the right bank of river Bhadra in the Bababudan schist belt and directly drains into the Bhadra Dam, a multipurpose dam built across the Bhadra River at Lakkavalli Village in the state of Karnataka, south India. The Somavahini Stream basin has many small perennial tributaries such as Tadve, Wate and Hipla in the Jagara Valley of Bhadra Wildlife Sanctuary (BWS) and receives water from these tributaries and also from many rivulets and small perennial water flow from shoal forests of Bababudan schist belt. The BWS covers most of the basin of the stream Somavahini and is located within the boundaries of Mullayanagiri, Dattapeeta and Kemmanugundi to the east. The forests of shola-grassland complex, Bhadra Reservoir and Lakkavalli Forest range to the north, coffee plantations and teak plantations to the south and Bhadra River to the west. The BWS encompasses the Lakkavalli forest area and Jagara Valley which are ecologically slightly different and covers 492.46 sq. km located in the districts of Chikkamagaluru and Shimoga (Kumar, 2000) and harbours a wide variety of terrestrial wildlife (Karanth, 1982; ZSI, 2013), besides a variety of fishes (Thippeswamy, 2007; Gopi, 2013), plankton (Thippeswamy, 2024) and benthos (Thippeswamy *et al*., 2008).

The stream basin has also been subjected to coffee plantations and other agricultural activities at Madla and Hipla villages including human settlements within the BWS and also outside the BWS of the stream basin. Coffee pulping industries surrounding the sanctuary discharge coffee effluents from pulping units into the Somavahini Stream during summer season and hence the stream water in the Sanctuary has a high organic load which makes the water non-potable (Kumar, 2000). Therefore, the wildlife within the Sanctuary, particularly aquatic organisms, which depend on the river, streams and rivulets for their water needs, is being affected (Sugunan, 1995). Further, water from Somavahini Stream is directly discharged into the Bhadra Reservoir which harbours a variety of commercial fishes such as major carps, minor carps, cat fishes, feather backs, other freshwater fishes as well as weed fishes (Ramakrishnaiah *et al*., 2000; Sukumaran and Das, 2005). The environmental inputs of physical and chemical variables (Thippeswamy *et al*., 2020) and biological (plankton, nekton) variables (Thippeswamy, 2008; Thippeswamy and Malathi, 2008; Thippeswamy *et al*., 2008) from upstream influences the structure and composition of biological communities of a reservoir (Sugunan, 1995; Kumar *et al*., 2011). Spatial and temporal variation in river water quality is directly related to various environmental conditions prevailing in the catchment area of rivers and streams. Meagre information on water quality parameters of stream Somavahini is available (Shubharekha *et al*., 2018; Thippeswamy *et al*., 2020). However, there is a dearth of information on spatial and temporal variability of water quality of stream Somavahini and its tributaries even to date. The data on monitoring of river water quality have been assessed using multivariate statistical techniques (Vega *et al*., 1998; Singh *et al*., 2004; Shrestha and Kazama, 2007; Yerel and Ankara, 2012; Malathi and Thippeswamy, 2013; Chounlamany *et al*., 2017; Thippeswamy *et al*., 2020). 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 (Lambrakis *et al*., 2004; Wu and Kuo, 2012). Therefore, the information generated using multivariate techniques in ecological assessments will be useful to undertake the restoration strategies at appropriate places in the river basin by the concerned managers and conservationists. The data generated in this study will be useful in the management of water and fishery resources of Bhadra Reservoir and Somavahini Stream, which directly drains into the reservoir.

Materials and methods

Study area

The combined flow of river Bhadra and its tributary Somavahini Stream after passing through the Bhadra Dam merges with river Tunga at Kudli, north of Shimoga town in the state of Karnataka and thereafter the combined flow known as river Tungabhadra which joins the river Krishna and ultimately drains in to the Bay of Bengal in the state of Andhra Pradesh. The Somavahini Stream basin in the Bababudan schist belt of the Western Ghats has extensive coffee plantations, paddy fields and arecanut and coconut plantations and has been subjected to anthropogenic activities including human settlements within and also outside of the BWS. A total of 4 stations were fixed in the Somavahini Stream basin for monitoring the stream water quality, all of which are exposed to the natural tropical moist deciduous forest environment. A total of 2 stations were established on the main Somavahini Stream; one each in the upstream, station 1 (Mut 1) (13º25'08"N; 75º38'34"E) at Honnala cross near Muthodi and downstream, station 4 (Heb 4) (13º30'41"N; 75º36'26"E) near Hebbe, stretches and 2 stations with one each on the Tadve tributary, station 2 (Jag 2) (13º27'10"N; 75º38'55"E), near Jagara and Hipla, station 3 (Hip 3) (13º30'42"N; 75º36'58"E), tributary near Hipla Village, were fixed to include heterogeneous agro-climatic conditions within the BWS. The water sampling stations and their locations are presented in Fig. 1. The sampling station Mut 1 was exposed to extensive coffee plantations, paddy fields, arecanut and coconut plantations as well as natural moist deciduous forest background whereas the sampling station Heb 4 is exposed to dry deciduous forest cover, agricultural activities and human settlements in the midstream area on left bank around Madla Village, and now the entire village is relocated outside the BWS (Karanth, 2007). The sampling station Jag 2 is located on the Tadve tributary which drains water from Jagara and also from the western part of the Bababudangiri hill range and joins the main Somavahini Stream on the right bank. It has natural dry deciduous forest background. The sampling station Hip 3 was situated on the Hipla tributary which drains water from western area of Kemmanugundi and northern part Bababudan hill range area of Hebbe Falls and joins Somavahini Stream south of Hipla

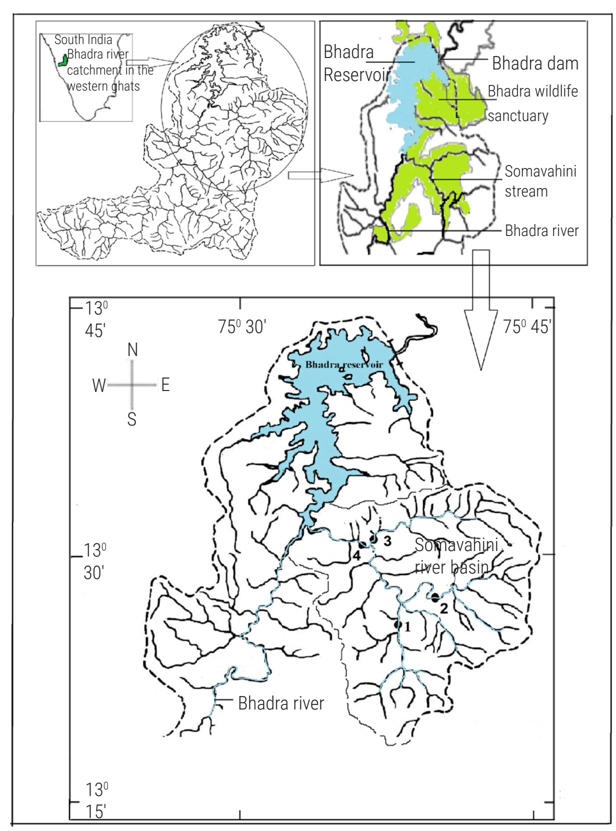

Fig. 1. Location of sampling stations for collection of water samples from the Somavahini Stream in the Bhadra Wildlife Sanctuary

Village, now the entire village is relocated outside the BWS (Karanth, 2007). The catchment area of Hipla Stream was exposed to coffee plantations in the hill range outside the BWS and also natural dry deciduous forest and tropical evergreen forest with shola forest background in the upper reaches (Karanth, 1982).

Sample collection

Water samples were collected for a period of one year from May 2001 to April 2002 at all 4 stations from the upstream to downstream stretch of the stream basin in the BWS. Water samples were collected in polyethylene bottles from just under the water surface and brought to the laboratory under refrigerated condition for analyses of water quality parameters. For estimation of dissolved oxygen (DO), the water samples were, fixed with Winkler's reagents in the field and analysed within 5 h. For the estimation of biological oxygen demand (BOD,) separate water samples were collected in BOD bottles, kept in refrigerated conditions and transported to the laboratory for incubation and analysis.

Analytical methods

Water temperature (WT) was recorded in the field using a glass laboratory Mercury thermometer having 0.2°C precision. Dissolved oxygen was analysed following Iodometric procedure (APHA, 1995). The hydrogen ion concentration (pH) and turbidity (Tur) were determined by pH meter and Nephelometer, respectively. Following standard procedures, total solids (TS), dissolved solids (DS), suspended solids (SS) and BOD were determined (APHA, 1995). Using water analysis kit (SYSTRONICS 371; ISO 9001: 2008 Co. Ahmedabad) the electrical conductivity (EC) of water was estimated. Total hardness (TH) was estimated using EDTA titrimetric method. Alkalinity (Al), chloride (Cl), calcium (Ca) and magnesium (Mg) were determined as per APHA (1995). Sodium (Na) and potassium (K) contents were determined by flame photometry employing a photometer (SYSTRONICS 127, ISO 9001: 2008 Co., Ahmedabad). The concentration of sulphate (SO_4) was determined by turbidometric method, inorganic phosphate (PO_4) by stannous chloride method, nitrate (NO_3) by brucine method, silicate (Si) by molybdosilicate method and iron (Fe) by Phenanthroline method (APHA, 1995). Water temperature was expressed in degree centigrade. The values of EC were expressed in ųScm^{-1} whereas turbidity was expressed in NTU. The results of analysis of TS, DS, SS, DO, BOD, TH, alkalinity, chloride, Ca, Mg, Na, K, NO_3, PO_4, SO_4, silicate and Fe were expressed in mg l^{-1}.

Statistical techniques

The standardised data of water quality was subjected to correlation analysis using Karl Pearson's coefficient of correlation to understand the relationship among the observed variables. Hierarchical agglomerative cluster analysis using Ward's method with Euclidean distance as a measure of similarity for variables (sample), spatial and temporal cluster analysis was carried out on standardised data set to generate variable (sample), spatial (station) and temporal dendrograms (Vega *et al*., 1998; Helena *et al*., 2000). Cluster analysis, PCA and FA were carried out after standardising through z-scale transformation to avoid error due to large variations in data dimensionality and to render the data dimensionless. The Kolmogorov-Smirnov (K-S) test was used to test the goodness-of-fit of the data to the normal distribution. According to the K-S test, water quality variables showed non-normal distribution. After identifying and giving treatment for outliers, the data were transformed through the logarithmic transformation technique. Subsequently, the data were subjected to Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests to examine the suitability of data for PCA and FA (Helena *et al*., 2000). Required statistical and mathematical computations were done using IBM SPSS software version 23. The variables were subjected to PCA to find the number of components that could 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 smaller set of independent (uncorrelated) variables (principal components), which include a linear combination of observable variables (Vega *et al*., 1998; Helena *et al*., 2000; Alberto *et al*., 2001). The data on variables were further subjected to factor analysis which extracts the new group of variables, known as variance factors (VF's) or factors by rotating the axis defined by PCA. The data was subjected to varimax rotation to generate variance factors (VF's) and factor scores (FS) for stations, months/seasons and variables (Vega *et al*., 1998; Singh *et al*., 2004).

Results and discussion

Univariate and bivariate analysis

The descriptive data on 21 water quality variables of stream Somavahini examined for a period of one year covering the four stations is presented in Table 1. The maximum values of NO_3 and Fe were noticed at station 1, whereas station 2 recorded the maximum values of TH and Mg. Station 3 showed the maximum values for WT, DS, BOD, pH, TH and Mg. The river water at station 4 registered the maximum values for a large number of variables (WT, TS, SS, DS, DO, Turbidity, alkalinity, chloride, EC, Ca, Na, K, silicate, PO_4 and SO_4) and such high values in the downstream could be due to accumulation of pollutants in stream water.

The turbidity value showed the minimum value at station 1 whereas WT, chloride, Ca and NO_3 registered the minimum values at station 4. A good number of variables showed the minimum values at station 2 (SS, BOD, pH, alkalinity, TH, Mg, Na, silicate, NO_3, PO_4, SO_4) and station 3 (WT, TS, DS, DO, EC, K, NO_3, Fe) indicating water coming from tributaries was not polluted. In the present study, the data set on water quality of all four stations were combined to calculate the correlation matrix since they are affected simultaneously by spatial and temporal variations (Verol *et al*., 2012) and the bivariate data on correlation matrix is presented in Table 2. The samples retrieved from the study area revealed 2-tailed correlation matrix, several correlations among the variables having significant relationships, with 33 variables being highly significant ($p<0.01$). High correlation (0.7-0.9) was noticed for TS with SS and DS as well as between TH and Mg, moderate correlation (0.5-0.7) for EC with Al, Cl, Na and Si and Al with pH, Cl and EC and TH with Ca and Mg and between pH and Al and between K and Si and low correlation (0.3-0.5) with 22 water quality variables. Further, several correlations among the variables (33 variables) are significant ($p<0.05$). Furthermore, many variables showed a negligible amount of correlation (0.0-0.3).

Table 1. Details of descriptive data of water quality variables from the Somavahini Stream in the Jagara Valley

Variable	Minimum			Maximum			Mean	Standard deviation
	Minimum value	Sampling month	Sampling station	Maximum value	Sampling month	Sampling station		
WT	18.00	Dec	3, 4	28.00	May	3, 4	22.16	2.60
TS	40.00	May	3	960.00	Oct	4	357.83	219.49
SS	20.00	May	2	760.00	Oct	4	177.00	132.57
DS	20.00	Aug	3	520.00	Jul, Nov	3, 4	182.08	144.18
DO	6.25	Sep	3	11.78	Mar	4	9.57	1.37
BOD	0.05	Jan	2	9.53	Dec	3	3.66	2.70
Tur	1.20	May	1	170.09	Jan	4	18.35	27.42
pH	6.09	Jun	2	8.41	Oct	3	7.49	.448
Al	25.00	Jul	2	148.00	Jan	4	67.74	26.16
Cl	2.30	May	4	319.86	Jan	4	24.14	44.31
EC	37.60	Apr	3	984.00	Jan	4	101.17	136.05
TH	2.00	Nov	2	55.00	Aug	2, 3	17.08	13.67
Ca	0.80	Nov	4	17.64	Jan	4	5.36	3.82
Mg	0.19	Apr	2	12.44	Aug	2, 3	3.29	3.29
Na	2.76	Nov, Jan '02	2	45.98	Jan	4	14.25	8.54
K	0.12	Aug	3	6.18	Jan	4	.74	.94
Si	53.55	Jul	2	242.66	Jan	4	120.15	39.28
NO3	0.05	Jun, Jul	2, 3, 4	3.40	Oct	1	1.07	.83
PO4	0.96	Jan	2	19.60	Feb	4	4.05	3.04
SO4	0.24	May	2	16.66	Jan	4	2.47	2.78
Fe	0.30	May	3	164.69	Jan	1	28.84	32.54

Table 2. Values of Pearson correlation coefficient of water quality variables of the Somavahini Stream in the Jagara Valley of the Bhadra Wildlife Sanctuary

	WT	TS	SS	DS	DO	BOD	Tur	pH	Al	Cl	EC	TH	Ca	Mg	Na	K	Si	NO_3	PO_4	SO_4
TS	-.406																			
SS	-.285	.804																		
DS	-.312	.810	.392																	
DO	-.410	.350	.200	.310																
BOD	-.445	.432	.293	.408	.481															
Tur	.258	.060	.051	.057	.086	-.136														
pH	-.180	.279	.386	.153	-.082	.286	.005													
Al	-.249	.040	.172	-.049	.044	.408	.028	.658												
Cl	-.398	.211	.234	.072	.122	.340	.012	.373	.621											
EC	-.236	.160	.143	.132	.034	.184	-.134	.284	.566	.519										
TH	.248	-.265	-.220	-.285	.155	.030	.045	-.287	.112	.200	.356									
Ca	.160	-.365	-.359	-.267	.131	.157	.097	-.238	.186	.207	.292	.686								
Mg	.316	-.111	-.072	-.149	.255	.013	.009	-.170	.060	.104	.260	.757	.219							
Na	.310	.023	-.060	.094	-.080	.144	-.032	.090	.231	.343	.530	.474	.377	.479						
K	-.132	.054	-.088	.191	-.014	-.089	-.095	.015	.247	.336	.474	.006	.099	.026	.390					
Si	.063	-.226	-.199	-.113	-.218	-.126	-.147	.082	.324	.307	.574	.191	.120	.158	.269	.559				
NO_3	-.326	.132	.307	-.004	-.294	-.032	-.274	.426	.338	.187	.237	-.278	-.349	-.176	-.229	.253	.319			
PO_4	-.181	.192	.116	.159	.105	.385	.114	.104	.212	.401	.095	.045	-.045	.135	.191	-.022	.013	-.053		
SO_4	.085	.478	.346	.397	.114	.008	.222	.068	.046	.337	.186	-.017	-.105	.133	.368	.311	.082	-.204	.113	
Fe	.048	.017	-.139	.203	.066	.045	.324	-.003	.075	.085	.069	-.114	.316	-.314	.206	.409	.144	-.153	-.142	.346

Thus, univariate analysis does not adequately depict simultaneous differences and similarities between parameters or samples (Dixon and Chiswell, 1996), as well as bivariate analysis. Therefore, the application of robust multivariate methods is warranted to elucidate the clear-cut simultaneous differences and similarities between parameters or samples. The problem of data reduction and interpretation of multi-constituent measurements can be more easily handled through the application of robust multivariate statistical methods (Wenning and Erickson, 1994).

Multivariate statistical methods

Kaiser-Meyer-Olkin (KMO), a measure of sampling adequacy, of greater than 0.5 and Baetlett's test of sphericity showing <0.05 generally indicate that the data are suitable for FA. In the present study, the KMO value was 0.526. The value of Bartlett's test of Sphericity of Chi-Square statistic (χ^2 = 735.895, d. f. 210) also reached the significant level (p<0.01) which indicated the occurrence of common factors between the data sets of the parent population. Thus, both these tests indicated that the data set was suitable for FA.

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 (Vega *et al*., 1998). In the present study using Hierarchical clustering (HC), a dendrogram showing segregations of water quality parameters based on similarity was produced and is presented in Fig. 2. The variable cluster analysis (VCL) for variables produced five distinct clusters which are linked to each other. The VCL dendrogram has two major groups of water quality parameters *viz*, the first group included solids (TS, DS, SS) of physical variables and DO, BOD and PO_4 of chemical variables in cluster 1 of similar sources and K, silicate, pH, alkalinity, chloride and NO_3 of chemical variables in cluster 2 of similar soil origin and agricultural sources. The second group included ionic group of variables (TH, Mg, Na, Ca) in cluster 3 representing soil origin, chemical (SO_4, Fe) and physical (Tur, WT) in cluster 4 indicating similar sources of forest background and anthropogenic activities and a physical variable (EC) in cluster 5 depicting elements from similar sources and distribution during the process of transportation in river water. Cluster 1 with physical variables of natural origin and chemical variables of non-point sources of anthropogenic origin linked with cluster 2 which encompasses variables (K, Si, pH, alkalinity, chloride, NO_3) of similar sources of soil origin and nutrient (NO_3) of natural and anthropogenic origin respectively. These clusters are linked with the second group which consisted of clusters 3-5. Cluster 3 included ionic non-point sources of variables (TH, Ca, Mg, Na) from natural mineral compositions. The cluster 3 is linked with cluster 4, both of which comprise physico-chemical variables (SO_4, Fe, turbidity, WT) from similar sources of soil origin. The cluster 5 comprising EC, a physical variable, is linked with cluster 3 and 4.

The spatial cluster analysis (SCA) produced a dendrogram and the same is presented in Fig. 3 in which all 4 sampling stations in the stream basin were grouped into two distinct clusters. Cluster 1 consisted of Jag 2 and Hip 3 stations representing the Tadve and Hipla tributaries, respectively, of the stream Somavahini. Cluster 2 was represented by 2 stations representing Mut 1 in the upstream stretch at Honnahalla near Muthodi and Heb 4 in the downstream stretch near Hebbe of the main Somavahini stream. The stations in the above two clusters had similar characteristic features and natural backgrounds that were affected by similar sources. The stations in cluster 1 representing station 2 (Jag 2) on Tadve tributary and station 3 (Hip 3) on Hipla tributary have similar source of water from Babubuden hill range in the eastern and northern part of the drainage of the stream basin and natural forest background. Hence, these two stations are sorted together, and are very similar to one another in water characteristics, from the other two stations on the main stream. Station 1 on the main Somavahini Stream of the cluster 2 has green cover with extensive coffee plantations in the upper reaches and also human settlements. The coffee pulp waste generated during coffee curing and also other agricultural wastes get into the river water through surface runoff. The foul odour and turbid water were observed at station 1 during January at the time of water sampling. Cluster 2 also represented by station 4, which is located in the downstream stretch of the main Somavahini Stream with natural forest background. The immediate upstream stretch of this station has been exposed to human settlements at Hipla and Madla villages and thus, contribution of wastes due to anthropogenic activities, which ultimately drain into the main stream and also due to accumulated pollutants from the upstream stretches. Station 4 is exposed to similar natural background of tropical forests with that of upstream stations and also anthropogenic activities such as coffee plantations, paddy cultivation and cultivation of other commercial plantation crops at Madla and Hipla villages. Furthermore, station 4 received polluted water from the upstream stretches of the main Somavahini stream in addition to non-polluted water from tributaries in the midstream resulting in dilution of the main river water. Therefore, station 4 is linked with station 1 and both are segregated together in cluster 2 and are linked only weakly with cluster 1. Thus, SCA segregated the river stretches based on

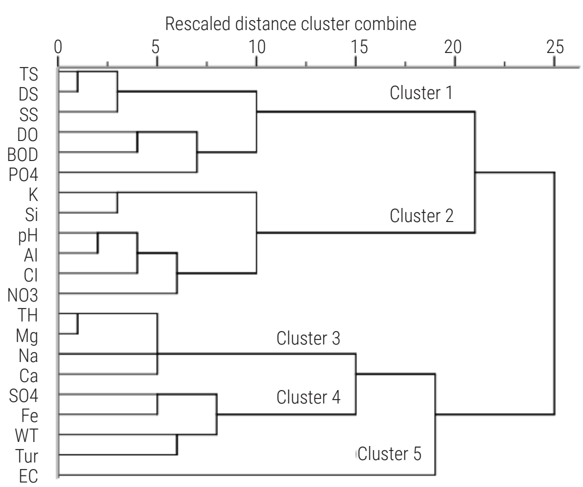

Fig. 2. Dendrogram showing the clusters of water quality variables according to water quality characteristics of stream water from the Somavahini Stream basin

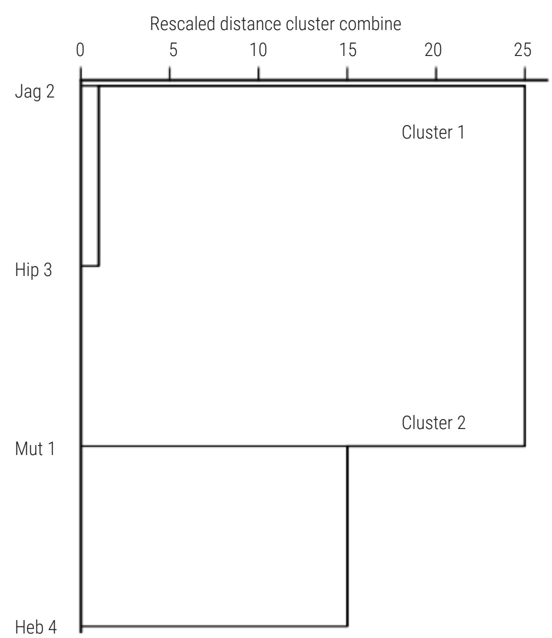

Fig. 3. Dendrogram showing the clustering of sampling sites according to characteristics of stream water from the Somavahini Stream basin

the similar background and characteristic features that are affected by similar sources of pollution in the Somavahini stream basin. The examination of water quality data using SCA revealed that cluster 2 comprising station 1 in the upstream at Muthodi and station 4 at Hebbe in the downstream stretches have high pollution load in the main Somavahini stream compared to cluster 1 which represents Tadve tributary (Jag 3) and Hipla tributary (Hip 3). Such similar studies have been carried out to understand the spatial similarities in water quality assessment of lotic water bodies (Alberto *et al*., 2001; Singh *et al*., 2004; Shrestha and Kazama, 2007; Pejman *et al*., 2009; Varol and Sen, 2009; Bu *et al*., 2010; Kumar *et al*., 2011; Varol *et al*., 2012; Wang *et al*., 2012; Muangthong and Shrestha, 2015; Thippeswamy *et al*., 2020).

The temporal cluster analysis (TCA) based on sampling months produced a dendrogram presented in Fig. 4 in which all the 12 sampling months were grouped into four distinct clusters according to characteristics of stream water in the present study. Cluster 1 consisted of 4 months (Oct, Nov, Dec, Feb) representing post-monsoon/winter (Oct, Nov, Dec) and summer/pre-monsoon (Feb) seasons. Cluster 2 consisted of 3 months representing July, August and March of monsoon (July, Aug) and summer/pre-monsoon (Mar) seasons. The months in the above two clusters had similar features regarding the source of water that were affected by rainfall during these months and similar climatic conditions. The SCA segregated the sampling months based on the similar environmental background and characteristic features that are affected (variables) by similar sources (water) in the Somavahini stream basin. Such similar observations have been reported by Varol and Sen (2009) on temporal patterns of water qualities which were not purely consistent with the four seasons or dry/wet seasons in Turkey. The analysis of TCA with months did not produce a clear-cut seasonal representation of months during the study period and resulted in overlapping of months in different seasons. This, perhaps, could be due to atmospheric disturbances, which usually induce tropical cyclones in the Bay of Bengal and the Arabian Sea during the onset and retrieval of both south-west and north-east monsoons and also due to local variation in climatic conditions with local showers (rainfall) and anthropogenic activities including agricultural activities in the river basin. Therefore, the water quality data set was further grouped into 4 seasons, which usually prevails at the study area, namely summer (Mar-May), monsoon (June-Aug), post-monsoon (Sep-Nov) and winter (Dec-Feb) and TCA was performed on these groups to understand the influence of environmental and climatic patterns according to the characteristics of stream water quality. The resultant TCA dendrogram is presented in Fig. 5 in which all 4 seasons of the year were segregated into two distinct groups.

The group one consisted of Cluster 1 with winter (Dec-Feb) and summer (Mar-May) seasons having similar characteristic, usually less, intermittent and scattered, nature of rainfall which influence the water quality of stream and cluster 2 with post-monsoon (Sep-Nov) season which experiences slightly more rainfall, due to retrieval of south-west monsoon and onset of north-east monsoon, and these two clusters are linked with the other group having monsoon (Jun-Aug) season in cluster 3. The monsoon season at the study area usually experiences assured rainfall of > 250 cm every year which affects the water quality in the stream due to surface runoff from natural forest area and agricultural fields. The clusters had similar climatic characteristics and natural background features that were affected by seasonal variations and environmental background with similar sources (rainfall) of water. Similar investigations have been reported in assessment of river water quality (Singh *et al*., 2004; Kumar *et al*., 2011; Varol *et al*., 2012). In the present study, cluster analysis revealed that the number of sampling months could be reduced without influencing the final outcome of the study and thus the cost and time of investigation could be reduced.

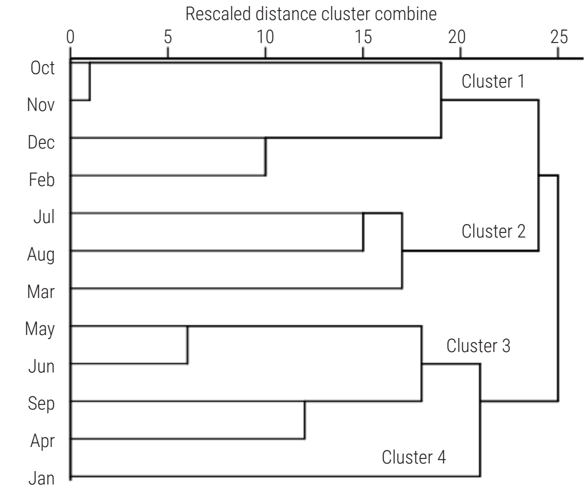

Fig. 4. Dendrogram showing the clustering of months according to characteristics of stream water in the Somavahini Stream

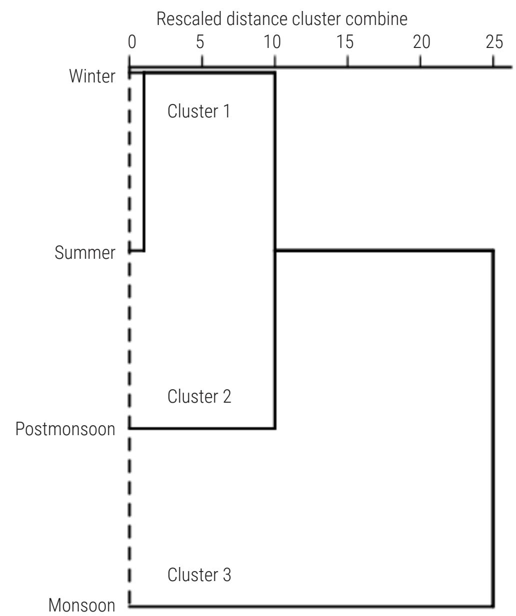

Fig. 5. Dendrogram showing the clustering of seasons according to characteristics of stream water from the Somavahini Stream basin

Principal component analysis

Principal component analysis helps to understand the correlation between the most important variables contributing to the data structure and provides information on the most meaningful components, which describe the whole data set through data reduction with a minimum loss of original information (Hotelling, 1933). It also permits identification of the possible components that influence water systems and are responsible for the variations in water quality, which thus offers a valuable tool for developing appropriate strategies for effective management of the water resources (Verol *et al*., 2012). The Scree plot generated in the present study was used to identify the number of principal components (Cattell, 1966) to be retained to comprehend the underlying data structure. In the present study, PCA of the entire data set revealed a total of six components that explained about 75.03% of total variance in the water quality data set. Eigen value > 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 (24.972%) is by unexplained variables. Principal component analysis produced data reduction from 21 to 6 components and explained 71.43% of total variance with 15.76% of loss of information. Components having criteria of loadings >0.50 are considered for identification of eigen vectors except for PO_4 since it showed the maximum eigen value of <0.38 in principal component 1 (PC1) and further lower values in the rest of the 5 PC's. The eigen values and their contribution to the total variance produced a small number of components (6) accounted for variation occurring in a much large number of variables (21). The total eigen values for PC1 to PC6 were 4.33, 3.74, 2.59, 2.09, 1.58 and 1.41, respectively and their corresponding percent of total variance were 20.62, 17.83, 12.35, 9.94, 7.58 and 6.72, respectively.

Factor analysis

The aim of factor analysis is to identify underlying factors that are responsible for the correlation among the variables and to reduce the contribution of less significant variables to simplify even further the data coming from PCA by rotating the axis defined by PCA and establishing a new set of variables called variance factors (VF's). The factor analysis did not produce the number of variables (VF's) below 6 determined by PCA and these six explained exactly the same proportion (75.03%) of the variation that the 6 PCA components explained since the data set used in FA was from PCA. However, the loadings of water quality variables in all the six VF's of FA were different and the corresponding eigen values and their percent of variance were also different. Further, PO_4 which was under PC1 in PCA along with WT, TS, SS, DS, BOD, pH, Al and Cl with the maximum eigen value of 0.377 and sorted to VF 3 in FA along with pH and Al with the maximum eigen value of 0.415 which is near to 0.5 loading, the criteria considered for identification of eigen vectors. The data on corresponding VF's, loadings and their explained variance are presented in Table 3. Variance factors having criteria of loadings >0.50 are considered for identification of eigen vectors for further exploration. The coefficients of variance factor with loadings >0.70 as strong and with >0.50 to <0.70 loadings as moderate loading are considered as significant and <0.5 loadings as low loading which are less significant. Variance factor 1 (VF 1), which explained 14.38% of the total variance, consisted of strong positive loadings on TS, SS, DS, moderate positive loading on SO_4 and moderate negative loading on Ca which could be due to water derived from the natural sources and also from non-point sources of pollution from anthropogenic activities, soil erosion due to weathering and surface runoff from the upper reaches of the river basin. This factor was composed of physical (TS, DS, SS) and anthropogenic variables (SO_4, Ca) derived from both natural and manmade activities. This VF also accounted for moderate negative loading on Ca. Surface runoff from these plantations during the monsoon might have resulted in high loadings of sulfate concentration. The absorption of Ca from water by various aquatic fauna, particularly small gastropods, could have resulted in negative loadings of Ca. The discharge of coffee pulp from coffee curing factories situated in the upstream of the stream Somavahini outside the sanctuary could have resulted in high loading of the physical variables. Variance factor 2 (VF 2) accounted for 13.66% of total variance, with strong positive loadings on TH and Mg and moderate positive loading on Na. This VF represents chemical variables due to mineral composition of the water derived from natural sources due to surface runoff from forest background and soil weathering. It is reported that the Bababudan melt has Mg-rich silicate phases (Rao and Naqvi, 1978).

Variance factor 3 (VF 3) accounted for 13.41% of total variance with high positive loadings on pH and alkalinity, moderate positive loading on chloride and low loading on PO_4 which represents chemical variables from non-point sources of pollution due to surface runoff from natural forest and also from agricultural fields (PO_4). Application of phosphate fertilisers and manures is very common in paddy cultivation, coffee and tea plantations, which are practiced in the river basin. Due to surface runoff from these fields, both organic and inorganic fertilisers reach river water. Variance factor 4 (VF 4) accounted for 13.04% of total variance with high positive loading on K and silicate and moderate loading on EC which could be due to mineral composition of the water derived from surface runoff of natural forest area and also from natural sources due to soil weathering, which deviates from the findings of Rao and Naqvi (1978) who reported that the Bababudan melt has

Table 3. Loadings of the first six factors, with varimax rotation, for data set of water quality variables from the Somavahini Stream in Jagara Valley

Variable	VF 1	VF 2	VF 3	VF 4	VF 5	VF 6
WT	-.152	.381	-.231	-.137	-.675	.354
TS	.893	-.082	.135	-.014	.331	-.007
SS	.744	-.055	.336	-.158	.089	-.138
DS	.739	-.140	-.065	.160	.376	.127
DO	.184	.172	-.085	-.105	.780	.080
BOD	.159	.052	.413	-.091	.730	.005
Tur	.080	.019	.133	-.242	-.150	.723
pH	.222	-.234	.795	.006	-.123	-.047
Al	-.113	.034	.869	.257	.118	.005
Cl	.096	.183	.672	.352	.248	.056
EC	.063	.337	.438	.648	.127	-.139
TH	-.333	.848	.011	.098	.132	.036
Ca	-.580	.405	.049	.216	.321	.376
Mg	.011	.907	-.018	.002	-.028	-.137
Na	.101	.642	.180	.434	-.073	.262
K	.102	-.021	.005	.884	.001	.057
Si	-.166	.133	.187	.738	-.226	-.162
NO3	.101	-.371	.394	.275	-.220	-.573
PO4	.168	.231	.415	-.164	.212	.053
SO4	.650	.211	.019	.296	-.082	.443
Fe	-.038	-.294	-.057	.470	.123	.732
Eigen value	3.020	2.868	2.816	2.738	2.278	2.036
% total variance	14.382	13.658	13.407	13.039	10.847	9.694
Cumulative % variance	14.382	28.040	41.447	54.487	65.334	75.028

low to moderate potash of tholeiitic association. This could be due to the application of potassium fertilisers in coffee plantations and this nutrient could have entered river system through surface run off that resulted in high loading of K.

Variance factor 5 (VF 5) accounted for 10.85% of total variance with moderate negative loading on WT and high positive loading on DO and BOD which accounted for physico-chemical variables. High water temperature reduces the DO content in water and hence negative loading of WT. The demand for dissolved oxygen will be more in organic matter-rich water due to biodegradation and 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 oxygen which also increases due to degradation of organic matter, oxidation of ionic minerals and accumulation of free carbon dioxide in water which ultimately changes the pH value in association with high BOD values. The high positive loading of DO is met by a natural mixing process of atmospheric oxygen while the stream is flowing on the stream bed which largely consists of rocks, cobbles and pebble stones. Variance factor (VF 6) accounted for 9.69% of total variance with high positive loading on turbidity and Fe and moderate negative loading on NO_3. This VF accounted for physical (turbidity) and mineral (Fe) and nutrient (NO_3) variables from non-point sources of pollution (coffee pulp), detritus from forest land and also points to the sources from agricultural inputs. The turbid waters have heavy loads of solids and detritus which are transported from upstream to downstream and also during the decaying process, nitrogen and phosphorus are released into the water, producing high loading of nitrogen. Further, application of nitrogen fertilisers such as calcium ammonium nitrate, ammonium sulphate nitrate, sodium nitrate, calcium nitrate (Norwegian saltpeter or nitrate of lime) and potassium nitrate are very common in coffee plantations since coffee plants have a high nitrogen requirement. In addition, organic manures are commonly used in coffee plantations and other agricultural crops. Thus, the nutrient NO_3, is contributed from agricultural runoff. The Bababudan schist belt contains conglomerates, quartzite, phyllites and banded iron formations in the stream basin and due to weathering process during south-west monsoon some of these elements are released into the stream water producing moderate loadings of Fe. The Bababudan belt is composed of banded iron with iron and silica along with a wide spectrum of minerals of geological sources (Arora *et al*., 1995).

It is well acknowledged that in coffee cultivation, NO_3, PO_4 and K are considered as major nutrients and applied profusely. The secondary nutrients like Ca, Mg and SO_4 are also commonly used along with micro-nutrients *viz*., Fe, Mg and Na*.* Perhaps, accumulation of minerals, detritus and other organic wastes in stream water resulted in high loadings in Mg, TS, K, alkalinity, TH, pH, DO, SS, DS, silicate, Fe, BOD and turbidity due to runoff from natural forest background, agricultural fields and also from coffee processing units in the catchment area and also due to other human activities within and outside BWS. Therefore, these variables represent the non-point source. The moderate loadings of WT, chloride, SO_4, EC, Na, Ca and NO_3 and low loadings of PO_4 in stream water could be due to natural forest background, mineralisation of soil and nutrient load due to agricultural activities in the stream basin. Similar studies have been conducted in various parts of the world for evaluation of river water quality (Alberto *et al*., 2001; Lambrakis *et al*., 2004; Mendiguchia *et al*., 2004; Singh *et al*., 2004; Varol *et al*., 2012).

Pollution causing variables

The data on pooled eigen vectors which accounted for 75.038% of total variance is presented in Fig. 6. The data indicated four major categories of water pollution in the Somavahini Stream based on total eigen vector, as presented in Table 4. The parameters having total eigen vector of <0.00 such as WT and NO_3 are considered as normal variables which contribute no pollution in the stream stretch and hence the water is normal or safe in regard to these variables. The variables having total eigen vectors in the range of >0.50 - <1.00, such as SS, turbidity, pH, TS, Ca, Mg, silicate, PO_4 and Fe are considered as medium pollution-causing variables and hence the water has a medium level of pollution due to these variables. The variables having total eigen vectors in the range of >1.00 - <1.50 such as TS, DS, DO, BOD, alkalinity, EC and K are considered as high pollution-causing variables and hence the water is highly polluted due to these variables. The variables, having total eigen vectors >1.50, such as chloride, Na and SO_4 are considered as very high pollution-causing variables and hence the water is highly polluted due to these variables. In the present study the residual variance due to unexplained variables was 24.97% which, perhaps, could be due to the variables which are not monitored in the present study.

Factor scores

The data on variation of factor scores between the four stations is presented in Fig. 7. The data on FS 1 revealed that station 4 showed high pollution due to TS, SS, DS, Ca and SO_4 whereas the other three stations in the upstream showed low pollution due to these variables (Fig. 7a). Similarly, FS2, in addition to station 1, also showed high pollution at station 4 due to TH, Mg and Na, but Tadve and Hipla tributaries exhibited no pollution due to these variables (Fig. 7a). The high concentrations of most of these variables at station 1 and station 4, perhaps, could be due to runoff from agricultural fields, mineral composition of water derived from natural sources and also due to anthropogenic activities in the upper reaches. The data on FS3 and FS4 for four sampling stations is presented in Fig. 7b. The data on factor score 3 showed the maximum loadings for variables such as pH, alkalinity, chloride and PO_4 at station 1. The data on FS 4 also showed the maximum loadings at station 1 for variables namely EC, K and silicate indicating high pollution due to these variables. The high values of these variables at station 1 could be due to surface runoff from mineral rich soil and also runoff from forest areas in the upper reaches of the stream Somavahini. The low scores of this factor in the subsequent downstream stations of the basin could be due to settling and dissolution and oxidation process

Table 4. Classification of water pollution at different sampling stations based on eigen vectors obtained from sampling stations in the Somavahini Stream basin of the Bhadra Wildlife Sanctuary

Category	Variance factor	
	Eigenvector	Variable
Safe / Normal	< 0.00	WT, NO_3
Low pollution	> 0.00 - < 0.50	-
Medium pollution	> 0.50 - < 1.00	SS, Tur, pH, TH, Ca, Mg, Si, PO_4, Fe
High pollution	> 1.00 - < 1.50	TS, DS, DO, BOD, Al, EC, K,
Very high pollution	> 1.50	Cl, Na, SO_4

Abbreviations for environmental variables are given in Table 1
None of the water quality variables examined were included under low pollution category

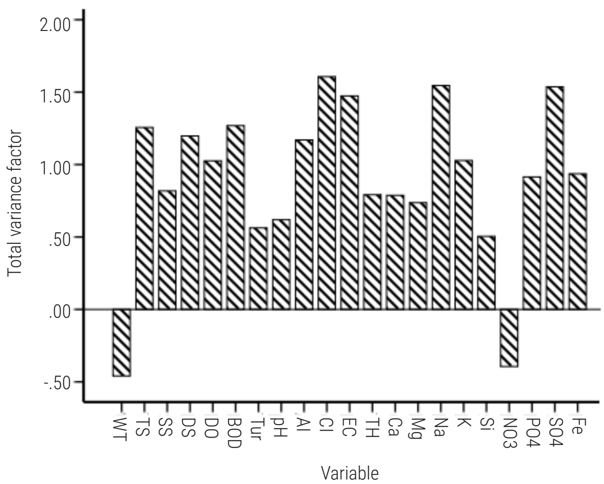

Fig. 6. Total eigen vectors for water quality variables from the Somavahini Stream basin

of some of these variables and other dissolved substances while moving along the stream. In the rest of the stations the pollution is negligible due to these variables. As seen earlier in FS1 and FS2, the station 2 and station 3 continued with low loadings for FS 3 and FS4 and this could be due to less human interferences in Jagara and Kemmannugundi areas, respectively, of the sanctuary. The data on FS5 and FS6 presented in Fig. 7c revealed that the FS5 showed high pollution due to WT, DO and BOD at station 1. Demand for DO is more for degradation of organic matter originated from anthropogenic activities and also from natural forest background. In the rest of the stations no pollution was observed by FS5. The data on FS6 showed pollution levels at station 2 and station 4 due to turbidity, NO_3 and Fe. The sources of nitrogen could be non-point sources due to agricultural runoff and other adjoining areas outside the sanctuary. The water pollution due to FS5 was low at station 2 and/or negligible at station 1 and at station 3.

The data on variability of number of factor scores (FS1 to FS6) within the four sampling stations is presented in Fig. 8. Factor score 4 showed the maximum pollution at station 1 (Fig. 8a) in the upstream due to EC, K and silicate accounted for soil weathering and agricultural activities in the upstream and no pollution caused by FS6 comprising variables such as turbidity, NO_3 and Fe at this station. Whereas FS1 to FS5 have not contributed pollution at station 2 but FS6 has contributed low pollution due to turbidity, NO_3 and Fe. All these six FS's at stations Mut 1 and Jag 2 run in an opposite direction in respect of water pollution which could be due to different input sources due to anthropogenic activities and also surface runoff from natural forest land causing low water pollution at station 2 by FS6 in the Tadve tributary. All factor scores accounted for water pollution at station 4 in the downstream of stream Somavahini except FS5, accounted for loadings of WT, DO and BOD and has not contributed pollution at stations 2-4. However, FS5 accounted for water pollution at station 1 in Somavahini upstream which could be due to input of coffee pulp from coffee curing units situated in the in the upstream. Factor scores (FS1 to FS6) have not contributed water pollution at station 3 in Hipla tributary (Fig. 8b) which drains the water from northern part of Jagara Valley of Kemmanugundi area of Bababudan hill range and joins the stream Somavahini on right bank near Hipla Village. Factor score 4 contributed least water pollution at station 3 followed by station 2 accounting for input from natural forest area. Factor score 2 with loadings of TH, Mg, Na and FS3 with loading of pH, Al, Cl and PO_4 have not accounted for water pollution at station 2 and station 3 accounting for natural input from the mountain area. However, it accounted for pollution at station 1 and station 4 in the main Somavahini Stream due to inputs from natural and anthropogenic activities in the upstream and accumulation of pollution in the downstream. Similarly, FS1 with TS, SS, DS, SO_4 and Ca also contributed to high pollution at station 4 in the downstream followed by station 1 in the main Somavahini Stream accounting for inputs of physical water quality variables due to runoff from agricultural lands and other anthropogenic activities. However, FS1 has not contributed to water pollution at station 2 in Tadve tributary

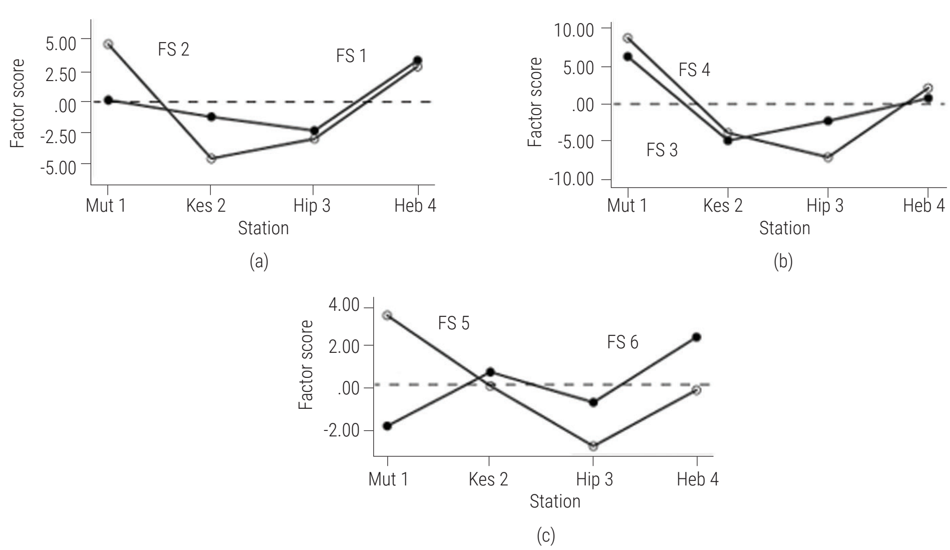

Fig. 7. Variability in total factor scores between sampling stations located in the Somavahini Stream basin. Open circles represent FS2, FS4 and FS5. Filled circles represent FS1, FS3 and FS6. (a) FS1 and FS2; (b) FS3 and FS4(c) FS5 and FS6

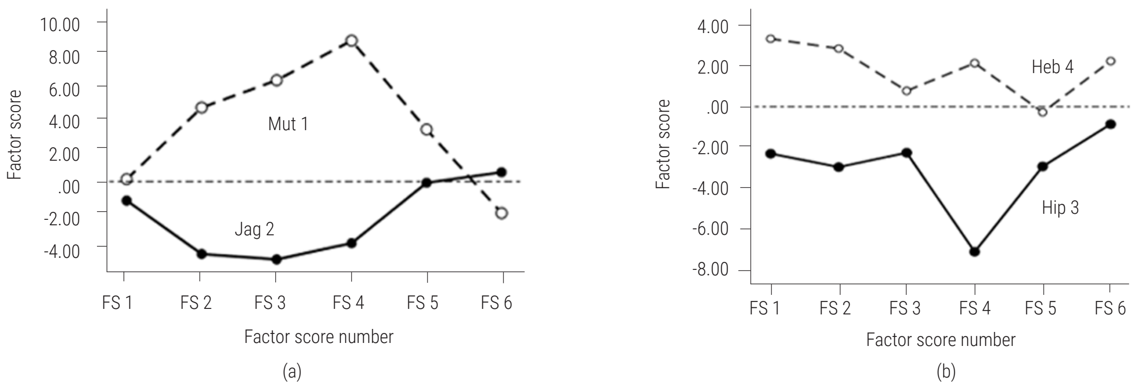

Fig. 8. Variability in total factor scores within sampling stations located in the Somavahini Stream basin. (a) Stations Mut 1 and Jag 2 and (b) Stations Hip 3 and Heb 4

and station 3 in Hipla tributary due to inputs from mountain slops through natural forest areas.

The date on total factor scores for 12 months of the present study is presented in Fig. 9 and the data revealed negative total factor score (less than zero) indicating that the stream water was not polluted during May '01, June, September, November, December and April '02. However, stream water was polluted during July '01, August, October, January '02, February and March. The Indian Peninsular region broadly experiences three seasons representing pre-monsoon from February to May (summer), from June to September (rainy) and post-monsoon from October to January (winter). However, Fig. 9 could not delineate the clear-cut seasonal pattern of water pollution due to interchanging of months in these seasons.

Polluted and non-polluted stations

The data on pooled factor score for four water sampling stations is presented in Fig. 10. The data revealed that the negative values of factor scores of less than zero (< 0.0) for sampling sites at station 2 in Tadve tributary and at station 3 in Hipla tributary indicating water is not polluted. The positive loadings of factor score (>10.00 - <15.00) for Hebbe (station 4) and factor score (>15.00) for sampling site at Muthodi (station 1) indicated high pollution and very high pollution, respectively, of stream water. The high factor scores correspond to high influence on the sampling sites (Mendiguchia *et al*., 2004; Felipe-Sotelo *et al*., 2007). Sampling station 1, located in the upper reaches, showed very high polluted water followed by station 4, located in the lower reaches, of the stream Somavahini. Station 1 received runoff from agricultural fields and also effluents from coffee pulping plants which have contributed high pollution load. A very bad foul odour of water was observed during January at the time of sampling at station 1. Further, low water flow and turbid water during summer months was also noticed at this station. The maximum values of NO_3 during October '01 and Fe during January '02 and the minimum value of turbidity during May '01 were noticed at station 1 (Table 1). The maximum value of WT and the maximum concentration of TS, SS, alkalinity, chloride, EC, Ca, Na, K, silicate, SO_4 and PO_4 were observed at station 4 (Table 1). Such high values at this station could be due to the disturbances in the upper reaches of station 4. However, station 4 also showed the minimum values of WT, chloride, Ca and, nitrite (Table 1) which could be due to winter season and dilution of stream water through natural mixing.

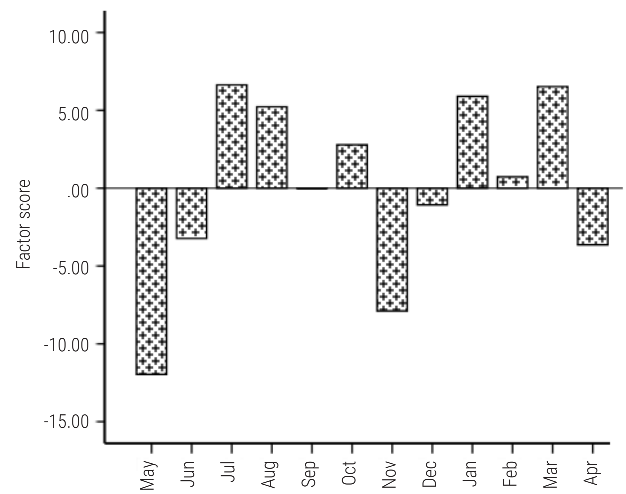

Fig. 9. Factor scores of water quality variables for months from the Somavahini Stream in the Bhadra Wildlife Sanctuary

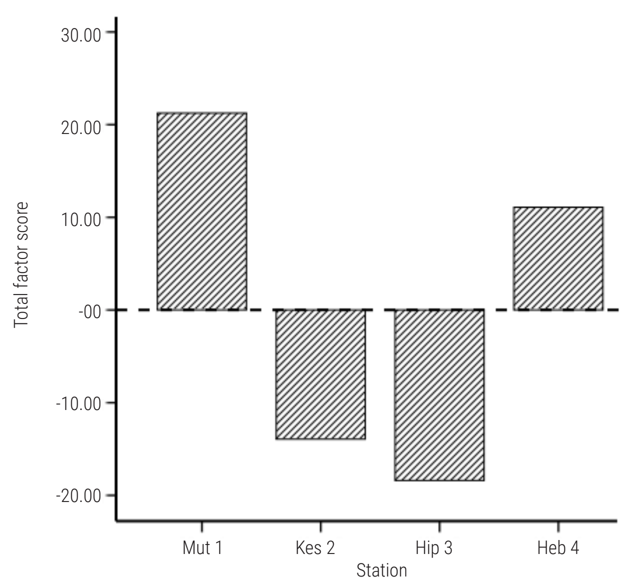

Fig. 10. Total factor scores for sampling stations located in the Somavahini Stream basin

As Somavahini Stream water flows downstream from station 1, the water gets mixed with the water from Tadve tributary which has no pollution (-12.08), thus reducing the pollution load to some extent by dilution and mixing processes in the main stream. However, the maximum values of TH and Mg during August were recorded at station 2. The minimum concentration of a large number of variables such as solids, BOD, pH, Na and PO_4, alkalinity, TH and Na, Mg, silicate and NO_3 and SO_4 were recorded in Tadve tributary which originates in the Bababudan mountain range of Mullayanagiri area and flows in the dry deciduous tropical forests of Jagara Valley. The water from Tadve tributary is not polluted, which is supported by a large number of variables registering the minimum values during the study period. Further, downstream of the main Somavahini Stream water is diluted with water from Hipla tributary, which flows from the Kemmnnugundi area of Bababuddangiri mountain range, water with no pollution (-19.34) which is supported by observations of minimum values of water temperature, total solids, DS, DO, EC, potassium, NO_3 and iron. However, station 3 (Hipla tributary) also showed maximum values in water temperature, dissolved solids, BOD due to summer season (WT) and monsoon floods (DS) which enhances BOD due to degradation of detritus. Thus, further reduction in pollution level at station 4 in the down-stream of the main Somavahini Stream due to dilution and mixing processes. Subsequently, with this pollution load, the stream water from the Somavahini is discharged into the backwaters of Bhadra Reservoir thereby contributing pollution into the main Bhadra River.

Factor score for stations varied from -0.19.4393 to 21.2481 in the present study. Accordingly, the sampling station 2 Tadve tributary and station 3 on Hipla tributary in the Somavahini Stream basin are grouped under safe water category (<0.0) based on their factor scores of -13.9396 and -19.4393, respectively. Station 4 at Hebbe, located in the downstream, and station 1 (Muthodi), located in the upstream, of the main Somavahini Stream were grouped under very high pollution category (>15.00) based on its factor score of 21.2481 and station 4 at Hebbe in the downstream was grouped under high pollution category (>10.00 - <15.00) based on its factor score of 12.2481. The highly polluted water from station 1 subsequently mixed with non-polluted water from Tadve tributary in the mid-stretch of the main stream and further mixing in the downstream stretch with non-polluted water from Hipla tributary resulted in comparatively low polluted water in the downstream stretch of the Somavahini Stream at Hebbe (station 4). Therefore, dilution of stream water has reduced the pollution level. However, the water pollution gets accumulated in the downstream stretches even though the natural processes of dilution and self-purification are operating in the stream basin. The stream water in the downstream stretch at station 4 showed still higher polluted water than that of Tadve tributary and Hipla tributary and slightly lower pollution than upstream water of the main Somavahini stream near Muthodi.

Water quality and health of the stream

The water quality variables affecting the health of the streams at different stretches either individually and/or as a group are presented in Table 5. The variables such as TS, SS, DS, Ca and SO_4 of VF 1, accounted for 14.38% of total variance, caused the maximum pollution either individually and/or as a group at station 1 and the health of the stream was also affected at station 4 in the downstream near Hebbe by these variables indicating the non-point, physical and agricultural sources of pollution at these sampling sites. The earlier study also revealed that the stream Somavahini at Muthodi had the maximum pollution due to DS (Thippeswamy *et al*., 2020). The contribution of Ca is considered as a result of cation-exchange processes at the soil-water interface and dissolution of Ca-bearing minerals (Varol and Sen, 2009; Varol *et al*., 2012). Application of gypsum powder (calcium sulfate) is also common in coffee plantations for better growth of plants. The variables (TS, SS, DS, Ca, SO_4) under this variance factor have not caused water pollution in the streams at station 2 in Tadve tributary and also at station 3 in the Hipla tributary. The variables (TH, Mg, Na) of VF 2, accounting for 13.66% of total variance, caused the maximum pollution either individually and/or as a group in the downstream station at Hebbe followed by the upstream station at Muthodi in the main stream Somavahini but have caused no pollution at station 2 in Tadve tributary or at station 3 in Hipla tributary.

The variables pH, alkalinity, chloride and PO_4 of VF 3 accounted for 13.64% of total variance, and caused the maximum pollution either individually and/or as a group in the downstream station at Hebbe followed by the upstream station at Muthodi in the Somavahini stream basin. The pH of water during the study period varied from 6.09 to 8.41 with an average of 7.49. The pH of stream water affects the coagulation reaction and diffuse reactions of suspended particles and also the vegetative growth. High concentration of PO_4 could be due to surface runoff from coffee plantations, soil erosion and other agricultural practices in upland areas. Washing of clothes and bathing (detergents) by local inhabitants also contribute to the concentration of PO_4 in water. The variables (EC, K, silicate) of VF 4 accounted for 13.04% of total variance and caused the maximum pollution either individually and/or as a group in stream Somavahini at station 4 in the downstream followed by station 1 in the upstream at Muthodi. This could be due to geological origin since the Bababudan schistose belt has Mg-rich silicate and low to moderate potash (Rao and Naqvi, 1978). However, VF4 has not exerted noticeable water pollution in Tadve and Hipla tributaries during the study period. The contribution of EC, K and silicate in river water was attributed to soil erosion from natural background, agricultural runoff and anthropogenic activities in the river basin.

The variables such as WT, DO and BOD of VF 5, accounted for 10.85% of total variance, and were responsible for the maximum pollution either individually and/or as a group at station 1 and did not exert noticeable water pollution in the subsequent downstream stations in the Somavahini Stream basin during the study period.

Table 5. Environmental variables causing water pollution either individually and/or as a group at different stretches (stations) based on factor scores in the Somavahini Stream basin of the Bhadra Wildlife Sanctuary

Variance factors (VF's)	Water quality variables	Stations*
VF1	TS, SS, DS, Ca, SO_4	1, 4
VF2	TH, Mg, Na	4, 1
VF3	pH, Al, Cl, PO_4	4, 1
VF4	EC, K, Si	4, 1
VF5	WT, DO BOD,	1
VF6	Tur, NO_3, Fe	2, 4

Abbreviations for environmental variables are given in Table 1
*Stations indicate pollution laevels in ascending order. Station 3 (Hip 3) has not contributed water pollution at a recognisable level based on factor scores

Low discharge of water during summer months has resulted in stagnation of water which accounted for high WT at this station. 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 stream water. The low water flow in the Tadve and Hipla tributaries coupled with high rates of evaporation of water due to high summer atmospheric temperature reduces the DO level in water. The BOD of river water 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 (Varol *et al*., 2012; Wu and Kuo, 2012). The eigen vectors *viz*, turbidity, NO_3 and Fe of VF 6, accounted for 9.69% of total variance, were responsible for high pollution either individually and/or as a group in the Tadve tributary followed by Somavahini downstream. Perhaps, surface runoff from iron-rich soil in the present study area might have contributed to the increased iron content in the lower stretch of the main Somavahini Stream. High content of Fe in the downstream of the main Somavahini Stream might have been further enhanced by inflow of water with high content of iron from Tadve and Hipla tributaries. High concentrations of Fe at station 2 and station 4 could be due to runoff from Fe rich soils in the stream catchment area. The Bababudan belt is rich in banded iron with iron and silica along with a wide spectrum of minerals (Arora *et al*., 1995). High iron concentration could be attributed in the water bodies to reducing conditions and low pH values (APHA, 1995) also. Amongst 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 (Varol *et al*., 2012; Wu and Kuo, 2012). The coffee plantations in the hilly regions of the catchment of the stream basin, as in the present study area, probably contributed high levels of ammonia than in pesticides, which are also applied in large quantities to control pests of these commercial plantation crops, and the oxidised products such as nitrates and nitrites coming from organic nitrogen have adverse effects on aquatic biota and even on human health (Wu and Kuo, 2012).

The pollution levels *viz*, moderate (>0.50 - 1.00) due to SS, turbidity, pH, TH, Ca, Mg, silicate, PO_4 and Fe, high pollution (>1.00 - <1.50) due to TS, DS, DO, BOD, alkalinity, EC and K and very high pollution (>1.50) due to chloride, Na and SO_4 in the stream basin (Table 4) indicated the accumulation of pollution at station 4, as the river moves downstream. The high pollution load in the downstream has been reported elsewhere (Kannel *et al*., 2007) in the urban river system and also in the Bhadra River from the natural forest background (Thippeswamy *et al*., 2020). Boraiaha *et al*. (2018) reported that Metabasalts of Bababudhan Group have moderate concentrations of Mg, Ca, Na and K oxides and are characterised by higher iron oxide. The cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), metal cation (Fe^{2+}) and anions (Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}) accounted for high mineral composition of water derived from natural and/or anthropogenic sources of soil erosion from mountainous area of Bababudan range and also due to anthropogenic activities in and around the BWS. These are responsible for very high pollution in the Somavahini Stream stretch. Most of these variables caused some level of stream water pollution in the basin, perhaps, due to high input thorugh surface runoff from Bababudan schist belt due to weathering processes. The maximum concentration of silicate was at station 4 during January. The loading of total eigenvector for silicate in the stream basin was 0.50 indicating medium pollution at station 4 and station 1 along with other variables. The contribution of silicate was attributed to soil erosion, agricultural runoff and also from other anthropogenic activities in the stream basin. When a stream has a relatively high level of suspended particles, its self-purification capacity will be lowered resulting in deterioration of water quality. However, in the present study the maximum value of SS at station 4 during October was noticed. The total loading of VF for SS was 0.82. Thus, SS and DS along with other variables such as Ca, alkalinity, chloride, K, silicate, EC and Na affected the health of the stream Somavahini in the upstream and downstream stretches in the Jagara Valley of BWS.

The present investigation forms a baseline data on water quality of the Somavahini Stream in the Jagara Valley of the BWS in the Western Ghats of India. Cluster analysis was applied for assessing the classification of sources/types of water pollution in different stretches in different seasons/months. Further, cluster analysis revealed that number of sampling months could be reduced. Application of PCA and FA in water quality analysis revealed that station 1 contributed the highest pollution followed by station 4 in the downstream of the main stream Somavahini. Further, it was revealed that Hipla tributary water was safe/normal water whereas Tadve tributary water had slight pollution. The water quality variables comprising WT, DO and BOD have caused high pollution at upstream station due to anthropogenic activities and subsequently these variables showed no pollution in streams and also at downstream station at Hebbe due to dilution. The water quality variables *viz*, turbidity, NO_3 and Fe at upstream station near Muthodi have caused no pollution and subsequently these variables caused slight pollution in Tadve tributary and high pollution at in the downstream of the main stream Somavahini Stream due to accumulation in stream water. The results revealed that there is no major water pollution threat in Somavahini Stream except at Honnahalla station 1 near Muthodi where a small quantity of coffee pulp waste is discharged during certain months. However, water quality data set on spatial and seasonal scales with additional variables over a long period of time frame from the entire stream basin in relation to forest cover within the BWL and land use pattern for agricultural activities outside the BWS in the watershed area of the Somavahini Stream is warranted to elucidate a clear-cut outcome on water quality of this stream basin, subjected to assured rainfall of >250 cm during the south-west monsoon season every year, for better management and conservation of aquatic and terrestrial wildlife of this sanctuary.

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