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Assessment of Physico-chemical Integrity of Lotic Ecosystems in Central Western Ghats through Multivariate Techniques

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KEYWORDS Aghanashini River Basin. Cluster Analysis. Principal Component Analysis. Stream. Water Discharge. Water Quality

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INTRODUCTION

The Western Ghats is a chain of mountains extending from north to south along western peninsular India, harbors diverse and endemic flora and fauna (Ramachandra et al. 2015). It has 37 west flowing and 3 east-flowing rivers and their tributaries (Sreekantha et al. 2007). Lotic ecosystem permit complex interactions as well as mass/energy transfer between all its abiotic and biotic entities and have the capability to recover itself from the minor perturbations (Sharma and Kansal 2013). Western Ghats harbor numerous sacred groves (also known as Devarakadus, Kavu etc.), which are patches of forests having spiritual and religious importance in addition to providing hydrological services, habitat, bio-geochemical cycling, etc. (Ray et al. 2015; Ramachandra et al. 2016a).

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Water quality of riverine systems depends on climate, topography, geology, soil properties, atmospheric deposition and catchment hydrology of a region. Variations in river flow affect water quality by increasing or decreasing the effects like dilution, residence time, mixing and erosion (Purnaini et al. 2018). The rate of evapotranspiration, infiltration, interception and percolation changes through modifications of catchment. Health of lotic ecosystems (streams and rivers) reflects a picture of ecosystem functioning as well as the prevailing human interactions including disturbances (Allan 2004). Anthropogenic activities in the catchment can also lead to higher concentrations of suspended solids, salts and nutrients (Lintern et al. 2018). Water bodies loose the capability of self-purification due to the influence of anthropogenic activities near the catchment (Aishvarya et al. 2018). Human activities in the watershed altering the landscape structure drives variability in the duration of flow and water quality (Huang et al. 2014). The alterations in natural flow regime, changes an ecosystem completely causing variations in physical, biological and chemical conditions of streams and its riparian zones, thereby affecting ecosystem biodiversity (Rolls et al. 2012; Bunn and Arthington 2002). Water discharge varies spatially as well as temporally, and increases along a stream network due to inputs from rainfall, tributaries and groundwater. The rate of flow recession affects the habitat preference, growth and survival of aquatic biota (Rolls et al. 2012).

Land cover in the catchment and riparian forests are vital ecological elements supporting diverse flora and fauna and perform a major role in nutrient cycling and maintaining pristine ecosystem (Girardi et al. 2016; Magdaleno and Martinez 2014). Important drivers of diversity include factors – type of the habitat, hydrologic variables, disturbance and stream morphometric, geologic and lithological variables (Tornwall et al. 2015). Precipitation rate, forests and soil characteristics in the Western Ghats decides the amount of water stored in vadose and saturated zones during monsoon, which later get released to streams in post monsoon season (Ramachandra et al. 2016a). Monitoring of hydrological variables with statistical analysis helps in better interpretation of hydrologic regime and quality of an ecosystem (Oketola et al. 2013).

Hydrological changes in forest dominated watershed are due to changes in LULC – land use and land cover altering the structure of the landscape (Cui et al. 2012). Water retention capability of the catchment declines with alterations in the catchment integrity. Forest type and its soil modify precipitation rate, biogeochemical processes, water yield, water discharge and habitats thus interfering with the quality of water flowing to streams and other hydrological aspects (Neary et al. 2009). Runoff and water yield reduces due to reduction in total forests, especially, old forest (Singh and Mishra 2012). Conversion of forest lands for agriculture/other land use increases overland flow bringing about a decline in recharge and finally, discharge to streams during non-monsoon seasons. The sub-basins receiving good rainfall, with native species of trees in the catchment (covering to an extent more than 60-65%) have increased stream flow even in lean seasons (Ramachandra 2014). Riparian zone regulates stream water quality and are involved in exchange and transfer of elements from terrestrial to aquatic ecosystems. The seasonal and spatial variations in stream water quality is governed by various abiotic, biotic and hydrological factors like temperature, light availability, turbulence, precipitation, terrain, surface runoff, soil, groundwater flow, vegetation, quantity and composition of litter, other land use practices and aquatic biota. The main objective of the current research is to investigate the changes in the physical, chemical and nutrient parameters in selected streams of Aghanashini river basin, mainly, Chandikaholé sub catchments.

MATERIAL AND METHODS

Aghanashini is a west flowing river with catchment area of 1450.9 sq.km (Fig. 1), spread across the districts of Uttara Kannada (Ankola, Kumta, Sirsi, Honavar, Siddapur) and portions of Shimoga (Sorab). The Aghanashini river originates in Sirsi taluk, Uttara Kannada district. The river has two sources – Bakurholé tributary (at Manjguni) and Donihalla (near Sirsi) which meets at Mutthalli (Balachandran et al. 2012; Ramachandra et al. 2015). Aghanashini river estuary has dense and diverse mangrove forests along the coast. Rainfall across the basins varies from as low as 3000 mm at the plains of Sirsi and to as high as over 5000 mm at the Ghats. Temperature in the basins varies from as low as 15.3^0 in January to as high as 35.4^0 in April. Elevation in the catchment varies between less than 0 meters to 786 m of Mean sea level (Ramachandra et al. 2016b). In the current study, Chandikahole's sub catchments were considered for assessment of flow. Chandikaholé originated at Yaana and joins Aghanashini at Uppinapattana. About 8 macro and micro watersheds were considered taking into account i) similar climatic conditions (about 3500 mm rainfall), ii) all the micro watersheds connect to a macro watershed, iii) variability in landscape, etc.

Yaana, Nanalli, Beilangi, Mastihalla, Harita are the micro watersheds connecting Aanegundi (AGT1), whereas Aanegundi (AGT1 and AGT2), and Bialgadde (BGT) are the macro watersheds. Aanegundi AGT1 and AGT2 join near Yaana cross along the Sirsi-Kumta Road. The descriptions of various micro/macro watersheds sampled are given in Table 1. Yaana and Nanalli catchments are dominated by evergreen forests, followed by Beilangi which consists of moist deciduous forests and evergreen forests whereas, rest of the catchment areas have mixed land use dominated by horticulture and agriculture activities.

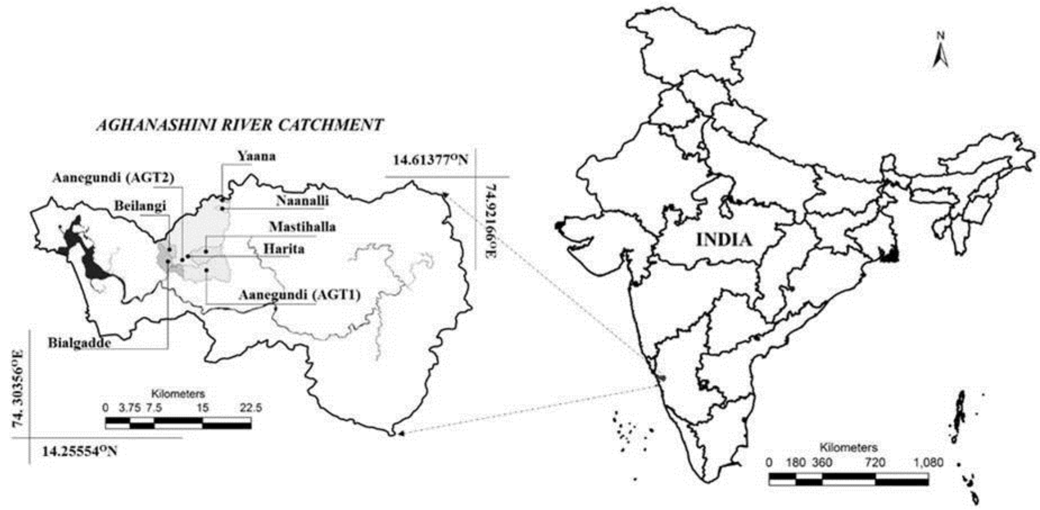


Fig. 1. Study area – Aghanashini river basin, Chandikaholé sub catchments

Table 1: Description of watersheds

S. No.	*Watershed*	*Area Ha*	*Major catchment*	*Land use*
1	Yaana	122.3	AGT2	Evergreen Forest
2	Nanalli	84.2	AGT2	Evergreen Forest
3	Beilangi	393.1	AGT2	Mixed Forest
4	Harita	12.6	AGT2	Mixed land use
5	Mastihalla	863.3	AGT2	Mixed land use
6	Aanegundi AGT2	7361.6	BGT	Mixed land use
7	Aanegundi AGT1	2012.6	BGT	Mixed land use
8	Bialgadde	10270.04	-	Mixed land use

Water Sample Collection

Water samples were collected covering all seasons for a period of two years during April, 2014 to March, 2016 from nine different sites namely Yaana (YK), Nanalli (YNK), Beilangi (BE), Harita (HA), Mastihalla (MH), Aanegundi (AG), Aanegundi tributary 1 (AGT1), Aanegundi tributary 2 (AGT2) and Bialgadde (BGT) and analysed physico-chemical parameters. Water temperature, discharge, EC, TDS, pH, and DO were measured at the collection site and samples were brought to the laboratory for further analysis.

The analysis of physico-chemical parameters like water temperature (laboratory thermometer); discharge (current meter), pH (Eutech: PCSTestr 35); total dissolved solids (Eutech: PCSTestr 35); electrical conductivity (Eutech: PCSTestr 35); turbidity (Hach Turbidimeter); dissolved oxygen (Winkler's Method); chemical oxygen demand (Closed reflux, titrimetric method); total alkalinity (Titrimetric method); biochemical oxygen demand (5 day BOD test); chloride (Argentometric method); total hardness and calcium (EDTA Titrimetric method); magnesium; nitrate (Phenol disulphonic acid method); orthophosphate (Stannous chloride method); sodium and potassium (Flame emission photometric method) of water samples collected from select streams were done according to the standard protocol of APHA AWWA WEF (2005).

Statistical Analysis

Multivariate techniques, Cluster Analysis (CA) and Principal Component Analysis (PCA) were computed using PAST software considering the water quality data. These techniques like principal component analysis (PCA) and cluster analysis (CA) helps in the data dimensionality reduction while prioritizing the factors responsible for variations in water quality parameters, thus helping in better interpretation of water quality data (Arslan 2009; Zarei and Bilondi 2013; Gebreyohannes et al. 2015; Ramirez et al. 2014). The assemblage of sampling locations based on their similarity were done through the cluster analysis (Bhat et al. 2014; Han et al. 2012; Mushatq et al. 2013).

Table 2a: Water quality variations among select streams across monsoon season

S.No.	*Parameters*		*Monsoon*								
			YK	*YNK*	*BGT*	*BE*	*AGT2*	*AG*	*AGT1*	*MH*	*HA*
1	*Water Temperature*	Avg.	25.2	25.5	27.5	26.8	27	27.5	26.9	25.7	27.4
		SD	0.91	0.60	1.56	0.78	1.43	0.93	1.51	2.20	1.66
2	*TDS*	Avg.	41.4	30.97	34.88	30.1	48.43	19.9	47.5	26.77	22.06
		SD	25.71	12.24	9.31	3.94	35.93	2.36	2.01	3.87	2.67
3	*EC*	Avg.	90.86	61.43	71.38	60.14	96.75	39.4	60.42	56.33	44.2
		SD	49.58	24.07	23.56	7.69	71.68	3.05	3.99	6.22	4.60
4	*pH*	Avg.	7.4	7.2	7.1	7	6.7	6.9	7.1	7.2	7.1
		SD	0.38	0.36	0.62	0.45	0.46	0.54	0.49	0.38	0.66
5	*Turbidity*	Avg.	7.64	51.45	19.26	13.92	35.65	6.67	11.25	35.92	45.66
		SD	1.01	21.86	7.85	5.02	17.82	4.36	6.06	29.50	32.17
6	*DO*	Avg.	6.77	6.77	6.34	6.25	5.89	6.23	6.6	6.17	6.28
		SD	2.09	1.80	1.54	1.86	1.29	2.89	2.11	1.72	2.24
7	*BOD*	Avg.	12.49	15.26	17.16	20.91	13.47	18.49	13.89	17.96	21.55
		SD	10.59	8.95	10.69	13.36	7.03	8.72	11.02	13.07	18.83
8	*COD*	Avg.	24.76	29.9	29.17	33.33	29.63	31.89	26.39	25.06	34.2
		SD	18.23	19.09	17.07	22.92	17.84	26.05	18.75	18.15	25.19
9	*Alkalinity*	Avg.	76.57	68.57	69	64.57	69.67	52	47.33	54.67	57.6
		SD	30.59	18.68	22.30	23.49	21.47	23.32	16.48	9.69	12.84
10	*Chloride*	Avg.	17.65	16.03	17.99	18.87	17.45	17.61	15.86	17.51	18.74
		SD	3.83	3.35	2.92	4.54	2.48	2.15	1.66	2.93	0.64
11	*Total Hardness*	Avg.	44.29	26.57	30.5	28	33.5	15.2	21.33	22.33	22
		SD	28.15	9.00	8.26	8.08	8.05	1.10	5.47	2.94	8.00
12	*Calcium*	Avg.	11.56	5.5	6.71	5.5	7.82	2.89	3.74	4.54	4.97
		SD	8.17	2.33	1.86	1.99	2.00	0.44	1.94	1.31	3.56
13	*Magnesium*	Avg.	3.76	3.13	3.35	3.48	3.41	1.95	2.93	2.68	2.34
		SD	1.92	0.84	1.21	1.17	1.22	0.00	0.44	0.86	0.63
14	*OP*	Avg.	0.149	0.467	0.12	0.263	0.246	0.291	0.328	0.226	0.317
		SD	0.13	0.62	0.11	0.34	0.23	0.36	0.53	0.25	0.34
15	*Nitrate*	Avg.	0.184	0.186	0.148	0.172	0.191	0.127	0.156	0.183	0.209
		SD	0.05	0.09	0.05	0.09	0.06	0.04	0.06	0.12	0.24
16	*Sodium*	Avg.	7.2	8.73	7.75	9.87	9.98	9.14	10.62	9.17	9.7
		SD	2.26	3.87	2.71	1.79	1.35	1.96	1.21	2.44	2.84
17	*Potassium*	Avg.	0.829	0.9	0.888	0.886	1.038	1.04	1	0.85	1.18
		SD	0.60	0.59	0.89	0.85	1.23	0.94	0.69	1.01	1.00
18	*Discharge*	Avg.	75.1	117.2	111.4	28.5	94.1	43.7	98.2	49.1	358.4
		SD	68.74	119.32	100.17	27.98	95.62	45.19	104.48	45.43	412.19

Note: parameter units: 1-°C; 3- µS/cm; 5- NTU; 2, 6-17 mg/l; 18-mm/day

Table 2b: Water quality variations among select streams across post-monsoon and pre-monsoon seasons

S.No.	Parameters		Post-monsoon							Pre-monsoon				
			YK	*YNK*	*BGT*	*BE*	*AGT2*	*AGT1*	*MH*	*YK*	*YNK*	*BGT*	*AGT2*	*BE*
1	*Water Temperature*	Avg.	24.2	24.8	27.5	26.3	26.5	29.1	26.7	24.5	24.9	29.6	28.8	25.9
		SD	1.51	1.75	2.08	1.6	2.23	2.31	1.66	1.18	1.2	2.4	1.98	
2	*TDS*	Avg.	68.9	34.8	32.1	20.8	37	21.6	21.4	105	56.8	39.8	50.6	41
		SD	14	8.66	4.28	1.05	2.27	3.19	1.37	26.1	3.31	1.71	10.2	
3	*EC*	Avg.	134	65.4	62.4	39.9	70.9	42	40.9	194	108	76.5	96.2	70
		SD	28.6	13.2	6.2	5.65	5.37	7.84	4.24	59.9	12.3	4.51	17.3	
4	*pH*	Avg.	8.6	8.3	8.2	7.6	8.2	7.8	7.7	8	7.9	7.3	7.5	7.5
		SD	0.37	0.69	0.42	0.48	0.37	0.64	0.58	0.73	0.7	0.53	0.53	
5	*Turbidity*	Avg.	4.28	10.3	2.06	2.51	3.27	1.1	1.6	3.28	9.8	3.42	2.57	2.11
		SD	0.7	2.65	0.62	0.51	1.63	0.06	0.18	0.63	1.86	1.75	0.64	
6	*DO*	Avg.	7.31	7.47	6.98	6.13	7.26	6.62	5.98	6.84	6.91	5.59	5.45	6.5
		SD	0.9	1.09	0.68	0.85	1.01	0.61	1.04	0.79	0.68	0.21	1.2	
7	*BOD*	Avg.	11	12	10.6	12.6	11.3	10.3	6.98	16.1	14.9	20.8	14.6	32.5
		SD	3.61	4.79	5.69	6.28	6.64	5.5	4.37	5.68	4.2	2.56	2.22	
8	*COD*	Avg.	22.7	20.4	24.1	28	19.4	17.7	18.2	24.7	29.6	45	30.1	40
		SD	5.99	8.3	7.19	6.47	11.7	8.81	6.56	5.58	7.32	16	8.76	
9	*Alkalinity*	Avg.	107	80	79	66.5	76	54.9	53.1	146	80	84	75.2	44
		SD	20.5	13	16.8	12.8	7.41	11.5	6.41	33.6	8.39	24.2	3.35	
10	*Chloride*	Avg.	18.5	19.4	19.5	19	19.2	18.5	18.7	17.5	17.8	22.7	17	17
		SD	5.15	5.42	5.46	4.42	5.58	6.08	2.89	3.2	2.15	12.4	2.25	
11	*Total Hardness*	Avg.	75.3	38.5	34.8	23	39.8	18.9	22.3	113	46.7	37	42.4	24
		SD	14	4.5	2.6	2.83	1.67	1.95	4.23	32.4	7.97	1.15	5.55	
12	*Calcium*	Avg.	21.4	9.32	8.52	5.11	9.72	4.01	4.81	31.7	11.8	7.82	9.62	4.01
		SD	4.96	2.26	1.13	1.13	1.31	1.13	1.46	10.3	2.76	1.21	0.98	
13	*Magnesium*	Avg.	5.3	3.72	3.29	2.5	3.78	2.16	2.51	8.36	4.22	4.27	4.48	3.41
		SD	0.61	1.07	0.73	0.31	0.73	0.74	0.66	2.33	1.59	0.83	1.17	
14	*OP*	Avg.	0.18	0.18	0.13	0.17	0.21	0.1	0.21	0.27	0.39	0.26	0.2	0.2
		SD	0.25	0.22	0.13	0.27	0.32	0.12	0.42	0.1	0.28	0.14	0.08	
15	*Nitrate*	Avg.	0.19	0.2	0.18	0.16	0.18	0.16	0.13	0.17	0.2	0.15	0.18	0.22
		SD	0.06	0.08	0.05	0.05	0.06	0.06	0.04	0.06	0.11	0.08	0.1	
16	*Sodium*	Avg.	9.06	11.9	19.8	8.78	11.2	10.6	10	9.55	13.5	8	10.8	9.1
		SD	4.21	3.94	1.93	3.95	2.22	4.89	5.98	1.88	2.01	1.12	5.35	
17	*Potassium*	Avg.	0.45	0.8	0.83	0.73	0.95	0.91	0.73	0.78	0.95	0.88	1.04	0.6
		SD	0.45	0.52	0.5	0.36	0.51	0.48	0.65	0.31	0.39	0.61	0.54	
18	*Discharge*	Avg.	6.6	3.6	1.4	1.6	1.7	1.4	1.6	0.6	0.8	0.1	0.1	0.0
		SD	5.47	2.76	1.19	1.24	2.01	1.27	1.65	0.42	0.54	0.1	0.09	

Note: Parameter units of: 1-°C; 3- µS/cm; 5- NTU; 2, 6-17 mg/l; 18-mm/day

RESULTS AND DISCUSSION

Stream water is being used for domestic purposes, irrigation, recreation, etc. Mapping and monitoring of water quality would help in maintaining the quality and sustainable management of the ecosystem. Water sampling was done at stations depending on the water availability in streams. Some streams are perennial like YK, YNK, BGT, BE1 and AGT2. AG1 and HA1 dries up in post monsoon season whereas, AG1, AGT1, MH1 and HA1 dries up during pre-monsoon. Variability in the physico-chemical parameters of streams monsoon, pre-monsoon and post-monsoon seasons are presented in Figure 2. Tables 2a and 2b lists water quality across sampling locations for monsoon and post-monsoon seasons respectively.

All ion values were very high in all seasons at Yaana in comparison to other streams due to anthropogenic stress. Yaana is a popular eco-tourist place visited by large number of pilgrims every day, and due to mismanagement of solid and liquid waste the stream is polluted. Turbidity ranges from 1.1 – 51.45 NTU and is very high in monsoon due to silt transport during runoff. pH which measures the alkalinity and acidity of water and influences chemical reactions in water bodies. pH in the sampled streams ranges from 6.7 – 8.6 and values are higher in post-monsoon and low during monsoon due to the presence of organic matter.

Dissolved oxygen in streams fluctuates due to movement/mixing of water, organic pollutants, photosynthetic and respiratory activities by flora and fauna in aquatic ecosystems. DO ranges from 5.45 – 16.26 mg/L and higher values during monsoon due to rapid water discharge with the aeration of water. COD ranges from 50.6 -17.71 mg/l and BOD ranges from 33.33 – 6.98 mg/l and higher BOD and COD values reflect the presence of organic matter. For unpolluted to moderately polluted water, BOD_5 values ranges between >1.0 to <10.0 mg/l (Salman et al. 2013). Turbidity, orthophosphate, BOD and COD were very high in monsoon due to inflow of suspended matter and organic compounds into streams with the catchment run off. TDS and EC are very high in pre-monsoon season, but very low in monsoon. TDS ranges from 104.67 – 19.9 mg/l whereas EC ranges from 194.33 – 39.4 µS. Variations in electrical conductivity are brought about by the inorganic dissolved solids such as chloride, calcium, magnesium, aluminium, nitrate, sulphate, sodium and iron. Organic compounds such as oil, phenol, alcohol and sugar are bad conductors and thus, affect the electrical conductivity (Gandaseca et al. 2011; Al-Badaii et al. 2013). The water discharge is very high at HA1 during monsoon (358.4 mm/day). In pre-monsoon season, water temperature, total alkalinity, chloride, total hardness, calcium and magnesium were very high because of very less water level and high evaporation rate. But, ion contents like chloride, total hardness, calcium and magnesium and nitrate were very low in monsoon season because of dilution effect.

Turbidity and ortho-phosphate were present in all sampling stations due to the entry of enormous quantity of rain water from the catchment during monsoon (Table 2a). The ion contents (TDS, EC, chloride, total hardness, calcium, magnesium and sodium), pH, total alkalinity were less due to the dilution with precipitation. Similar study reports of increased suspended solids, turbidity and COD during monsoon as the rivers received silt and debris from the catchments, which lowered the ionic contents due to the dilution (Rani et al. 2011). Large amount of phosphates entered the stream in rainy season from surrounding catchment areas dominated by rocks (Singh et al. 2013).

During post-monsoon season (Table 2b), high pH and DO prevailed due to increased algal photosynthesis. The turbidity had decreased due to low discharge while organic matter and nutrient levels (COD, ortho-phosphate, nitrate, potassium and BOD) decreased due to enhanced algal uptake and microbial activity. The water temperature in post-monsoon appeared to be suitable for the phytoplankton growth and reproduction (Nassar et al. 2014). Higher chloride levels in post-monsoon season was due to reduction in water levels and concentration of salts with the enhanced evaporative losses at higher temperatures (Shetty et al. 2013). The DO level depended on all the abiotic and biotic factors (Hacioglu and Dulger 2009) evident from higher DO levels with turbulence and lowered DO during higher organic content with escalated decomposition rates. Similarly, DO vary with temperature (Arslan 2009).

The sampling sites had high ionic (TDS, EC, total hardness, calcium, magnesium, sodium) and organic content (COD and BOD) but low DO and water discharge during pre-monsoon peri-

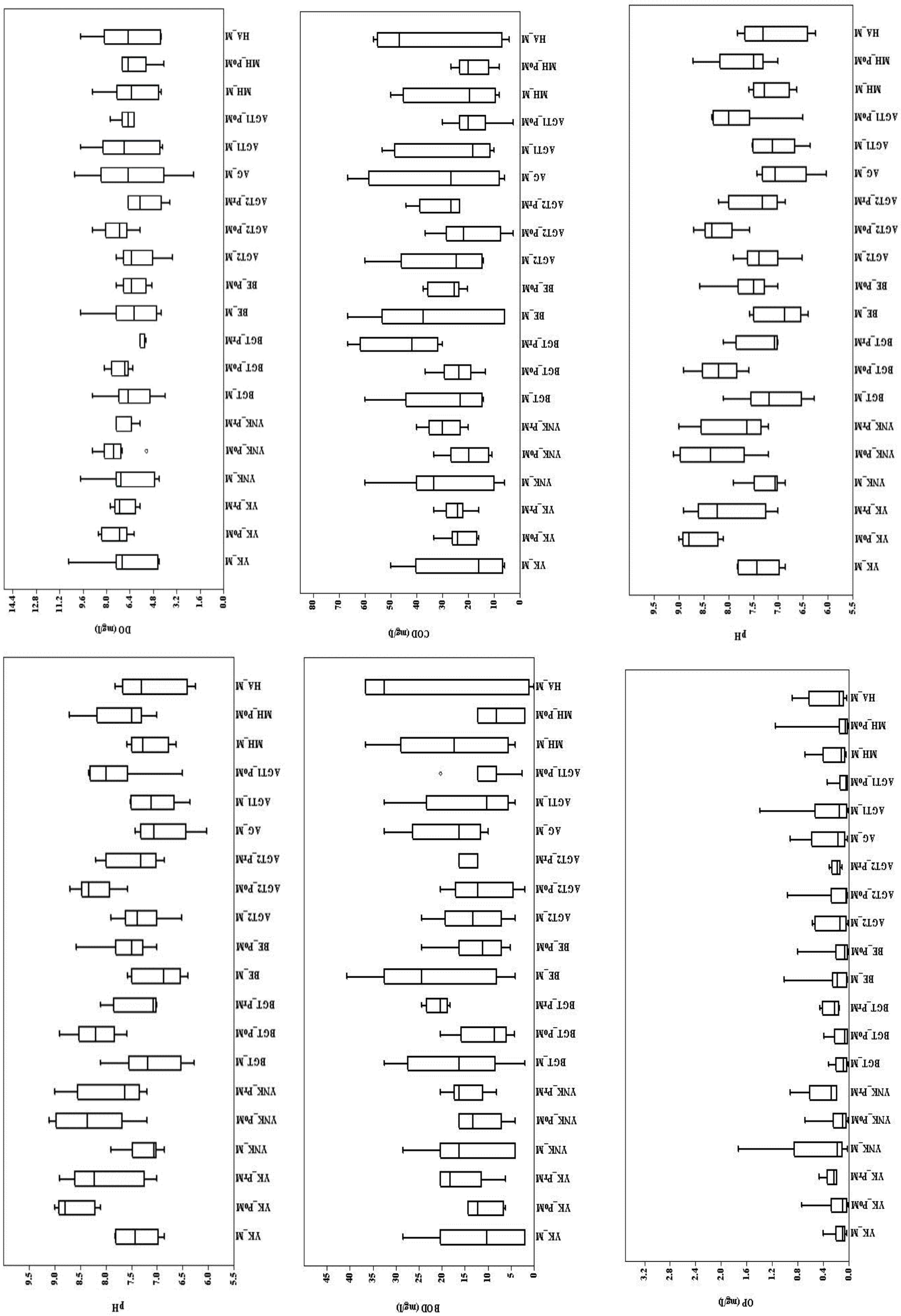


Fig. 2. Variations in water quality among 9 select streams in monsoon, post-monsoon and pre-monsoon seasons

od (Table 2b). Chandrabhaga River, Maharashtra had maximum BOD of 31mg/l in summer and minimum BOD recorded was 9.9 mg/l in winter (Watkar and Barbate 2015). During pre-monsoon season, YK was found to have high pH and ion contents such as TDS, EC, total alkalinity, total hardness, calcium and magnesium. Turbidity, orthophosphate, sodium, water discharge and DO were higher in YNK. COD, water temperature and chloride were higher in BGT. Temperature and precipitation influences the discharge pattern in rivers (Kriauciuniene et al. 2012). Variations in temperature alter the physico-chemical properties of water and accelerate various chemical reactions as well as metabolic activities. BOD and nitrate are higher in BE1. The amount of nitrates in water increases due to heavy rainfall, land drainage, oxidation of ammonia (Vankar et al. 2018); and the agricultural activities which makes use of huge amount of chemical fertilizers and animal farming (Dunca 2018).

Principal Component Analysis (PCA)

In order to prioritize the factors affecting water quality of the sampled streams, PCA was performed on data for monsoon, pre-monsoon and post-monsoon seasons. PCA of 18 physico-chemical variables pertaining to water samples from 9 different sampling points (during April, 2014 to March, 2016) helped in understanding the main decisive factors of stream water quality across seasons. PCs chosen based on Eigen values (of 1.0 or greater are considered significant), which explained maximum variance of experimental dataset (Fig. 3) and are grouped as "strong" (>0.75), "moderate" (0.75 - 0.50) and "weak" (0.50 - 0.30), according to the loading values (Liu et al. 2003).

Here, the first PC corresponds to the higher eigenvalue (10.76), accounting for 59.79 percent of the variance with strong positive loading (>0.75) on pH, calcium, magnesium, ortho-phosphate, nitrate, potassium, DO and discharge, whereas high negative loadings on WT, EC and total alkalinity during monsoon (Fig. 3a). PC 2 corresponding to the second eigenvalue (4.12) accounted for 22.87 percent, contributed by BOD. PC 2 showed moderate positive loading (>0.50) on Water temperature, COD, chloride, BOD and sodium. The third factor corresponding to the third eigenvalue (1.68) accounted for about 9.32 percent showed high positive loadings on turbidity.

During post-monsoon (Fig. 3b), PC 1 explained seventy-five percent of the total variance (eigenvalue of 13.50) and showed strong positive loading (>0.75) on TDS, EC, total hardness, calcium, magnesium, ortho-phosphate, nitrate, potassium and water discharge, whereas high negative loadings on water temperature, pH, COD, total alkalinity, chloride and DO. PC 1 showed moderate positive loadings (>0.50) on sodium, BOD and DO. PC 2 corresponding to the second eigenvalue (1.66) accounted for 9.21 percent of the total variance, showed moderate negative loading on turbidity. PC 3 (eigenvalue of 1.39) accounted for 7.73 percent of the total variance showed moderate positive loading (>0.50) on sodium.

During pre-monsoon (Fig. 3c), the first PC explained 63.45 percent of the total variance (eigenvalue of 11.42) and was best represented by turbidity, total hardness, calcium, magnesium, ortho-phosphate, nitrate, potassium and discharge. PC 1 showed strong negative loadings on WT, COD, chloride and BOD and moderate positive loading on DO. PC 2 corresponding to the second eigenvalue (4.47) accounted for 24.83 percent of the total variance was loaded by TDS, EC and pH. The third factor corresponding to the second eigenvalue (1.47) accounted for approximately 8.17 percent of the total variance showed moderate positive loading on sodium and turbidity.

Thus, PCA revealed, the parameters like EC, TDS, ortho-phosphate, nitrate, total hardness, calcium, magnesium, potassium and water discharge played an important role in these sampling sites. These variations are due to varied land uses in the catchments of lotic ecosystems – Yaana (YK), and Nanalli (YNK) has evergreen forest whereas Beilangi (BE) has mixed type of forest. The other sampling sites like Harita (HA), Mastihalla (MH), Aanegundi (AG), Aanegundi tributary 1 (AGT1), Aanegundi tributary 2 (AGT2) and Bialgadde (BGT) have mixed land use dominated by horticulture and agriculture activities. Landscape alterations in catchment due to the anthropogenic factors changes the quantity (stream flow) and quality of streams (Petersen et al. 2017). Water discharge played an important role in the present study. The marked difference in seasonal variations in river discharge and concentration of pollutants is due

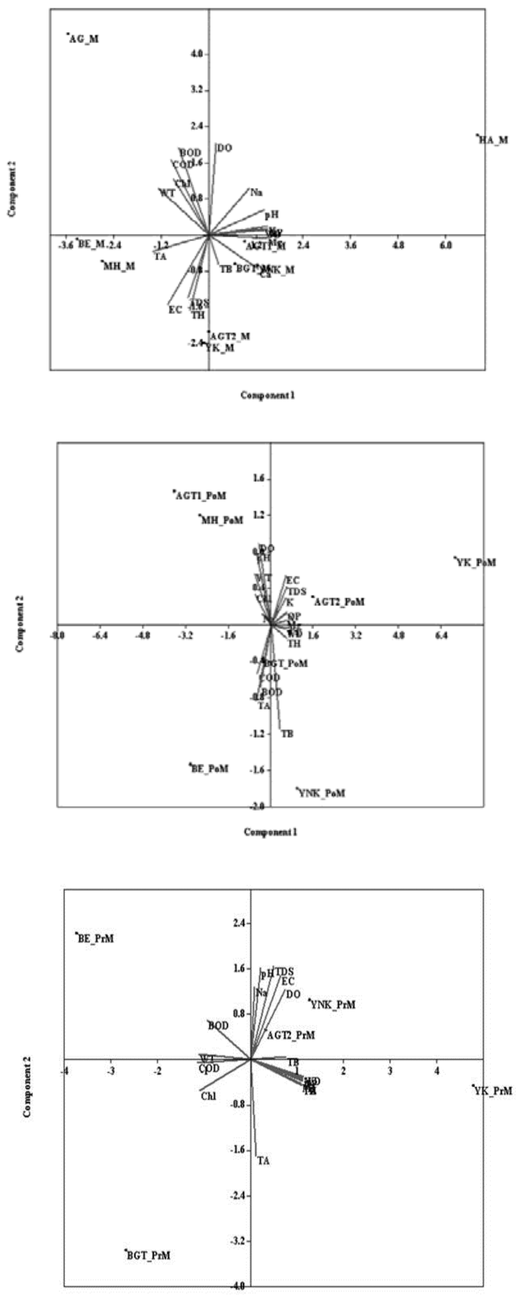
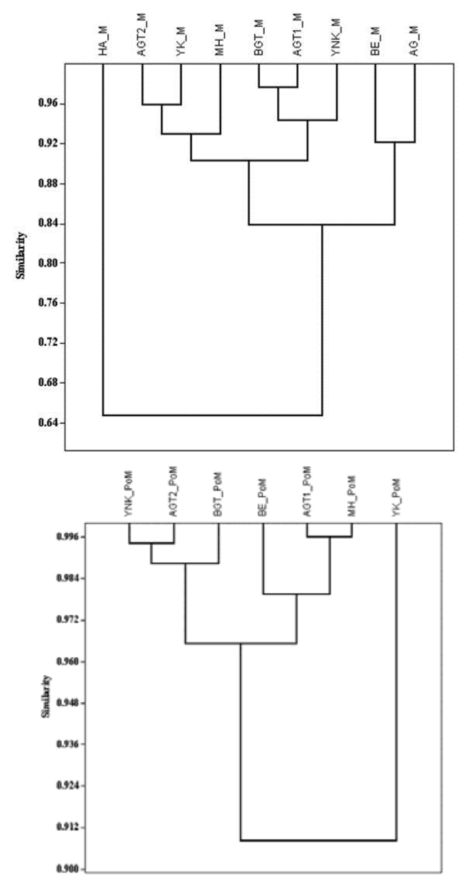


Fig. 3. Principal component analysis for physico-chemical parameters of different streams in Aghanashini river basin of Central Western Ghats during a) monsoon, (b) post-monsoon and (c) pre-monsoon seasons
Source: Author

to variations in precipitation, surface run-off, interflow, groundwater flow etc. (Singh et al. 2004).

Cluster Analysis

Cluster analysis of physico-chemical parameters of different streams in Aghanashini river basin showed varied patterns during monsoon, post-monsoon and pre-monsoon seasons (Fig. 4). Four clusters were evident based on water quality parameters of monsoon (Fig. 4a). Harita has high water temperature, turbidity, COD, orthophosphate, nitrate, sodium, potassium, BOD and water discharge. AGT2, YK and Mastihalla had high ionic contents as evident in levels of TDS, EC, total alkalinity, total hardness, calcium and magnesium. BGT, AGT1 and YNK had high total hardness, DO and alkaline pH. Beilangi and AG had high chloride but comparatively low pH,



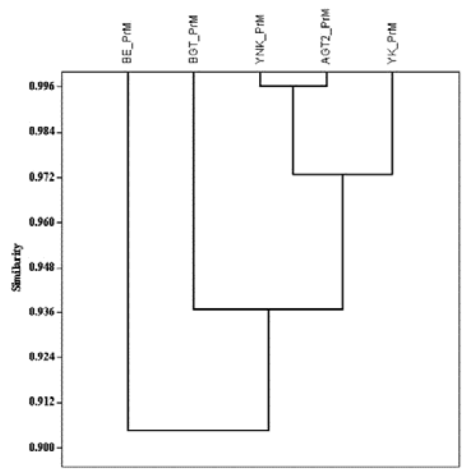


Fig. 4. Cluster analysis of physico-chemical parameters of different streams in Aghanashini river basin of Central Western Ghats during a) monsoon season, (b) post-monsoon and (c) pre-monsoon season.
Source: Author

ABBREVIATIONS
WT: Water Temperature (°C); TDS: Total Dissolved Solid (mg/l); EC: Electrical Conductivity (µS/cm); TB: Turbidity (NTU); DO: Dissolved Oxygen (mg/l); BOD: Biochemical Oxygen Demand (mg/l); COD: Chemical Oxygen Demand (mg/l); TA: Total Alkalinity (mg/l); Chl: Chloride (mg/l); TH: Total Hardness (mg/l); Ca: Calcium (mg/l); Mg: Magnesium (mg/l); OP: Orthophosphate (mg/l); N: Nitrate-nitrogen (mg/l); Na: Sodium (mg/l); K: Potassium (mg/l); WD: Water Discharge (mm/day).

turbidity, calcium, total hardness, nitrate, DO and water discharge. Among all the stations, Harita had highest discharge in monsoon season which had influenced the water quality.

Figure 4b illustrates of the three clusters during post-monsoon. YK reveals of disturbance with high TDS, pH, EC, COD, total alkalinity, total hardness, magnesium, ortho-phosphate, nitrate, DO and water discharge but low water temperature, chloride, sodium and potassium. BE, AGT1 and Mastihalla had high water temperature but low water discharge, ionic, organic and nutrient levels. YNK, AGT2 and BGT had high turbidity, chloride, sodium, potassium and BOD. During pre-monsoon, about four clusters are evident in Figure 4c. BE had high nitrate and BOD but low ionic contents, ortho-phosphate and discharge. BGT had high water temperature, COD and chloride. YNK and AGT2 had high turbidity, ortho-phosphate, sodium and potassium. YK had high TDS, EC total alkalinity, pH, DO, total hardness, magnesium and calcium. Yaana is famous for two rocky outgrowth of solid black, crystalline karst limestone. This is evident from the sampled water at Yaana with high ion contents and pH due to the influence of calcium carbonate. All stations showed wide seasonal variations in all the physico-chemical parameters mainly due to variations in discharge. Climate, watershed characteristics and forest cover also play a decisive role in quality and quantity of water in a forested watershed (Gokbulak et al. 2017).

CONCLUSION

Monitoring of lotic ecosystem through the analyses of physico-chemical parameters in the streams of the Aghanashini river basin in the Central Western Ghats revealed that water discharge played an important role evident from TDS, EC, total hardness, calcium, magnesium, ortho-phosphate, nitrate, potassium, etc. Higher ion concentrations at Yaana are due to anthropogenic influences due to influx of tourists. Water discharge plays an important role in lotic ecosystems as per PCA and Cluster analysis. Water discharge is highest in Harita compared to other sampling stations due to catchment run off that also brought in suspended matter (turbidity), nutrients (orthophosphate and nitrate) and organic contents (COD and BOD). Climate, season, types of forest, rocks, soil, land use like agriculture and horticulture fields have influenced the quality of water in streams. This necessitates an understanding of hydro-morphological with chemical characteristics for sustainable management of lotic ecosystems.

RECOMMENDATIONS

The following measures have to be adopted to protect the lotic ecosystems in central Western Ghats: (i) avoid littering of wastes near water bodies, (ii) restrictions on letting untreated sewage and industrial effluents, (iii) adoption of constructed wetlands to prevent agricultural runoff with high nutrient loads, (iv) conservation of sacred groves and native forest ecosystems to enhance the water retention capability of the catchment and to avert scarcity of water quantity and quality, (v) planting native species in the catchment to enhance water infiltrations, (vi) restrictions on large scale monoculture plantations in the catchment, (vi) protection of the shoreline and riparian vegetation zone, (vii) evolve sustainable management strategies to mitigate pollution due to tourism, (viii) restriction on the use of fertilizers in agriculture and horticulture fields, (ix) restriction on the diversion of streams that alters natural flow impacting downstream biota and people's livelihood, etc.

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