ISSN: 0973-4929, Vol. 15, No. (1) 2020, Pg. 11-23

Current World Environment

www.cwejournal.org

Water Quality Assessment using Environmetrics and Pollution Indices in A Tropical River, Kerala, SW Coast of India

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Abstract

Envirometrics and pollution indices are proxies to assess water quality of a wetland ecosystem. Hence, the present study is focused on establishing water quality and elucidating the pollution status of Karamana River (KR) in Kerala, SW coast of India. The Karamana River Basin – KRB (n=6th; L= 68 km, A=695 km^2), is the main source of water for domestic and drinking purpose in Thiruvananthapuram city. The Killi River (n= 5th; L= 24 km, A= 102 km^2), the largest tributary of KR, carry heavy load of pollutants mainly from city and joins KR towards its downstream side. For this study, about 12 sampling stations were selected along the KR from upstream to downstream (interval= ~3km), and water samples (n=12x2= 24) were collected during non-monsoon (NON) and monsoon (MON) of 2015 to assess the variability and sourcing of key hydrochemical variables. Environmetric methods, viz., Pearson Correlation and Principal Component Analysis (PCA) were applied for apportionment of pollution sources significantly responsible for the surface water quality. It was found that sewage effluents and seawater intrusion were the primary factors deteriorating water quality in downstream. Further, the results of water quality analyses and Pollution Indices, viz., Organic Pollution Index (OPI), Eutrophication Index (EI) and Comprehensive Pollution Index (CPI) indicate that lower reaches (L= ~4 km) of KR is seriously polluted. A distinct Zone of Pollution Influence (ZPI) has been delineated based on the indices and this attempt is first of its kind in KR. The present study provides several noteworthy contributions to the existing knowledge on the factors influencing surface water quality and serves as a baseline data for watershed managers and administrators.

Article History

Received: 12 January 2020
Accepted: 15 March 2020

Keywords

Comprehensive Pollution Index;
Environmetrics;
Eutrophication Index;
Organic Pollution Index;
Pollution Sources;
Water Quality.

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Doi: http://dx.doi.org/10.12944/CWE.15.1.04

Introduction

Over the years, rivers are progressively subjected to environmental stress caused by human intervention.[1] Water quality of a river is being carved up by several interrelated factors, which are subjected local and temporal variations in addition to discharge.[2] As a result of increased anthropogenic pressure including pollution, large-scale damming, sand mining etc., the natural self purification capacity of rivers becomes restricted to a minimal level.[3] Excessive loading of nutrients into the riverine environment in the form of eutrophication turns out to be a threat to human health as well as other biota in freshwater ecosystem.[28, 29] Consequently, understanding the extent of water quality degradation and sources of pollution is important for an effective management of water resources.

Conventional techniques of descriptive analysis to interpret river water quality have several limitations[4] of not detecting correlation between variables and poor delineation in the pollution source apportionments influencing the quality status. The use of environmetric techniques has potentialities to surpass these limitations.

Environmetrics are Multivariate statistical techniques applied in environmental problems. Application of environmetrics, i.e., multivariate statistical techniques, is an important tool for environmental decision making in water quality problems.4 Correlation Analysis and Principal Component Analysis (PA) have been applied successfully in scrutinizing latent factors and mechanisms influencing water quality worldwide.[5,6,7,8,9,10,11]

Further, pollution indices provide supplementary information on water quality in a single value by comparing different variables as per the standards. A plethora of various water quality indices is available in literature[12] and based on the purpose of assessment, water quality indices were formulated worldwide viz., Harkins Index,[13] Horton Quality Index,[14] Water Quality Index,[15] Agricultural Water Quality Index[16] etc. Again, to assess the grade of pollution, certain specific pollution indices, viz., Carlson's Trophic State Index,[17] Organic Pollution Index,[18] Comprehensive Pollution Index,[19] Eutrophication Index[20] have been commonly applied in numerous studies.[21,22,23,24,25]

Karamana River (KR) is the main resource to meet the domestic and drinking purpose of Thiruvananthapuram city. This tropical river is suffering from invariable pressure of fast growing urbanization analogous to other overpopulated river basins globally[26,27,28] and the available data on water quality of this river is very sparse. Hence, monitoring the water quality of this river is very relevant in the current scenario. It is against this backdrop, the present study was carried out to provide an overview of pollution status and its underlying sources in KR using environmetric techniques viz., Pearson Correlation analysis and Principal Component Analysis coupled with pollution indices viz., Organic Pollution Index (OPI), Eutrophication Index (EI) and Comprehensive Pollution Index (CPI).

Study Area

The Karamana river basin, KRB (n= 6^{th}; L= 68 km; A = 702 km^2), is one of the prominent river basins in southern Kerala, SW India. The basin lies between latitudes 8°27'36"N to 8°38'24"N and longitudes 76°54'0" to 77°15'0"E. The Karamana river (KR) originates from Chemmunji Motta and Aathiramala peaks of Western Ghats, and flows westward and debouch into the Arabian sea at Poonthura (estuary), SW of Thiruvananthapuram. The Killiyar (n= 5^{th}; L= 24 km, A= 102 km^2) merges with KR ~3 km upstream of Poonthura estuary (Fig.1). TS canal (Parvathy Puthanar Canal), running parallel to the coast with untreated sewage effluents rushes in, further pollutes the lower reaches of KR. The average annual stream flow of KR is calculated to be 836Mm.[3.30]

Methodology

The sampling was carried out during non monsoon-NON (March) and monsoon-MON (June) seasons in 2015. A total of 12 sampling stations were identified from upstream to downstream (interval = 3 km) and physico-chemical parameters were analyzed using standard procedures.[31,32]

Correlation and factor analyses were done using SPSS 17 software. The Spearman correlation was calculated by applying the Pearson correlation formula to the ranks of the data.

Pearson's correlation analysis (r) is a measure of the extent to which two quantitative variables are linearly related. It summarizes the magnitude of a linear relationship between pairs of variables. The value of relationship takes values ranging from -1 to +1, where +1 represents an absolute perfect positive linear relationship, 0 represents no linear relationship, whereas -1 represents an absolute inverse relationship between the bivariates. The sign in front of the correlation coefficient value determines the direction of the relationship. A plus sign denotes a positive relationship and a minus sign denotes negative correlation. The correlation (r) provides a standardized measure of the linear association between two variables, as given in Eq.1.

$$r=\frac{\sum_{i=1}^{n}(xi-\bar{x})(y-\bar{y})}{(n-1)_{SxSy}}$$

where x and y are the bivariates to be correlated and Sx and Sy are the sample standard deviations of variables x and y, respectively.

PCA reduces a relatively large number of variables into a smaller set of variables that still captures the same information.[33] PCA is about extracting a set of independent linear combination of parameters of the study so as to capture the maximum amount of variability of a given dataset. PCA can be calculated using Eq.2.

Fij+fjlzi1+fj2zi2+...fjmzm+eij

Where j is the measured variable, f is the factor loading, z is the factor score, e is the residual term accounting for errors, i is the sample number, and m is the total number of factors.

Varimax rotation method was applied in factor analysis by rotating the axis defined by PCA according to well-established rules to find a simple structure of datasets. By this method, variables are obtained in which original variables are demonstrated more clearly[33] thus by achieving a simpler and meaningful representation of the underlying factors.[34]

Table 1: Portrait of sampling stations with salient features

Sample ID	Sampling stations	Latitude and Longitude	Remarks
S1	Aryanad Bridge	N 08°34’37.8”, E 77°05’12.6”	Thick riparian vegetation
S2	Uzhamalakkal	N 08°35’12.4”, E 77°03’48.1”	Rubber plantation
S3	Koovakudi Bridge	N 08°34’26.1”, E 77°02’14.8”	Rubber plantation, upstream of dam
S4	Aruvikkara Dam	N 08°34’14.8”, E 77°01’17.3”	Agriculture, dam, tourism
S5	Irumba	N 08°33’47.1”, E 77°00’15.6”	Illegal sand mining
S6	Vellaikkadavu	N 08°31’51.6”, E 77°00’44.9”	Agriculture, sewage discharge, sand mining
S7	Kundamankadavu Bridge	N 08°30’57.2”, E 77°00’03.4”	Waste dumping visible, sand mining
S8	Karamana Bridge	N 08°28’39.3”, E 76°58’12.4”	Automobile effluents, less flow of river, thickly populated banks
S9	Madhupalam	N 08°27’48.0”, E 76°57’28.0”	Fish kill visible, river velocity very less
S10	Kalladimukham	N 08°27’11.9”, E 76°57’36.2”	Killiyar confluences with Karamana river
S11	Thiruvallam	N 08°26’25.0”, E 76°57’16.0”	Parvathi Puthanar Canal confluences with Karamana river, Faecal contamination, velocity very low.
S12	Poonthura	N 08°25’35.0”, E 76°57’32.1”	Estuary, Tourism activities

Further, to evaluate pollution status of the river, the Organic Pollution Index (OPI), Eutrophication Index (EI) and Comprehensive Pollution Index (CPI) were calculated.

Organic Pollution Index (OPI) was calculated by involving the values of four parameters, viz., Chemical Oxygen Demand (COD), Dissolved Inorganic Nitrogen (DIN), Dissolved Inorganic Phosphorus (DIP) and Dissolved Oxygen (DO).[18]

Organic Pollution Index (OPI) = COD/CODs + DIN/DINs + DIP/DIPs + DO/DOs

OPI<0: Excellent; 0-1: Good; 1-2: Begin to be contaminated; 2-3: Lightly polluted; 3-4: Moderately polluted; 4-5: Heavily polluted.[18] CODs, DINs, DIPs and DOs are the standard concentrations as defined in BIS and WHO.

Eutrophication Index (EI) was used for evaluating the trophic condition of water body.

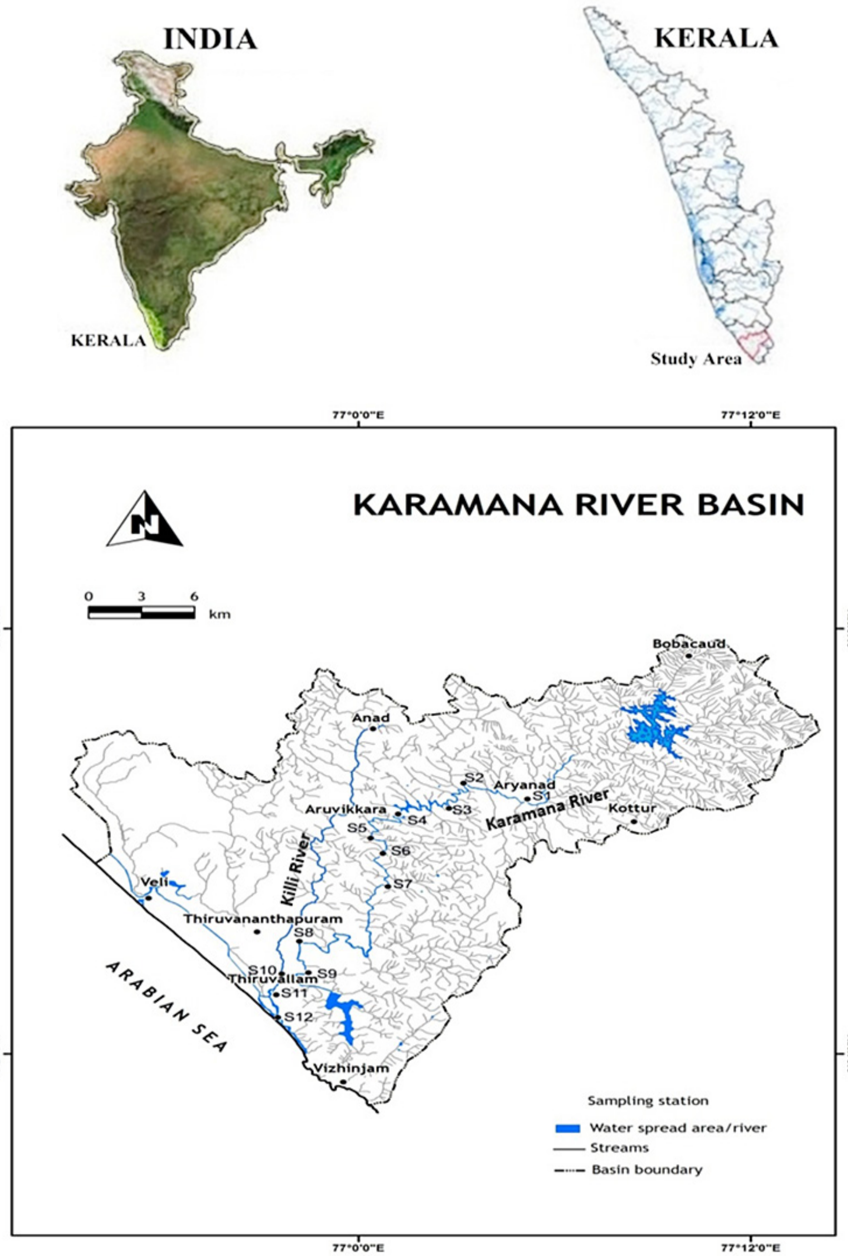

Fig.1: Location map of the study area

Eutrophication Index (EI) = (COD×DIP×DIN)/4500,

Where, the units of COD, DIN and DIP are mg/L. EI>1: Eutrophication; EI<1: No Eutrophication.[20]

Comprehensive Pollution Index (CPI) was calculated based on the assessment of single factor index and combined effect of all factors evaluated. CPI is used for evaluating pollution degrees of the water body in various locations.

Comprehensive Pollution Index (CPI)

$$= \frac{1}{n}\sum_{i=1}^{n} PI$$

Pollution Index (PI) = (Measured concentration of individual parameter)/(Standard permissible concentration of parameter)

CPI<0.8: Qualified; 0.8-1: Basically quantified; 1-2: Polluted, CPI>2: Seriously polluted.[19]

Table 2: Physico-chemical parameters of Karamana River, Non-monsoon

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	Mean
Temp (°C)	30.1	30.4	30.2	29.3	30.2	30.4	31.6	32.3	32.6	32.3	32.8	33	31.3
pH	6.5	6.2	6.3	7.31	7.2	7.42	7.29	7.32	7.53	7.7	7.86	7.96	7.2
DO (mg/L)	7.6	7.3	6.8	6.6	6	6.7	6.2	5.8	3.6	1.1	0.2	0.8	4.9
BOD (mg/L)	0.6	0.8	1.1	2.4	2.9	3.8	3.6	7.3	12.8	46.2	52.3	48.2	15.2
COD (mg/L)	4.1	5.9	6.3	14.3	11.2	18.7	21.2	26	47	88.2	127.8	119.1	40.8
TH (mg/L)	14	30	14	19	24	50	62	88	127	153	182	221	82
Ca (mg/L)	8.8	20.2	12.2	16.2	18.3	43.4	54	73.5	109	130.2	154.3	190	69.2
Mg (mg/L)	0.85	8.17	0.36	1.39	0.7	4.51	6.36	10.7	15.37	20.61	24.32	29.02	10.2
Na (mg/L)	1.4	1	1	0.9	1.2	1.4	52.1	163	221	824	1569	2530	447.2
K (mg/L)	0.5	0.4	0.6	0.6	1.4	2.2	1.1	5.6	7.8	16.2	38.6	78.3	12.8
Cl (mg/L)	12	19	28.3	34.5	78.9	112	219.83	290.74	336.84	758.1	912	1012.2	317.9
SO_4 (mg/L)	3.3	14	7.7	9.2	14.3	19.3	17.6	28.2	59.3	77.8	162.2	376.2	65.7
NO_3 (mg/L)	1.2	2.6	4.2	2.3	2.2	3.7	10.2	27	39	46.2	49	52	19.9
NO_2 (mg/L)	0.17	0.27	0.3	0.22	0.28	0.37	0.46	0.61	0.62	0.68	0.71	0.75	0.4
NH_3 (mg/L)	0.01	0.04	0.03	0.02	0.1	0.09	0.12	0.21	0.17	0.73	0.65	0.24	0.2
DIN (mg/L)	1.38	2.91	4.53	2.54	2.58	4.16	10.78	27.82	39.79	47.61	50.36	52.99	20.6
DIP (mg/L)	0.2	0.3	0.4	0.3	0.2	0.2	0.5	0.7	0.9	0.6	1.1	0.9	0.5

DO-Dissolved Oxygen, BOD-Biochemical Oxygen Demand, COD-Chemical Oxygen Demand, TH- Total Hardness, DIN-Dissolved Inorganic Nitrogen, DIP-Dissolved Inorganic Phosphorus

Results and Discussion

The results of surface water chemistry variables for Non Monsoon (NON) and Monsoon (MON) are summarized in Table 2 and 3. Spatio-temporally, pH ranged from slightly acidic to alkaline.

DO in KR were found to be less than the standard limit (6 mg/L)[35] in downstream during both seasons, which is due to the input from nutrient rich Killi river and TS Canal (Fig.1). BOD values exceeded the standard limit (2 mg/L)[35] from middle stream towards downstream (i.e., S6 to S12), which shows a strong signature of anthropogenic influence. The BOD signature reflects high loading of organic compounds enhancing microbial growth, thus by reducing the level of DO in the water. The Cl level also showed an increasing trend from station 8 downwards, exceeding permissible limit (250 mg/L)[35] for both seasons which shows marine influence. NO_3 also exceeded the standard limit (45 mg/L)[35] in the last three stations (S10-S12) in the downstream during both seasons (Table 2 and 3) which may be due to sewage input. The overall water quality was good in the upstream and middle stream stretches (S1 to S6); whereas it declined from middle stream (S7) and poor towards downstream, especially the last 4 km stretch of the lower reaches.

The general cation trend during NON was $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ (Mean=447.17, 69.17, 12.77 and 10.20 mg/L respectively) and $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ (203.6, 59.85, 8.57 and 4.42 mg/L respectively) during MON. However, the anion trend during NON and MON followed the same order as $Cl^- > SO_4^- > NO_3^- > PO_4^- > NO_2^-$ (NON mean=317.87, 65.75, 19.97, 0.52, 0.45 mg/L respectively; MON mean=213.88, 36.12, 21.06, 0.93 and 0.62 mg/L respectively).

From the study, it is evident that most of the attributes like TH, Ca, Mg, Na, K, Cl, NO_3, NO_2, SO_4, BOD and COD exhibited an increasing trend from upstream downwards for both seasons. While, other variables like temperature, NH_3 and DIP (Fig. 2) showed an erratic trend, the DO showed a declining trend from upstream to downstream for both seasons (Fig.2).

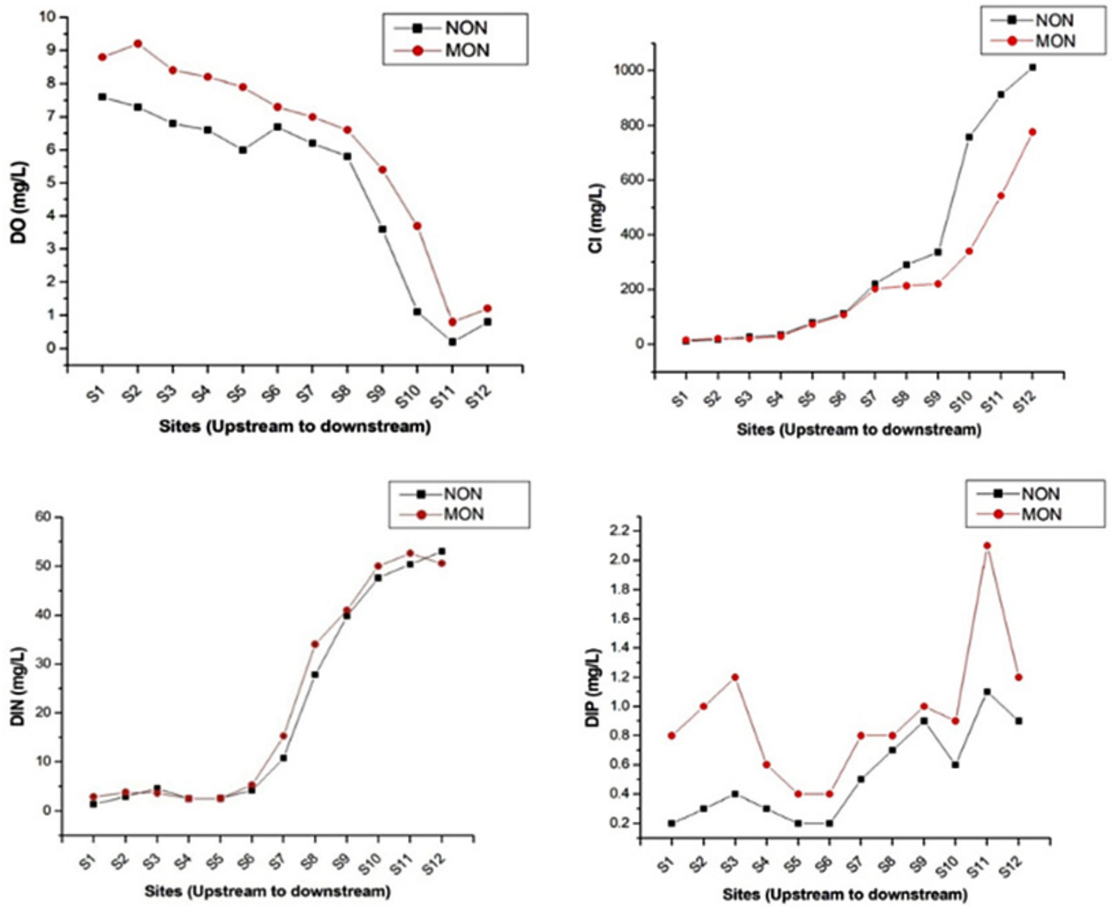

Fig. 2: Spatio-temporal variation of DO, Cl, DIN and DIP from upstream to downstream.

Environmetrics

Environmetrics, also known as multivariate statistical analysing techniques, viz.,Correlation and Principal Component analyses were carried out to identify the factors influencing water quality of KR.

Correlation Analysis

Pearson correlation was examined among the major ions and other physical parameters measured.

During NON, the SO_4 showed weak correlation (0.408) and insignificant ($p >> 0.05$) correlation with NH_3, significant ($p < 0.05$) and moderate correlation ($r \geq 0.60$ to < 0.80) with NO_3, DIN and DIP, which suggests that the source of these nutrients might be wastewater effluents discharged into the river, as leaching is not favoured during this dry period. Ca revealed strong significant relationship with Mg, Na, SO_4 and Cl, which is an indication of seawater intrusion. During MON, the DO and DIN were significantly associated with strong negative correlation (-0.920), and DIN due to a permutation of both anthropogenic as well as atmospheric inputs. NH3 was in moderate correlation (0.643) and insignificant ($p>>0.05$). As Mg significantly ($p<0.05$) and strongly ($r\geq0.80$) correlated with Na, K and Cl, while K was found to be correlated with Cl and SO_4, all implies that the origin of these nutrients are most likely to be the same and the source might be that of leaching. Moderate correlation of SO_4 with NO_3, NO_2 and DIP indicates mixing of nutrient rich sewage with freshwater.

Principal Component Analysis (PCA)

The results of PCA during NON and MON are shown in Table 4 and 5.

Table 4: Principal component matrix for KR, Non monsoon

Rotated Component Matrix[a]			
Parameters	Components		
	1	2	3
Temp	.868	.328	.325
DIP	.826	.367	.304
NO_2	.805	.363	.440
NO_3	.720	.448	.512
DIN	.719	.444	.517
Ca	.657	.590	.462
TH	.655	.590	.466
Mg	.626	.594	.465
SO_4	.355	.917	.173
K	.336	.913	.223
Na	.346	.865	.356
Cl	.516	.625	.581
COD	.472	.623	.612
NH_3	.386	.127	.902
BOD	.389	.585	.706
DO	-.519	-.518	-.664
pH	.493	.372	.516
Eigen Value	14.63	1.09	.61
% of variance	86.04	6.40	3.57

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Table 5: Principal component matrix for KR, Monsoon

Rotated Component Matrix[a]			
Parameters	Component		
	1	2	3
NH_3	.928	.265	.045
Na	.879	.319	.310
BOD	.829	.391	.347
K	.825	.492	.231
SO_4	.804	.469	.350
COD	.784	.473	.377
Cl	.776	.518	.299
DO	-.725	-.556	-.373
Ca	.710	.636	.280
TH	.700	.638	.290
Mg	.598	.578	.375
NO_2	.290	.923	.149
pH	.590	.761	.029
NO_3	.508	.706	.438
DIN	.519	.704	.430
Temp	.064	.376	.888
DIP	.445	.002	.855
Eigen Value	14.03	1.23	0.93
% of Variance	85.51	7.24	5.47

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 4 iterations.

In order to determine the factors affecting hydrochemical regime of study area, Principal Component Analysis (PCA) was applied and the analysis during Non monsoon revealed three Principal Components (PCs) effective in explaining the variations in water quality (Table 4).

PC I during Non Monsoon explained 86.04% of total variance (Table 4) with high loadings for temperature, temperature, DIP and NO_2 showed strong positive loading (>0.750) whereas, factors such as NO_3, DIN, Ca, Mg, total hardness showed moderately positive loading (<0.750) which suggests that nitrification is affected by increase in water temperature,36 and adsorption of DIP into river sediments is increased water temperature conditions[37] during dry season. The NO_3, DIN, Ca, TH and Mg showed moderately positive loading, which suggests that NO_3 as the major source of DIN in KR. The combination of Ca, Mg and TH revealed that these parameters are influenced by a single source likely seawater intrusion. The results also indicated that there is a continuum mixing between nutrient-rich sewage effluent and seawater. PC II accounts for 6.40% of total variance (Table 4). SO_4, K and Na were found to have strong positive loading and this reflects weathering and saline water ingression. The sum of absolute contributions of parameters on PC III yields only 3.57%. Among those factors, NH_3 had the strongest loading (0.902), whereas BOD, DO and pH exhibited moderate loading, highlighting anthropogenic pollution. BOD and DO are in a moderate negative relationship.

Principal Component Analysis (PCA) during monsoon revealed three PCs effective in explaining the variations in the water quality, and these factors explained 95.56% of total variance (Table 5). PC I accounted for 85.51% of total variance (Table 5) with a strong positive loading of NH_3, Na, K, BOD, SO_4, COD and Cl. While DO displayed moderate negative loading; Ca, TH and Mg showed moderate positive loading. This component evinces an influence of marine spray, leaching of secondary salts and surface runoff. The sum of absolute contributions of parameters on PC II yielded only 7.24%. NO_2 and pH revealed strong positive loading, whereas; NO_3 and DIN had moderate positive loading. The relationship between nitrification and pH has been studied by many researchers.[38, 39, 40, 41] PC III explained 5.47% of total variance. Temperature and DIP were the parameters having strong positive loading in this component (Table 5). This could have been due to the facts that, phosphate release from sediment increases with increase in temperature, as a result of mineralization.[42, 43,44] The release of phosphorus at the sediment-water interface results in an increase in dissolved inorganic phosphorus in the overlying water.[43, 45, 46, 43]

Pollution Indices

The results of Organic Pollution Index (OPI), Eutrophication Index (EI) and Comprehensive Pollution Index (CPI) of Karamana River for non monsoon and monsoon 2015 are shown in Table 6 and 7 respectively.

Table 6: Variation of Pollution Indices in Karamana River during Non Monsoon (2015)

Sites	OPI	Status	EI	Status	CPI	Status
S1	-1.24	Excellent	0.00	No Eutrophication	0.36	Qualified
S2	-1.04	Excellent	0.00	No Eutrophication	0.37	Qualified
S3	-0.86	Excellent	0.00	No Eutrophication	0.37	Qualified
S4	-0.49	Excellent	0.00	No Eutrophication	0.43	Qualified
S5	-0.54	Excellent	0.00	No Eutrophication	0.45	Qualified
S6	-0.27	Excellent	0.00	No Eutrophication	0.56	Qualified
S7	0.16	Good	0.02	No Eutrophication	0.58	Qualified
S8	0.89	Good	0.11	No Eutrophication	0.85	Basically Quantified
S9	2.68	Lightly	0.38	No Eutrophication	1.15	Polluted
S10	5.36	Heavily	0.56	No Eutrophication	3.06	Seriously Polluted
S11	7.68	Heavily	1.57	Eutrophication	3.48	Seriously Polluted
S12	7.14	Heavily	1.26	Eutrophication	3.42	Seriously Polluted

Organic Pollution Index (OPI) in the river index varied between -1.24 to 7.68 during NON and -1.39 to 7.21 during MON (Table 6 and 7), ranging from excellent to heavily polluted categories during both seasons. This range was found to be higher than OPI obtained in few other parts of the world. This high level of OPI in the downstream (L= 4km) is a clear indication of untreated sewage input and poor dilution capacity of river.[3] Surface water samples from the locations S1-S8 of KR (fig. 1) were representatives of excellent to good classification based on OPI results.

Table 7: Variation of Pollution Indices in Karamana River during Monsoon (2015)

Sites	OPI	Status	EI	Status	CPI	Status
S1	-1.39	Excellent	0.00	No Eutrophication	0.41	Qualified
S2	-1.33	Excellent	0.00	No Eutrophication	0.44	Qualified
S3	-1.11	Excellent	0.00	No Eutrophication	0.43	Qualified
S4	-1.07	Excellent	0.00	No Eutrophication	0.43	Qualified
S5	-0.98	Excellent	0.00	No Eutrophication	0.43	Qualified
S6	-0.59	Excellent	0.00	No Eutrophication	0.50	Qualified
S7	-0.04	Good	0.05	No Eutrophication	0.57	Qualified
S8	0.75	Good	0.14	No Eutrophication	0.73	Qualified
S9	2.19	Lightly	0.40	No Eutrophication	0.99	Basically Quantified
S10	4.59	Heavily	0.81	No Eutrophication	2.38	Seriously Polluted
S11	7.21	Heavily	2.84	Eutrophication	2.94	Seriously Polluted
S12	6.72	Heavily	1.51	Eutrophication	2.94	Seriously Polluted

During NON, Eutrophication Index (EI) ranged from 0 to 1.57, and 0 to 2.84 during MON, which is a clear indication of eutrophication in downstream. Yadav *et al.,* 2018[24] assessed water quality using EI in Chambal river (North India), and these EI values were lower compared to values obtained in KR. High EI values (>1) clearly indicated mixing of nutrient-rich water in lower stretch (L=3 km; S11 and S12). TS canal overloaded with pollutants[49] confluences at this region, marking it as one of the major threatening point sources of pollution in KR (fig.3).

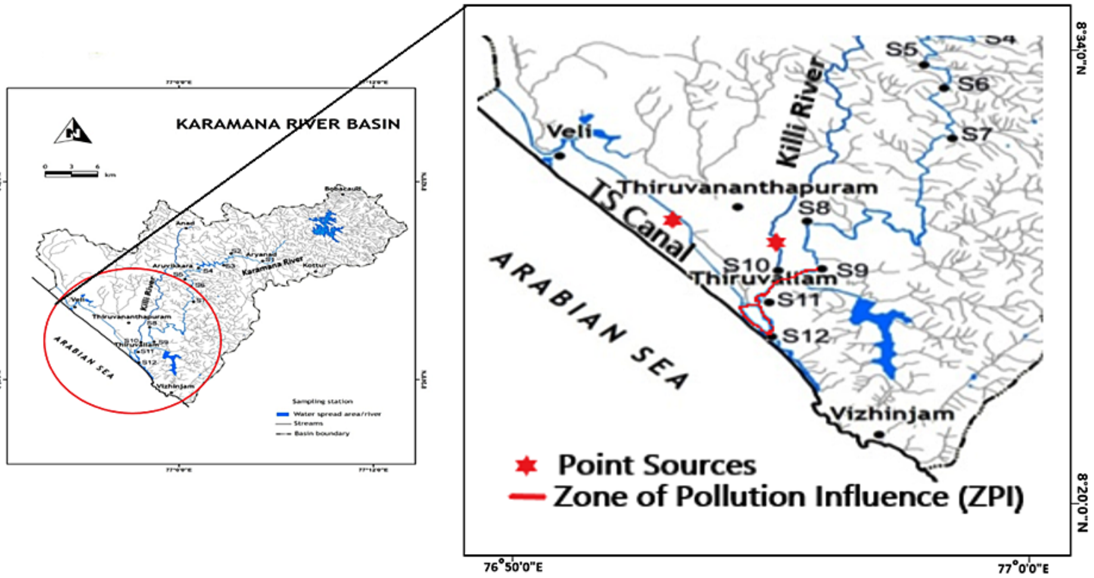

Fig. 3: Pollution zonation map of Karamana River with point sources.

Comprehensive Pollution Index (CPI) values ranged from 0.36 to 3.48 during NON and 0.41 to 2.94 during MON, which could be classified from qualified to seriously polluted during both seasons. These values were much higher than CPI of few other Indian rivers,[24,50] but much lesser than CPI of Hindon river, North India,[51] which ranged from 2.68 to 7.12. The results of CPI followed almost same trend as OPI.

Compiling the results obtained from pollution indices and water quality assessment, it is evident that the final 4 km stretch of KR is severely polluted. Intriguingly, this stretch coincides with the zone identified as one of the most critically polluted Indian River stretches based on Criteria-I by CPCB.[52] From these results, a distinct stretch of ~4km in the downstream up to estuary is identified as the "Zone of Pollution Influence (ZPI)" (Fig. 3).

Conclusion

The results of study seem to provide evidence on the water quality variations in Karamana River-KR (Kerala, India). From the physico-chemical analyses of surface water samples for non-monsoon (NON) and monsoon (MON) seasons, it is interpreted that water quality is good from upstream to middle stream (L=45 km). Most of the parameters (pH, Cl, DO, BOD, NO_3 etc.) exceeded CPCB 1995 desirable limits[35] in the hindmost stretch of downstream region (L=4 km). The application of Environmetric analysis viz. Pearson Correlation Analysis and Principal Component Analysis (PCA) connote that hydrochemical attributes of KR is primarily governed by natural (weathering, atmospheric deposition, seawater intrusion) as well as anthropogenic (sewage inflow) perturbation. The above findings are corroborated by the Eutrophication Index (EI) values, and based on this; river is affected by eutrophication in the last ~ 3 km of lower reaches. Again, the results of Comprehensive Pollution Index (CPI) and Organic Pollution Index (OPI) indicate that the downstream ~ 4 km fluvial stretch, up to estuary is severely polluted. The identified zone of pollution influence (ZPI) in this river needs utmost attention by stakeholders and administrators for pollutant mitigation programmes. Application of environmetric and pollution index tools is an emergent technique in this river; consequently, very little work has been reported on relationship of physicochemical parameters and water pollution source apportionments in KR. These environmental tools provided a more objective interpretation of surface water physicochemical parameters and identification of pollution source as part of the effort toward sustainable management of this river basin.

Acknowledgement

This work is the first part of research work done by the first author during 2015 and thank university of Kerala for providing fellowship to carry out this work.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The authors do not have any conflict of interest.

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