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Comparative study of water quality between upstream and downstream of Thamirabarani River using multivariate statistical tools

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The present investigations were focused on the systematic analysis of surface water quality of the Thamirabarani River from upstream (Pechiparai dam to Gnaramvilai) to downstream (Vettuvenni to Thengaipattinam estuary) during the period from September 2020 to January 2021. The different hydrochemical parameters such as temperature, pH, EC, TDS, fluoride, turbidity, nitrate, phosphate, sulphate, chloride, calcium, magnesium, total hardness, DO, BOD, bicarbonate, carbonate, sodium and potassium were determined upstream (S1-S5) and downstream (S6-S10) of the river water samples. The results showed that the weighted Arithmetic Water Quality Index (WAWQI) values designated two sampling stations out of ten sampling stations 'Good' category and another eight sampling stations 'poor - unsuitable' category. The results obtained were subjected to multivariate statistical analysis using Correlation matrix the significant relationship among the parameters (significance level with 0.01 and 0.05) PCA and Cluster was also calculated to determine the high pollution loads in the water sample. The mean values of the respective major ions determined are represented in the Schoeller-Berkaloff diagram. From this study the water quality was severely polluted both upstream and downstream region the water quality index and multivariate techniques can be employed for monitoring river resources which can help inadequate planning and management of the Thamirabarani river system.

Key words: Correlation analysis, cluster analysis, hydrochemical parameters, principal component analysis, statistical analysis, water quality index.

INTRODUCTION

Water is one of the main sources on which our existence and settlement are built upon, water sources can be found in the forms of rivers, glaciers rain water, ground water etc. Degradation of those natural water resources

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and management of available fresh water is becoming more challenging due to various reasons such as climate change, Geology, topography and soil type (Abeysinghe and Samrarakoon, 2017). Surface waters including rivers are among the major sources of irrigation water in developing countries particularly in arid and semi-arid regions (Sani et al., 2020). The water quality of the river is deteriorated mainly by natural processes and through anthropogenic activities like discharge of industrial sewage, domestic wastewater and agricultural drainage water to the river; however, the main pollutants for river pollution are the industrial sewages, domestic wastewater and agricultural drainage water (Shil et al., 2019).

The increased application of commercial fertilizer and widespread use of a variety of new pesticides, insecticides, herbicides and weed killers in agricultural practices are resulting in a host of new pollution problems from land drainage. This type of agricultural pollution has a severe impact on water pollution as most of the pollutants are resistant to natural degradation. Although concentration of the pollutants is still rather low, many of these compounds are toxic to human or animal life; some of them are carcinogenic or have serious ecological implications (Uddin et al., 2014).

River water is necessary for domestic usage, irrigation, fish culture (Kido et al., 2009) industrial production and numerous other activities, anthropogenic impacts directly affect watershed hydrology (Claessens et al., 2006) all of which influence water quality. Currently, more than 80% of the freshwater is used for irrigation and the remaining 20% is used for other requirements, this freshwater resource also supports the social, cultural, economic, and political development of humans. Most of these activities are largely related to the availability and distribution of riverine systems (Sharma and Rvichandran, 2021) therefore the monitoring of river water quality is essential for understanding the current condition of the river and for controlling water quality impairments under various conditions (Pingping et al., 2011).

Therefore river water quality often reflects the conditions prevailing in the catchment and is an indication of the river health as such, water quality monitoring programs of rivers are essential in the determination of pollution trends and pollution sources in order to initiate management strategies however processing complex, large data sets collected through monitoring programs and determination of underlying trends of water quality variation are crucial for taking decisions related to pollution prevention and catchment management efforts (Jayawardana et al., 2016). Multivariate statistical techniques are used to better understand the two or more variables of water quality studies. They give simple and easy results to interpret the environmental data and to identify the possible factors and locations that influence the water systems and base for further water resources management as well as a solution for pollution problems in many countries of the world including India (Sharma and Ravichandran, 2021; Bodrud-Doza et al., 2016; Adebola et al., 2013; Venkatesharaju et al., 2010; Andrade et al., 2008; Jaji et al., 2007).

WQI is widely used tool in different parts of the world to solve the problems and management strategies for improving water quality. The present investigation with the analysis of Thamirabarani river is suitable for drinking and domestic purposes and also to suggest the treatment process based on the results obtained, thus looking forward to reducing the cause of water issues in the country.

MATERIALS AND METHODS

Study area

The four major rivers that flow in the Kanyakumari district are, Thmirabarani, Valliyar, Pazhyar, and Paraliyar. Thamirabarani river confluences with the Arabian sea near Thengapattanam estuary about 56 km west of Kanyakumari district (Kokila and Rathika, 2016). Kodayar River is the major river system in Kanniyakumari district. It originates at Muthukuzivayal plateau of Valiamalai hill and travels through forest land and stored at Pechiparai dam. The river flows in two taluks of Vilavancode and Kalkulam viz., Kodayar, Pechiparai, Ambadi,Kaliyal, Gnaramvilai, Kuzhithurai, ST Mancadu and Thengapattanam about 56 km (35 mi) west of Kanyakumari town (Ponmurugaraj et al.,2019). Figure 1 shows the Kanyakumari district map.

Sample collection

Water samples were collected from 10 stations starting from upstream (Pechiparai dam) to downstream (Thengaipattinam estuary). The description of sampling locations was represented in Table 1. The samples were collected in 5-liter polyethylene (PE) bottles, which were washed with de-ionized water before use. Parameters like temperature were measured at the spot immediately after the collection of the samples.

Analytical methods

The collected water samples in ten different stations were analyzed and their hydrochemical analysis was carried out in Environmental Science Laboratory by using standard procedure (APHA, 2005). All reagents used were of analytical grade and solutions were made of distilled water. The studied hydrochemical parameters, symbols, units, analytical methods and their standard values were listed in Table 2.

Weighted arithmetic water quality index method

The weighted arithmetic WQI approach classifies the quality of water based on the grade of purity and accommodates the most frequently observe factors (Rao and Rao, 2010). The following equation is used for the calculation of WQI (Brown et al., 1972).

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

Figure 1. Kanyakumari district map.

Table 1. Description of sampling location in Thamirabarani river.

Sampling Location		Locations		Description of location and land use types
No	Name	Longitude	Latitude	
1	Pechiparai	77.234940	8.441760	Largest dam in Kanyakumari
2	Ambadi	77.288075	8.434295	Rubber Estates
3	Kaliyal	77.250812	8.383987	Residential waste water from Kaliyal.
4	Moovatrumugham	77.302378	8.336287	The river Kothai and Pahrali unify to flow south west towards the Arabian sea
5	Gnaramvilai	77.222254	8.321978	Brick industries, Sand Mining
6	Vettuvenni	77.207429	8.312045	Vehicle repairing and service centres, Fish markets
7	Athencode	77.178656	8.306023	Forest, Agriculture area
8	Ganapathiyan Kadavu	77.161428	8.274634	Residential and Agricultural Waste water
9	Painkulam	77.172455	8.275101	Dense coconut trees and Coastal plains
10	Thengaipattinam	77.167776	8.238387	Long Seashore is a major tourist area

Table 2. Analyzed water quality parameters with their standard.

No.	Parameter	Symbols	Units	Analytical methods	Standard value	
					BIS (1975)	WHO (1993)
1	Temperature	Tem	°C	Thermometer	40	-
2	pH	pH	-	pH meter	6.5-8.5	6.5-8.0
3	Electrical conductivity	EC	µS/cm	Conductivity meter	300	-
4	Total dissolved solids	TDS	ppm	Conductivity meter	-	1000
5	Fluoride	F^-	mgL^{-1}	Fluoride meter	1.0	
6	Turbidity	Tur	NTU	Turbidity Meter	-	5
7	Nitrate	NO_3^-	mgL^{-1}	UV–Visible spectrophotometric	-	45
8	Chloride	Cl^-	mgL^{-1}	Silver nitrate Method	250	-
9	Calcium	Ca^{2+}	mgL^{-1}	Complexometric titration method	75	-

Table 2. Cont'd

10	Magnesium	Mg^{2+}	mgL^{-1}	Complexometric titration method	30	-
11	Total hardness	TH	mgL^{-1}	EDTA titrimetric	300	-
12	Dissolved oxygen	DO	mgL^{-1}	Winkler's method	5	-
13	Biological oxygen demand	BOD	mgL^{-1}	Winkler's method	5	-
14	Total alkalinity	TA	mgL^{-1}	H_2SO_4 titrimetric	200	-
15	Sodium	Na+	mgL^{-1}	Flame photometric	200	-
16	Potassium	K+	mgL^{-1}	Flame photometric	200	-
17	Phosphate	PO_4^{3-}	mgL^{-1}	UV–Visible spectrophotometric	-	1.0
18	Sulphate	SO_4^{2-}	mgL^{-1}	Gravimetrically by using $BaCl_2$	200	-
19	Bicarbonate	HCO_3^-	mgL^{-1}	H_2SO_4 titrimetric	-	-
20	Carbonate	CO_3^-	mgL^{-1}	H_2SO_4 titrimetric	-	-

$$W_i = \frac{K}{S_i} \qquad (2)$$

$$Q_i = \frac{(V_i - V_0)\times 100}{(S_i - V_0)}$$

$$K = \frac{1}{\sum_{i=1}^{n}\frac{1}{S_i}}$$

Where, Vi- is the concentration of ith parameter in the analyzed water, Vo- is the ideal value of ith parameter in pure water and Vi = 0 (except for pH = 7.0 and for DO = 14.6 mg/L), Si is recommended standard value of ith parameter, Wi is the unit weight for each water quality parameter, K is the proportionality constant weight arithmetic water quality index (WAWQI) range and their status were depicted in Table 5.

RESULTS AND DISCUSSION

Hydrochemical parameters

Water samples were collected from upstream and downstream of the Thamirabarani River in Kanyakumari district and then systematically analysed as per the standard protocol. The values of various water-quality hydrochemical parameters are summarized in Table 3. The mean of the respective major ions in the upstream and downstream were represented by using the Scholler Berkaloff diagram by using diagramme software (Figure 4). It is a very useful tool for visualizing the relative abundance of common ions in water samples. In the present investigation, the samples from upstream showed Ca^{2+} - Mg^{2+} - HCO_3^-+CO_3^{2-} type and the samples from downstream showed Cl^- - Na^++K^+ - Ca^{2+} type.

The maximum average temperature (29.0°C) was observed downstream. Factors like temperature bring about changes in the pH of water. The higher pH (7.39) values observed suggest that carbon dioxide, carbonate and bicarbonate equilibrium is affected more due to changes in physico-chemical condition (Meenakshi and Heenasaraswat, 2021). The EC was relatively high in downstream (2500 µs/cm). The maximum mean TDS (1532 mgL^{-1}) of water was observed at downstream. The highest TDS and EC due to runoff inflow from both uraban and rural regions as well as leachate from a nearby landfill site (Kasa et al., 2022). The highest mean concentration of fluoride (0.12 mgL^{-1}) was recorded at downstream. The underwater light situation was indicated by turbidity. During the study, the high turbidity (5.38 NTU) was recorded at downstream.

In view of DO and BOD which the highest mean value were observed at upstream (13.4 mgL^{-1}) and downstream (3.84 mgL^{-1}). The highest value of DO and BOD indicate drains and also increasing the organic load (El-Amier et al., 2015).

There were relatively high nutrient concentrations in this basin. For example, the maximum value of nitrate (31.52 mg L^{-1}) and phosphate (6.96 mg L^{-1}) were noted at downstream and upstream respectively. Commonly nitrate is a naturally occurring form of nitrogen that is very mobile in water. River water which is high in nitrate level is potentially harmful to human and animal health; in fresh water of estuarine systems close to land, nitrate can reach high levels that can cause the death of aquatic life. However, nitrate is much less toxic than ammonia and nitrite (Badii et al., 2013).

Magnesium content of water is considered as one of the most important qualitative criteria in determining the qualitative criteria in determining the quality of water for irrigation, generally calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yields as the soils become more alkaline (Sulekh et al., 2011). The highest mean concentration of Ca^{2+} (352.0 mgL^{-1}) and Mg^{2+} (134.40 mgL^{-1}were observed at downstream, relatively sulphate and chloride were high in the downstream with the mean 6.65 mg L^{-1} and 2979 mgL^{-1} respectively. Chloride as anion occurs in all natural waters in widely varying concentrations. The origin of chloride in surface water is from weathering and leaching of sedimentary rocks, domestic and industrials wastes discharge municipal influence etc. The higher concentration of

Table 3. Comparative study of experimental water quality data in Thamirabarani river.

Parameter	Upstream								Downstream							
	S1	S2	S3	S4	S5	Min	Max	Mean	S6	S7	S8	S9	S10	Min	Max	Mean
Tem	29.0	28.0	28.0	28.4	29.2	28.0	29.2	28.5	28.6	28.8	28.8	29.2	29.4	28.6	29.4	29.0
pH	7.61	7.31	7.35	7.41	7.238	7.24	7.61	7.39	7.222	7.24	7. 27	7.53	7.64	7.22	7.64	7.38
EC	240	240	340	320	340	240	340	296	380	360	380	1480	9900	360	9900	2500
TDS	440	420	440	420	420	420	440	428	500	480	600	4680	1400	480	4680	1532
F^-	0.1088	0.0788	0.0924	0.0958	0.1176	0.08	0.12	0.10	0.1188	0.113	0.1292	0.1388	0.1192	0.11	0.14	0.12
Turb	0.24	0.24	0.24	0.28	0.4	0.24	0.40	0.28	0.42	0.5	0.62	10.16	15.2	0.42	15.20	5.38
NO_3^-	26	25.8	25.1	27.9	20.9	20.90	27.90	25.14	20.2	35.2	26.6	28.2	47.4	20.2	47.40	31.52
Cl^-	1.2	3.454	42.542	46.086	51.416	1.20	51.42	28.94	58.496	62.048	97.538	4450.2	10230	58.5	10230	2979.7
Ca^{2+}	288	208	384	208	200	200.0	384.0	257.6	248	336	328	416	432	248	432.0	352.0
Mg^{2+}	71.68	40.32	129.92	35.84	49.28	35.8	129.9	65.4	58.24	103.04	80.64	71.68	358.4	58.2	358.40	134.40
TH	45	50	77.5	105	135	45.0	135.0	82.5	107.5	117.5	156.5	1094.9	2184.8	108	2184.8	732.24
DO	11.2	14.4	13.6	13.6	14	11.2	14.4	13.4	12	15.2	13.2	14.8	9.6	9.60	15.20	12.96
BOD	2.4	4.4	2.8	4.0	4.4	2.40	4.40	3.60	2.8	4	3.2	5.2	4.0	2.80	5.20	3.84
TA	67.12	89	100.1	72	84	67.1	100.1	82.4	102.6	91	109.6	114	313.6	91.0	313.60	146.16
Na^+	4.4	10	8.4	12.8	13.6	4.40	13.60	9.84	16.8	19	28.2	53.6	1056.2	16.8	1056.2	234.76
K^+	1.2	2.2	3.0	3.8	4.0	1.20	4.00	2.84	4.0	5.2	5.4	17.2	62.6	4.00	62.60	18.88
PO_4^{3-}	7.8	7.8	6.6	6.6	6.0	6.00	7.80	6.96	6.6	8.2	5.8	5.6	7.2	5.60	8.20	6.68
SO_4^{2-}	0.0	0.0	0.0012	0.0024	0.0652	0.00	0.07	0.01	1.1838	4.4712	5.5732	8.8376	13.163	1.18	13.16	6.65
HCO_3^-	66.2	82	128.2	169.4	176.4	66.2	176.4	124.4	178.8	198.2	123.6	113.2	162.8	113	198.20	155.32
CO_3^{2-}	0.002	0.008	0.06	0.192	0.32	0.00	0.32	0.12	0.3	0.2	0.06	1.3	9.68	0.06	9.68	2.31

chloride responsible for laxative effect to the human beings, similar result was obtained by Verma and Khan (2015).

The maximum value of sodium (234.76 mgL^{-1}) and potassium (18.88 mgL^{-1}) was recorded at downstream. High concentration of sodium and potassium makes the water unsuitable for domestic use and causes severe health problems such as kidney disorder and nervous disorder in the human body (Ravikumar et al., 2020).The maximum average value of carbonate (2.31 mgL^{-1}) and bicarbonate (155.32 mgL^{-1}) were observed at downstream of the river. The highest mean values of TH (732.24 mgL^{-1}) and TA (146.16 mgL^{-1}) were noted at downstream respectively. According to (Tanushree and Gupta, 2021) dissolved calcium and magnesium ions are the main contributors of TH in water bodies and the bulk of its source is contributed by the surrounding rocks present in the water bodies. Total alkalinity is mostly due to calcium carbonate ($CaCO_3$) and also important for sustaining aquatic life (Joshi et al., 2022). The total alkalinity was above 200 mgL^{-1}, for maintaining WHO and BIS standards.

The average values of EC, TDS, Turbidity, chloride, TH, sodium, phosphate maximum permissible limit BIS and WHO in the downstream. Similarly, calcium, magnesium and phosphate were above the permissible limit BIS 1975 and WHO, 1993) in both regions (upstream and downstream). The graphical representation and spatial variation of the determining parameters indicate clearly the river water quality decreases as one goes from upstream to downstream in Figure 2.

Weight Arithmetic Water Quality Index (WAWQI)

Table 4 shows the comparative study of experimental water quality index in the

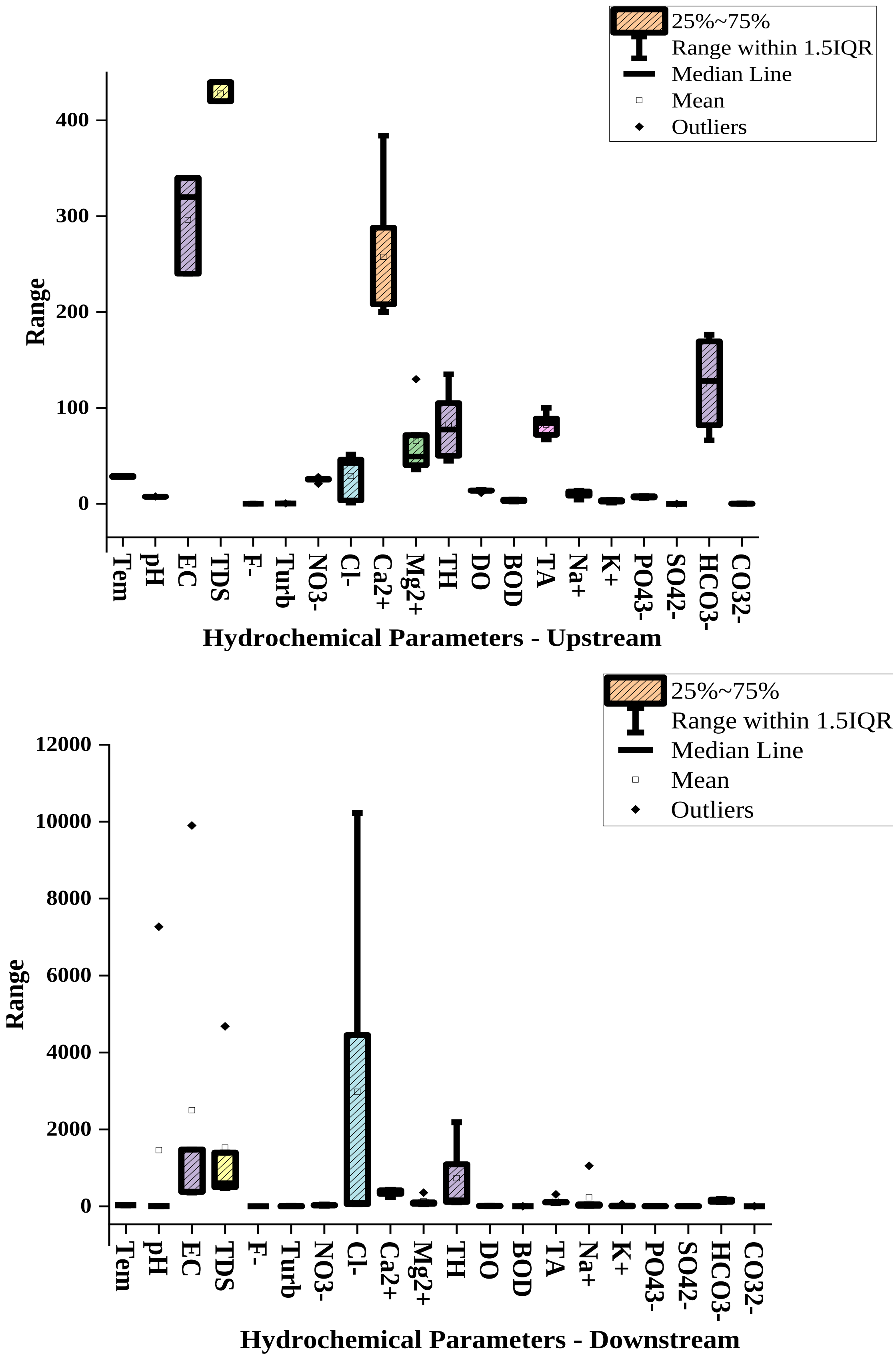

Figure 2. Box plot of water quality parameters in Thamirabarani river.

Table 4. Comparative study of experimental water quality index in Thamirabarani river.

WQI range	Water Quality Status (WQS)	Upstream			Downstream		
		Sampling stations	Calculated WQI	Status	Sampling stations	Calculated WQI	Status
0-25	Excellent	S1	50.28	Good	S6	51.61	Poor
26-50	Good	S2	53.16	Poor	S7	29.55	Good
51-75	Poor	S3	60.03	Poor	S8	58.37	Poor
76-100	Very poor	S4	52.24	Poor	S9	88.63	Very poor
Above 100	Unsuitable for drinking and fish culture	S5	55.38	Poor	S10	114.17	Unsuitable
Average		Upstream	54.22	Poor	Downstream	68.47	Poor

Thamirabarani River. The results show that the WAWQI value varies between 50.28 to 60.03 whereas the mean value of 54.22 indicates poor water quality of river Thamirabarani in upstream. Furthermore, the WAWQI of downstream varies between 29.55- 114.17, whereas the mean value of this region is (68.47), which also indicates the poor quality of water. Poor quality water in Thamirabarani reason could be happened due to leaching of ions, direct discharge of effluents, and agricultural impact (Sahu and Sikdar, 2008; Islam et al., 2015).

The value of WAWQI was found to be decreasing from upstream to downstream, which mainly is on account of organic pollutants coming from agricultural runoffs. Monitoring station number 10 was considered as extremely polluted.

The results show that the water quality index could be used effectively for water supply purposes. Similar research has been conducted by Tripsthi and Singal (2019) in Ganga River and (Magadum et al., 2017) in Vishwamitri River Gujarat. The graphical representation of WAWQI has been shown in Figure 3.

Hydrochemical parameters relationships

Pearson's correlation matrix between upstream and downstream is presented in Table 5. The dependability of water quality parameter in the samples of water collected from the upstream and downstream sampling sites was determined by regression analysis by determining correlation coefficient of the various parameters investigated. These correlation coefficient values are helpful in calculating the concentration of water quality parameters with the help of (Y= Ax + B) equation. The analysis shows a strong relationship between monitoring water quality parameters (Liu et al., 2003) in the Thamirabarani River with 0.01 and 0.05 significant levels. The correlations were more significant in the downstream compared to the upstream.

Principal Component Analysis (PCA)

The principal component analysis was carried out on the correlation matrix to compress the number of variables (Farnham et al., 2003; Gou et al., 2007). In the present study, the spatial distribution of water quality parameters in Thamirabarani river is depicted by a scree plot and loading plot (Figure 5). The 'Scree plot' is used to identify the number of components that explains most of the variation in the data. The 'Loading plot' is also compatible with these findings. Each component is thought to be of a similar origin. Different components are considered as of different origins.

Cluster Analysis (CA)

Cluster analysis is an unsupervised pattern recognition technique that classifies stations based on their similarities. The dendrogram are self-explanatory and give the classification of the parameters as per the methods used. Dendrogram helps with investigation and understanding of the sampling sites with respect to the variables and their sources (Shirani et al., 2020). Cluster analysis was performed by using Minitab software as a measure of similarity. This is the preferred method because it more accurately classifies the groups. As shown in the dendrogram (Figure 6), the four groups obtained were:

Group I: S1, S2, S3, S4, S5, S6, S7
Group II: S8
Group III: S9
Group IV: S10

Stations from upstream (S1-S5) to downstream (S6 and S7) were in Group I, and the close relation between these stations was related to

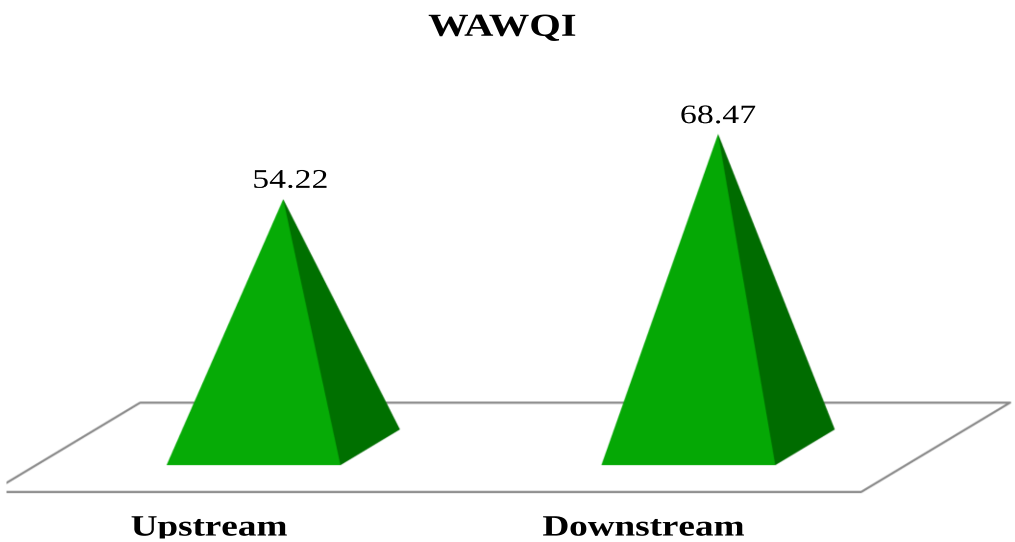

Figure 3. The graphical representation of WAWQI.

Table 5. Correlation matrix of water parameters in Thamirabarani river between upstream and downstream.

	Tem	pH	EC	TDS	F^-	Turb	NO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	TH	DO	BOD	TA	Na^+	K^+	PO_4^{3-}	SO_4^{2-}	HCO_3^-	CO_3^{2-}
a)	**Upstream**																			
Tem	1																			
pH	0.195	1																		
EC	0.055	-0.552	1																	
TDS	-0.033	0.621	-0.106	1																
F-	0.943	0.128	0.332	0.117	1															
Turb	0.672	-0.572	0.558	-0.527	0.699	1														
NO_3^-	-0.540	0.573	-0.387	0.145	-0.594	-0.792	1													
Cl^-	0.111	-0.566	0.981	-0.263	0.350	0.630	-0.352	1												
Ca^{2+}	-0.331	0.295	0.177	0.903	-0.094	-0.510	0.117	-0.001	1											
Mg^{2+}	-0.289	0.118	0.309	0.837	-0.027	-0.352	-0.067	0.125	0.979	1										
TH	0.407	-0.615	0.834	-0.512	0.538	0.885	-0.545	0.906	-0.358	-0.214	1									
DO	-0.463	-0.933	0.413	-0.700	-0.433	0.323	-0.249	0.449	-0.342	-0.215	0.448	1								
BOD	-0.038	-0.770	0.165	-0.973	-0.160	0.554	-0.284	0.292	-0.818	-0.717	0.520	0.817	1							
TA	-0.596	-0.675	0.396	0.080	-0.423	-0.046	-0.328	0.273	0.445	0.568	0.060	0.643	0.132	1						
Na^+	0.031	-0.802	0.613	-0.850	0.060	0.703	-0.321	0.725	-0.614	-0.489	0.839	0.794	0.866	0.173	1					

Table 5. Cont'd

K^+	0.052	-0.730	0.868	-0.582	0.205	0.696	-0.342	0.936	-0.305	-0.173	0.931	0.669	0.606	0.253	0.920	1				
PO_4^{3-}	-0.254	0.606	-0.965	0.272	-0.477	-0.753	0.524	-0.980	0.045	-0.104	-0.946	-0.429	-0.318	-0.269	-0.722	-0.918	1			
SO_4^{2-}	0.675	-0.585	0.500	-0.418	0.705	0.975	-0.906	0.540	-0.408	-0.235	0.795	0.296	0.483	0.064	0.589	0.585	-0.690	1		
HCO_3^-	0.199	-0.599	0.889	-0.499	0.362	0.732	-0.338	0.960	-0.279	-0.159	0.964	0.507	0.495	0.111	0.860	0.980	-0.947	0.610	1	
CO_3^{2-}	0.523	-0.571	0.732	-0.569	0.605	0.937	-0.580	0.821	-0.476	-0.338	0.985	0.392	0.561	-0.059	0.827	0.874	-0.882	0.848	0.916	1
b)	**Downstream**																			
Tem	1																			
pH	-0.272	1																		
EC	0.814	-0.285	1																	
TDS	0.586	-0.289	0.074	1																
F-	0.316	0.296	-0.159	0.807	1															
Turb	0.970	-0.386	0.860	0.572	0.278	1														
NO_3^-	0.769	-0.266	0.855	-0.002	-0.313	0.706	1													
Cl^-	0.939	-0.360	0.949	0.386	0.105	0.977	0.792	1												
Ca^{2+}	0.965	-0.180	0.672	0.630	0.380	0.877	0.744	0.821	1											
Mg^{2+}	0.750	-0.238	0.981	-0.072	-0.299	0.771	0.913	0.885	0.628	1										
TH	0.950	-0.352	0.935	0.422	0.145	0.985	0.779	0.999	0.838	0.867	1									
DO	-0.364	0.059	-0.792	0.284	0.269	-0.502	-0.441	-0.641	-0.137	-0.765	-0.617	1								
BOD	0.701	-0.388	0.197	0.869	0.523	0.610	0.355	0.460	0.806	0.127	0.489	0.378	1							
TA	0.779	-0.217	0.996	0.020	-0.166	0.829	0.831	0.927	0.630	0.980	0.913	-0.833	0.124	1						
Na^+	0.768	-0.251	0.996	-0.010	-0.223	0.814	0.858	0.918	0.623	0.990	0.902	-0.818	0.124	0.997	1					
K^+	0.868	-0.301	0.995	0.173	-0.075	0.907	0.853	0.975	0.736	0.964	0.966	-0.745	0.289	0.985	0.983	1				
PO_4^{3-}	-0.074	-0.462	0.211	-0.544	-0.906	-0.098	0.514	0.027	-0.071	0.353	-0.004	-0.048	-0.127	0.184	0.253	0.158	1			
SO_4^{2-}	0.982	-0.132	0.850	0.456	0.257	0.933	0.823	0.931	0.952	0.810	0.939	-0.429	0.599	0.828	0.817	0.892	-0.047	1		
HCO_3^-	-0.359	-0.491	0.040	-0.666	-0.961	-0.303	0.205	-0.170	-0.415	0.158	-0.206	-0.112	-0.401	0.028	0.090	-0.031	0.914	-0.351	1	
CO_3^{2-}	0.811	-0.303	1.000	0.075	-0.167	0.860	0.852	0.949	0.665	0.980	0.935	-0.794	0.196	0.995	0.996	0.994	0.218	0.844	0.052	1

each other. Group I (cluster 1) had a maximum number of samples (10 stations) with similar characteristics of water. Whereas Group II, III and IV stations reveal that they have anthropogenic sources mainly agricultural fields that discharge their effluent into the river water.

Conclusion

The prime objective of this research was to assess the quality and suitability of the Thamirabarani river water for domestic purposes. According to BIS and WHO the findings revealed that the hydro chemical parameters except for pH, DO and Phosphate, all the reaming water quality parameters were exceeding in the downstream sampling stations. The value of WAWQI was found to be decreasing from upstream to downstream, which mainly is on account of organic pollutants coming from agricultural runoffs and sewage water. The multivariate statistical analysis like Correlation matrix, PCA, Cluster analysis revealed that the water quality is severely polluted due to anthropogenic activities. Therefore it is concluded that the river is severely polluted especially at downstream and unsafe for domestic consumption. Thus better water quality of sustainable water environment could be achieved by making management strategies such as sewage water treatment facilities should be

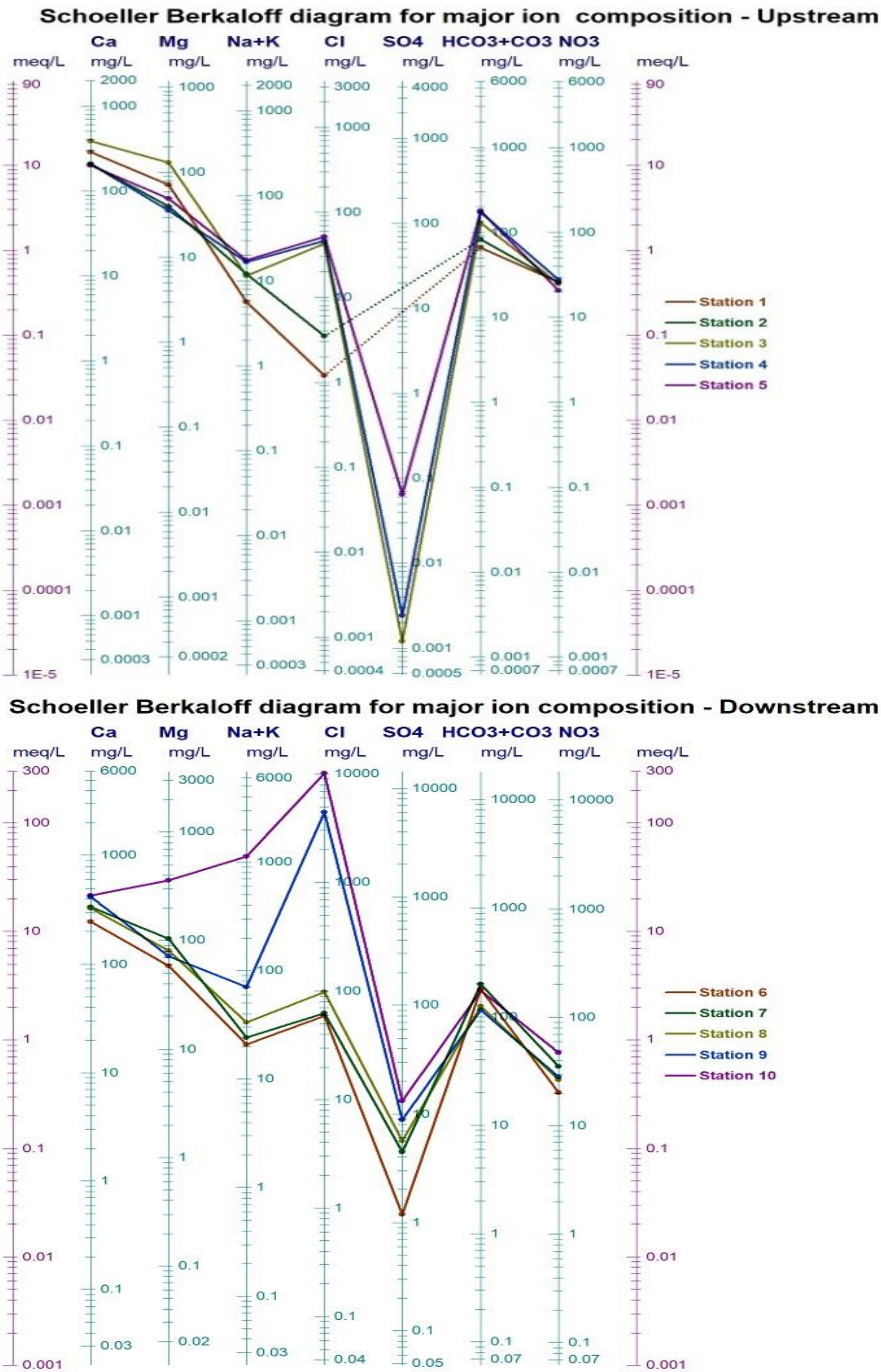

Figure 4. Schoeller Berkaloff diagram for major ion composition Thamirabarani river.

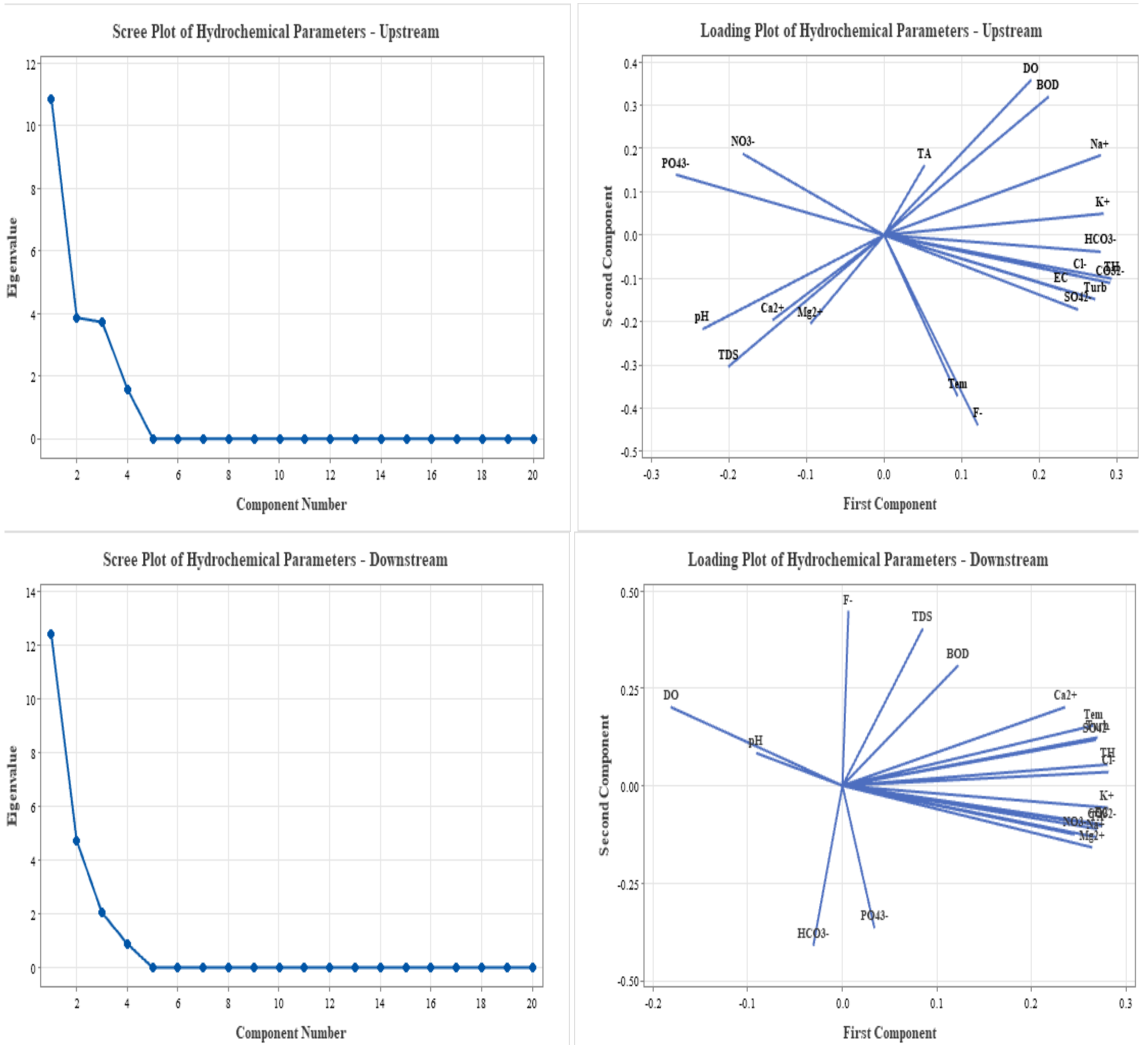

Figure 5. Spatial distribution of water quality parameters in Thamirabarani river.

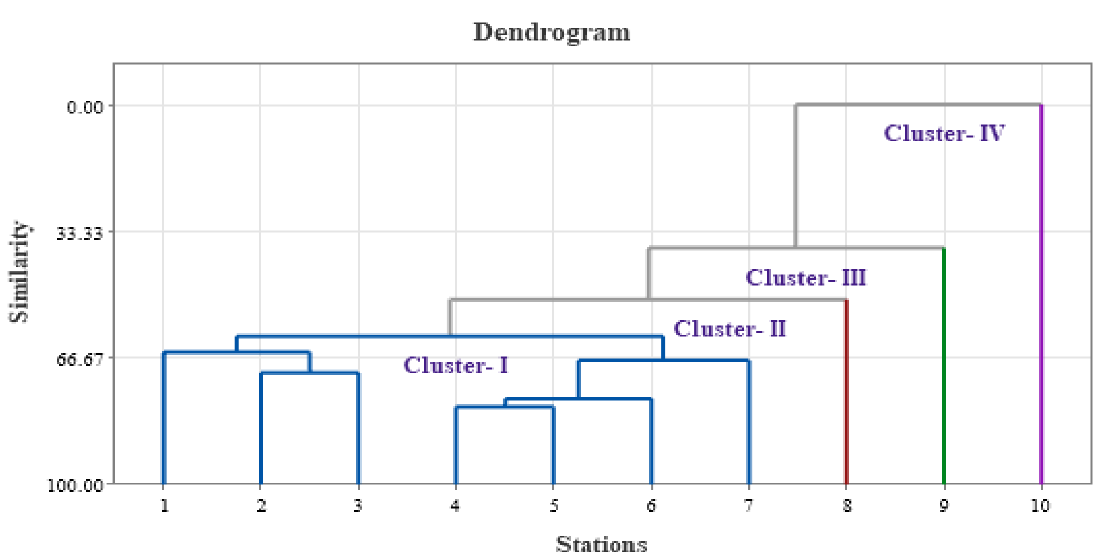

Figure 6. Dendrogram based on the cluster analysis.

provided to nearby villages, and also adequate treatment should be given to the small-scale industrial effluent before discharging in to the natural water body.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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