Appraisal of seasonal variations in water quality of river Cauvery using multivariate analysis

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ABSTRACT
The present study determines the water quality (WQ) of river Cauvery and its distributaries in Tiruchirappalli district, Tamil Nadu state, India, through WQ parameters and also using multivariate analysis. The water samples were collected by grab sampling method during the four seasons, namely, winter, summer, southwest, and northeast monsoons of the year 2014–15. The study reveals that total dissolved solids, turbidity, total alkalinity, total hardness, biological oxygen demand, chemical oxygen demand, and total coliform results of river Cauvery and the distributaries exceed the drinking water standards, which are mainly in summer. Also, the outcomes of principal component analysis and cluster analysis confirmed the high pollution loads in the water samples. It could be caused by the sewage discharges from residential and commercial areas. Moreover, solid wastes dumping and all sorts of cleaning activities were found at all stations. The present study concluded that the water from river Cauvery and its distributaries are not potable directly. With awareness creation and water treatment methods among the consumers, the river system can be conserved for proper uses.

Introduction
Freshwater is an important resource for supporting life and the environment and its progress. Good water quality (WQ) leads to a healthier environment, thus improving human life (Kumar, Sharma, & Rai, 2017a). The surface waterbodies like rivers, lakes, and wetlands are the main source of water for domestic, agricultural, and industrial purposes (Eliku & Leta, 2018; Mishra & Kumar, 2020). Currently, more than 80% of the freshwater is used for irrigation and the remaining 20% is used for other requirements (CPCB, 2012). 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 (Aggarwal & Arora, 2012; Baskar et al., 2013; De, 2010; Karthick & Ramachandra, 2007). River Cauvery plays a vital role in recharging the groundwater level and supports a major portion of the population in southern India. It is the main source of water for the livelihood activities of the people of Karnataka and Tamil Nadu states. Nearly 77% of the area in the river Cauvery basin is used as a drainage area (Jayaram, 2000).

The quality of river systems is directly and indirectly changed by climatic factors (surface run-off, land erosion, weathering of rocks) and human interventions (Kumar, Sharma, & Taxak, 2017b) particularly in the urban areas and agricultural activities around the rural areas (Ayeni, 2010; Kankal, Indurkar, Gudadhe, & Wate, 2012; Raj & Azeem, 2009). Wastewaters from these sources contain toxic organic and inorganic substances in addition to heavy metals (Alkarkhi, Ahmad, & Easa, 2009; Kumar, Bish, Joshi, Singh, & Talwar, 2010; Muduli, Swain, Bhuyan, & Dhal, 2006; Sinha, Saxena, & Saxena, 2006; Yerel & Ankara, 2012), that cause severe damage to the ecosystem like eutrophication and pose serious health issues (Alcamo, Henrichs, & Rosch, 2000; EIWR, 2008; Meitei & Bhargava, 2004). It is a serious and growing problem in most developing countries including India (Miller, 2010). During the last several decades, the WQ of the Indian rivers including river Cauvery has been deteriorating due to continuous discharge of partly/unreated industrial effluent, urban run-offs, and sewages from the point and non-point sources (Duran & Suicmez, 2007; Mishra & Kumar, 2020; Mishra, Kumar, & Shukla, 2020; Raja, Amarnath, Elangovan, & Palanivel, 2008; Sivakumar, Mohanraj, & Azeem, 2000; Smitha, Byrappa, & Ramaswamy, 2007). Some of the tributaries and distributaries of Cauvery are also becoming highly polluted. River Noyyal has now been termed as a ‘dead river’ due to heavy chemical pollution from Tirupur industrial area (Adhilakshmi,Mariappan, & Sashirega, 2004). Several studies have revealed that the above various discharges were the major sources of pollution in river...
Cauvery and its distributaries/tributaries, namely, Amaravati river, Arasalar channel, Bhavani river, Koraayar channel, Kudamurutti channel, Noyyal river, and Uyyakondan channel (Annalakshmi & Amsath, 2012; Hema, Subramani, & Elango, 2010; Jameel & Hussain, 2005; Jeena, Sharma, & Kalavathy, 2012; Kalavathy, Sharma, & Sureshkumar, 2011; Kathiravan, Brindha, & Natesan., 2010; Usharani, Umarani, Ayyasamy, Shanthi, & Lakshmanaperumalsamy, 2010; Varunprasath & Daniel, 2010; Venkatachalapathy & Karthikeyan, 2013; Vimala et al., 2006).

Multivariate techniques are suitable for reducing the WQ parameters and the determination of relationship among them, and clustering the samples as well (Praus, 2007). Bhardwaj, Singh, and Singh (2010) used the PCA tool on the WQ of Chhotti Gandak river, Ganga plain, and concluded that PCA determines the assemblage of WQ, and the origin of pollutants from domestic and agriculture areas. PCA expressed that all the physicochemical parameters equally and significantly contributed to WQ variations in the river Cauvery basin and CA revealed different clusters between the stations, reflecting WQ features (Venkatesharaju, Ravikumar, Somashekar, & Prakash, 2010; Yerel & Ankara, 2012). Thareja, Choudhury, and Trivedi (2011) also suggested that the PCA technique was a useful tool for the identification of important river WQ monitoring and parameters. Such studies are not available on north side channels, namely, Ayyan, Peruvallai, Pullambadi, Panguni, and Koolayar of river Cauvery. Prevention and treatment of polluted water are possible only after the appropriate diagnosis of the source. Hence, identification of the level and source of pollution becomes the basic requirement for further steps. This study aims at the assessment of this basic requirement of river Cauvery and its distributaries using environmetrics. The multivariate analysis like principal component analysis (PCA) and hierarchical cluster analysis (HCA), etc. are the easy approaches of the appraisal of WQ for supporting water management and conservation of water resources.

In the present study, 28 sampling stations were chosen in the five distributaries (Ayyan, Peruvallai, Pullambadi, Panguni, and Koolayar) of river Cauvery (Figure 1) in Manachanallur and Laligudi Taluks, Tiruchirappalli district. The selection of sampling spots depends upon riverfront accessibility and local human activities (bathing, washing, cleaning, dumping and burning of solid wastes, open defecation, and soaking of materials).

**Materials and methods**

**Study area**

The study area is situated on the north banks of the Cauvery river and lies between the geographic coordinates of 10°53′N; 78°34′E and 10°56′N; 78°55′E and spread over approximately 350 km², which falls under Manachanallur and Laligudi town panchayats. It contributes to the economy through its agricultural activities that cover 50% of the area of these taluks. The agricultural sector is the major source of income to the people of both the taluks, following being the major crops: paddy, sugarcane, banana, black gram, turmeric, gingili, chilly, onion, etc.

**Water sampling and analyses**

Subsurface water samples were collected from the shore side of the river by grab sampling method in new, sample rinsed 2 liters plastic cans from each location of river Cauvery (CY) and its five distributaries. Sampling was done in the daytime between 8.00 am and 9.00 am at each sampling location during winter (February), summer (April), southwest monsoon-SWM (August), and northeast monsoon-NEM (November) of the year 2014–15. The samples were transported to the laboratory and analyzed on the same day. In summer, there was no water available at some stations in Laligudi taluk. At these times, water was not collected. pH and dissolved oxygen (DO) were determined in the field itself. Samples for microbial analysis were taken in separate 100 ml pre-sterilized plastic bottles and packed in the icebox. Each of the water samples was analyzed for 28 physicochemical and microbiological parameters using APHA, AWWA, WEF (1998) standard methods (Table 1). Each WQ analysis was carried out in three replicates and the mean values of the raw data of each sample were considered for further study. Table 1 also shows the drinking WQ standard values of BIS (2012) and CPCB (2008).

**Multivariate statistical methods**

Multivariate statistical techniques are data analysis methods used to better understand the two or more variables of WQ 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 (Adebola, Seun, & Oladele, 2013; Andrade, Palacio, Souza, Leao, & Guerreiro, 2008; Bodrud-Doza et al., 2016; Jaji, Bamgbose, Odukoya, & Arowolo, 2007; Venkatesharaju et al., 2010). The statistical analysis of WQ results was executed by PCA and HCA using SPSS, version 18 software. They used widely in recent years for analyzing WQ data and describe the meaningful information (Kazi et al., 2009; Salah, Turki, & Al-Othman, 2012; Varol, Gokot, Bekleyen, & Sen, 2012; Yerel & Ankara, 2012). PCA was applied...
for each sampling location to identify the most influential parameter of WQ deterioration and to predict the source of pollution in the river system (Tripathi & Singal, 2019). Further, HCA was performed to construct a cluster of sampling locations that depicts the similarity in pollution load among the sampling locations (Kumar, Mishra, Taxak, Pandey, & Yu, 2020).

**Table 1.** Physico-chemical and microbiological parameters.

| SL.No. | Parameters                      | Permissible value | Unit       | Method               |
|--------|---------------------------------|-------------------|------------|----------------------|
| 1      | pH                              | 6.5–8.5           | pH         | pH meter             |
| 2      | Electrical Conductivity (EC)     | -                 | µS/cm      | Conductivity meter   |
| 3      | Total Dissolved Solids (TDS)     | 500               | mg/L       | Gravimetric          |
| 4      | Total Solids (TS)               | -                 | mg/L       | Gravimetric          |
| 5      | Turbidity                       | 1.0               | NTU        | Nephelometric        |
| 6      | Phenolphthalein Alkalinity (PA)  | -                 | mg/L       | HCI Titrimetric      |
| 7      | Total Alkalinity (TA)           | 200               | mg/L       | HCI Titrimetric      |
| 8      | Total Hardness (TH)             | 200               | mg/L       | Complexometric       |
| 9      | Dissolved Oxygen (DO)           | 6.0               | mg/L       | Modified Winkler’s   |
| 10     | Chemical Oxygen Demand (COD)    | 30.0              | mg/L       | Reflux strong oxidation |
| 11     | Biological Oxygen Demand (BOD)  | 2.0               | mg/L       | 5 days incubation    |
| 12     | Chloride                        | 250               | mg/L       | Argentometric        |
| 13     | Fluoride                        | 1.0               | mg/L       | SPANDS               |
| 14     | Nitrite                         | 0.06              | mg/L       | Colourimetric        |
| 15     | Nitrate                         | 45.0              | mg/L       | Colourimetric        |
| 16     | Sulfate                         | 200               | mg/L       | Turbidimetric        |
| 17     | Phosphate                       | <0.2              | mg/L       | Stannous chloride    |
| 18     | Carbonate                       | -                 | mg/L       | HCI Titrimetric      |
| 19     | Bicarbonate                     | -                 | mg/L       | HCI Titrimetric      |
| 20     | Total Nitrogen (TN)             | -                 | mg/L       | Kjeldhal             |
| 21     | Calcium                         | 75.0              | mg/L       | Complexometric       |
| 22     | Magnesium                       | 30.0              | mg/L       | Complexometric       |
| 23     | Sodium                          | 200               | mg/L       | Flame Emission photometric |
| 24     | Potassium                       | 200               | mg/L       | Flame Emission photometric |
| 25     | Silicate                        | -                 | mg/L       | Colourimetric        |
| 26     | Iron                            | 0.3               | mg/L       | Colourimetric        |
| 27     | Total Coliform (TC)             | 0/100 ml sample   | MPN/100 ml | Multiple tube fermentation |
| 28     | Fecal Coliform (FC)             | 0/100 ml sample   | MPN/100 ml | Multiple tube fermentation |

**Results and discussion**

**Physicochemical and microbial characteristics of water samples**

The pH of CY and all distributaries were within the range (6.5–8.5) during winter, summer, and SWM. However, pH was deviated (>8.5) in CY, AY1, AY2, PV1-PV3,
PB1-PB3, and PG3 during NEM. These fluctuations may be due to variations in water flow and photosynthetic activity of aquatic plants (Begum & Harikrishna, 2008).

EC varied from 315 to 996 μs/cm during the study period. The downstream stations were found to have high EC values on all channels, mainly Koolayar recorded with high EC values in all seasons. It was due to wastewater discharges from residential areas and run-off from agricultural lands. TDS values were found to be within range during SWM at all stations. It was exceeded in some samples during the other three seasons. The primary sources for elevated TDS are agricultural run-off, riverfront activities, leaching of soil, industrial effluents, and sewage discharges. The low water level during the dry season causes TDS to be high and vice versa in wet seasons (Moniruzzaman, Elahi, & Jahangir, 2009). The minimum value of TS was found in SWM at CY (220 mg/L) and the maximum was found in winter at KY3 (690 mg/L). The maximum value of turbidity was found at PB2 (9.3 NTU) in winter. It was due to a low flow of water and high sewage confluence from the local area. The values of turbidity in SWM and NEM were within the limit except in Panguni and Koolayar channels. Both channels were disturbed by agriculture and surface run-offs. TA of CY and all distributaries exceeded the limit during winter and summer, which was seen within the limit during SWM. In NEM, two samples (PG1, PG2) of Panguni and two samples (KY1, KY2) of Koolayar were slightly exceeded. PA was found in most of the stations during NEM and SWM while it was found at few stations of winter and summer seasons. The amount of carbonate varied between 0 and 48 mg/L during the study and the maximum amount was recorded at almost all stations in NEM. The bicarbonate content varied from 48.8 to 341.6 mg/L, which was maximum at station KY1 during winter. TH of CY and all channels were within the limit during SWM and NEM. It was exceeded in Panguni and Koolayar channels during the winter season. In summer, it was elevated in PV3 and all samples of Pullambadi, Panguni, and Koolayar channels. During dry seasons, the water flow was low. The riverfront activities and domestic discharges could be the reason for high hardness. The calcium and magnesium values were within the limits during SWM and NEM. It slightly exceeded at station KY1, KY2 during winter. However, calcium content deviated in PV3, PB1, PB2, PG1, PG2, PG3 & KY1 during summer. Mg exceeded at all stations during winter and summer. The maximum sodium

| Parameters | PC1 | PC2 | PC3 | PC4 | PC5 |
|------------|-----|-----|-----|-----|-----|
| Cl−        | 0.908 | 0.081 | 0.028 | −0.234 | 0.001 |
| EC         | 0.888 | 0.261 | 0.068 | 0.197 | 0.152 |
| TDS        | 0.853 | 0.291 | 0.122 | 0.205 | 0.174 |
| Na+        | 0.780 | 0.432 | 0.313 | 0.193 | 0.131 |
| TS         | 0.763 | 0.422 | 0.181 | 0.279 | 0.135 |
| K+         | 0.755 | 0.089 | −0.305 | −0.076 | −0.345 |
| HCO3−      | 0.682 | 0.494 | −0.365 | −0.049 | −0.099 |
| TA         | 0.678 | 0.576 | −0.158 | −0.148 | −0.112 |
| TN         | 0.580 | 0.039 | −0.328 | 0.371 | 0.154 |
| BOD        | 0.527 | 0.456 | 0.316 | 0.401 | −0.423 |
| Mg2+       | 0.144 | 0.859 | −0.087 | 0.161 | −0.296 |
| Fe         | 0.195 | 0.740 | −0.385 | 0.103 | 0.046 |
| NO3−       | 0.499 | 0.722 | 0.187 | 0.202 | 0.300 |
| Si         | 0.391 | 0.676 | −0.010 | −0.415 | −0.105 |
| TH         | 0.616 | 0.660 | 0.257 | −0.220 | −0.016 |
| Turb.      | 0.384 | 0.609 | 0.372 | 0.420 | −0.202 |
| SO42−      | 0.290 | 0.568 | 0.500 | 0.074 | 0.080 |
| PA         | −0.050 | 0.139 | 0.946 | −0.137 | −0.032 |
| CO32−      | −0.050 | 0.139 | 0.946 | −0.137 | −0.032 |
| pH         | 0.195 | −0.120 | 0.871 | −0.067 | 0.045 |
| PO43−      | 0.028 | 0.505 | −0.568 | −0.357 | 0.050 |
| TC         | 0.080 | 0.025 | −0.100 | 0.867 | −0.030 |
| FC         | 0.104 | 0.019 | −0.097 | 0.857 | −0.051 |
| Ca2+       | 0.494 | 0.072 | 0.233 | −0.721 | 0.147 |
| F−         | 0.243 | 0.590 | 0.086 | 0.629 | 0.045 |
| COD        | 0.448 | 0.472 | 0.152 | 0.541 | −0.460 |
| NO2−       | 0.464 | 0.117 | −0.340 | −0.008 | 0.678 |
| DO         | 0.049 | −0.265 | 0.488 | −0.243 | 0.661 |
| Eigen Value| 11.45 | 4.62 | 3.75 | 2.37 | 1.36 |
| % Variance | 40.89 | 16.51 | 13.39 | 8.47 | 4.85 |
| Cumulative %| 40.89 | 57.40 | 70.79 | 79.26 | 84.11 |
(117.6 mg/L) and potassium (13.2 mg/L) were found at PG3 in summer and the minimum was recorded at CY in SWM. The results of silica varied between 7.6 and 32.4 mg/L throughout the study. The iron content was within the desirable limit (0.3 mg/L) in all seasons.

DO of PV2, PV3, PG2, and PG3 in winter and all water samples in summer have not met the permissible limit (6.0 mg/l). This fluctuation can be due to the mixing of oxygen-demanding wastes. Only PG4 and PG5 in SWM and the first station of all channels in NEM have not met the standard. High DO in most of the samples during rainy seasons would have been caused by the turbulent flow of water and high dissolution of atmospheric oxygen. BOD and COD of CY and its distributaries have exceeded their standard limits during winter, summer, and NEM. However, the BOD and COD fluctuated at all stations during SWM. It was caused by organic matter which comes from plant extracts, solid wastes dumping, sewage discharges, and agricultural run-off. These activities are regularly practised all along the study area particularly in Samayapuram, Lalghudi and Poovalur town panchayats.

The results of chloride and fluoride of all stations were within their limits in all seasons. TN ranged between 0.7 and 5.6 mg/L in this study. The maximum TN was recorded at PV5 in winter and minimum TN was measured at station CY, AY1, PV1, and PB1 during SWM. The nitrite of all stations was found between 0.0 and 0.52 mg/L. During SWM, most of the samples were not found with nitrite content. The nitrate and sulfate of all stations in all seasons were found well within their standards. The phosphate content varied between 0.03 and 0.14 mg/L and all values were found with low levels in all seasons.

TC of CY and its distributaries found with more coliform content except for SWM. FC varied between 9 and 8000 MPN/100 ml. The high value of TC was recorded at PV3 in winter and high FC was recorded at stations AY4, PV3, PV5, PB3, PG4, PG5, and KY1. This may be due to a large number of sewage discharges containing human waste.

**Principal component analysis**

To identify the important parameters in the WQ of river Cauvery and its distributaries, PCA was performed for the 28 variables of four different seasons. The results of PCA for WQ parameters during winter, summer, SWM, and NEM are presented in Tables 2–5.

| Parameters | PC1  | PC2  | PC3  | PC4  |
|------------|------|------|------|------|
| EC         | 931  | .299 | .019 | .119 |
| TDS        | 935  | .302 | .007 | .121 |
| TS         | 896  | .361 | .128 | .138 |
| TC         | 865  | –.386| –.352| .162 |
| Na         | 858  | .377 | –.048| .290 |
| Si         | 852  | .240 | –.207| –.149|
| Mg         | 852  | .428 | .177 | .173 |
| Ca         | 832  | .483 | .128 | .157 |
| TH         | 822  | .509 | .149 | .081 |
| PO4         | 815  | .374 | –.416| –.017|
| FC         | 807  | –.092| –.354| .172 |
| HCO3         | 763  | .107 | .156 | .482 |
| SO4         | 748  | .476 | –.053| .070 |
| NO3         | 746  | .048 | –.268| –.585|
| TN         | 700  | .490 | –.274| .092 |
| TA         | 700  | .030 | .459 | .444 |
| Fe         | 581  | –.059| –.436| .150 |
| F         | –.115| .911 | –.189| .198 |
| DO         | –.203| –.826| .214 | .366 |
| Turb.      | .331 | .823 | .040 | .202 |
| Cl         | .591 | .756 | –.132| .050 |
| COD        | .393 | .749 | –.387| .042 |
| BOD        | .461 | .748 | –.454| –.009|
| CO2         | –.018| –.210| .954 | .006 |
| PA         | –.018| –.210| .954 | .006 |
| pH         | .014 | –.427| .655 | .557 |
| NO2         | .558 | .173 | –.084| .712 |
| K         | .498 | .288 | –.180| .612 |
| Eigen Value| 16.15| 4.66 | 2.59 | 1.67 |
| % Variance | 57.68| 16.63| 9.25 | 5.96 |
| Cumulative %| 57.68| 74.31| 83.56| 89.52 |
Table 4. PCA for water quality parameters during SWM season.

| Parameters | PC1 | PC2 | PC3 | PC4 | PC5 |
|------------|-----|-----|-----|-----|-----|
| TA         | .825| .114| .195| −.103| .338|
| TS         | .819| .223| .205| .381| .120|
| Na⁺        | .817| .020| .361| .320| .175|
| TDS        | .814| .212| .191| .404| .121|
| TH         | .813| .313| .231| .188| .305|
| EC         | .809| .206| .175| .400| .109|
| Cl⁻        | .788| .219| .282| .337| .286|
| Ca²⁺       | .777| −.005| .420| .323| −.140|
| K⁺         | .737| .092| .520| .333| .118|
| Mg²⁺       | .680| .363| .460| −.079| .202|
| PO₄³⁻      | .676| .389| .095| .435| .270|
| SO₄²⁻      | .673| .468| .454| .161| .220|
| DO         | −.630| −.350| −.285| −.256| −.403|
| NO₃⁻       | .626| .194| .009| .334| .589|
| Turb.      | .615| .255| .563| .211| .289|
| TN         | .571| .281| .556| −.118| .458|
| CO₂⁻       | −.135| −.971| −.025| −.092| −.056|
| PA         | −.135| −.971| −.025| −.092| −.056|
| pH         | −.154| −.904| −.206| −.236| −.103|
| HCO₃⁻      | .567| .750| .129| .006| .233|
| F⁻         | .392| −.115| .750| .208| .037|
| Fe         | .491| .250| .695| .252| .127|
| Si         | .034| .371| .690| .404| .038|
| NO₂⁻       | .314| −.103| .637| .037| .616|
| BOD        | .364| .366| .464| .432| .416|
| TC         | .341| .157| .241| .848| .124|
| FC         | .384| .138| .253| .837| .145|
| COD        | .286| .400| .142| .444| .673|
| Eigen Value| 18.12| 3.02| 1.64| 1.47| 1.01|
| % Variance | 64.88| 10.79| 5.85| 5.23| 3.39|
| Cumulative %| 64.88| 75.67| 81.53| 86.76| 90.36|

The PCA of the winter season showed five principal components, which explained 84.1% of the total variance. PC1 explained 40.9% of the variance representing Cl⁻, EC, TDS, Na⁺, TS, K⁺, HCO₃⁻, TA, TN, and BOD. PC2 dominated by Mg²⁺, Fe, NO₃⁻, Si, TH, turbidity, SO₄²⁻, accounted for 16.5% of the variance. PC3 explained 13.4% of the variance and loaded with PA, CO₃⁻, pH, PO₄³⁻. PC4 loaded with TC, FC, Ca²⁺, F⁻, COD, accounted for 8.5% of the variance. PC5 was responsible for 4.9% of the variance and represented by NO₃⁻ and DO. The component plot of the winter season (Figure 2) showed five Eigen values, which are greater than 1 and hence significant. In summer, four principal components explained 89.5% of the total variance. PC1 represented 57.7% of the variance and is concerned with 17 parameters out of 28. PC2 had 16.6% of the variance and associated with F⁻, DO, turbidity, Cl⁻, COD, and BOD. PC3 had 9.3% of the variance represented by CO₂⁻, PA, and pH. PC4 was explained with 6% of the variance concerned with NO₃⁻ and K⁺. The component plot of the summer season is shown in Figure 3. It was established that the first four Eigen values are greater than 1 confirming their significance.

The PCA of SWM showed 90.4% of the total variance and it extracted five components of the variables. PC1 comprised 16 WQ parameters out of 28, which accounted for 64.9% of the variance. PC2 had 10.8% of the variance with CO₃²⁻, PA, pH, HCO₃⁻. PC3 was found with 5.9% of the variance and it consisted of F⁻, Fe, Si, NO₃⁻, and BOD. PC4 was explained with 5.2% of the variance and concerned with TC and FC. PC5 was loaded with 3.6% of the variance, which was accounted for by COD. The Eigen values are greater than 1 confirming their significance of SWM is plotted in Figure 4. The PCA of NEM showed six components, which explained 88.4% of the total variance. EC, TDS, TS, turbidity, NO₃⁻, F⁻, SO₄²⁻, Fe, TA, PO₄³⁻, DO, Na⁺ were aligned in PC1 and which was explained with 49.5% of the variance. PC2 had 17% of the variance and was concerned with PA, CO₃²⁻, pH, HCO₃⁻, Cl⁻. PC3 had 8.8% of the variance and loaded with COD, BOD, K⁺. PC4 was explained with 5.8% of the variance and connected with TC, FC, Ca²⁺, TN. PC5 was loaded with 4% of the variance and related by Si, Mg²⁺, TH, and PC6 were associated with NO₃⁻ with 3.8% of the variance. The significant six Eigen values of NEM are plotted in Figure 5.

According to Liu, Lin, and Kuo (2003), the classification of the absolute loading values >0.75 is of strong significance. Using this classification, the most important parameters that contribute to variations in the
Table 5. PCA for water quality parameters during NEM season.

| Parameters | PC1  | PC2  | PC3  | PC4  | PC5  | PC6  |
|------------|------|------|------|------|------|------|
| EC         | 0.915| 0.189| 0.199| 0.087| 0.114| 0.143|
| TDS        | 0.915| 0.188| 0.200| 0.084| 0.112| 0.141|
| TS         | 0.909| 0.205| 0.200| 0.138| 0.103| 0.138|
| Turb       | 0.774| 0.359| 0.420| 0.119| 0.130| 0.085|
| NO₃⁻       | 0.697| 0.465| 0.399| 0.098| −0.143| 0.078|
| F⁻         | 0.657| 0.422| 0.033| 0.302| −0.043| −0.404|
| SO₄²⁻      | 0.654| 0.432| 0.470| 0.301| 0.035| −0.031|
| Fe         | 0.615| 0.270| 0.581| 0.149| −0.112| 0.135|
| TA         | 0.542| 0.495| −0.086| −0.245| 0.245| 0.454|
| PO₄³⁻      | 0.525| 0.478| 0.413| 0.121| −0.207| 0.059|
| DO         | 0.523| −0.240| 0.409| 0.230| −0.515| 0.277|
| Na⁺        | 0.513| 0.494| 0.446| −0.257| 0.266| 0.217|
| PA         | −0.189| −0.935| −0.078| −0.050| −0.185| −0.022|
| CO₂⁺       | −0.189| −0.935| −0.078| −0.050| −0.185| −0.022|
| pH         | −0.271| −0.868| −0.104| −0.082| −0.265| −0.099|
| HCO₃⁻      | 0.421| 0.842| 0.081| −0.023| 0.142| 0.237|
| Cl⁻        | 0.405| 0.578| 0.220| −0.379| 0.293| 0.294|
| COD        | 0.201| 0.065| 0.861| 0.201| 0.085| 0.262|
| BOD        | 0.367| −0.098| 0.833| 0.176| −0.010| 0.099|
| K⁺         | 0.145| 0.533| 0.746| −0.080| −0.040| −0.231|
| FC         | 0.147| 0.042| 0.273| 0.881| 0.016| −0.125|
| TC         | 0.162| 0.078| 0.339| 0.871| −0.015| −0.079|
| Ca²⁺       | −0.056| 0.129| 0.125| −0.829| 0.174| −0.173|
| TN         | 0.495| 0.304| −0.030| 0.544| 0.095| −0.201|
| Si         | −0.083| 0.370| −0.114| −0.042| 0.738| −0.246|
| Mg²⁺       | 0.465| 0.361| 0.255| 0.015| 0.590| 0.191|
| TH         | 0.446| 0.487| 0.175| −0.386| 0.534| 0.258|
| NO₂⁻       | 0.284| 0.366| 0.316| −0.038| −0.129| 0.759|
| Eigen Value| 13.74| 4.77| 2.46| 1.63| 1.11| 1.06|
| % Variance | 49.46| 17.04| 8.78| 5.81| 3.95| 3.78|
| Cumulative %| 49.06| 66.10| 74.88| 80.68| 84.63| 88.40|

Figure 2. Component loadings plot of water quality in winter season.

WQ of river Cauvery and its distributaries are presented in Table 6. During summer, the maximum number of variables was found with strong significant loadings. As there was less water during this season, the dilution effect would have been minimum. This could be the possible reason for the highest number of parameters contributing to strong positive component loading.
EC, TDS, TS, and turbidity are significantly correlated to each other. It is caused by the run-off from human activities (riverfront activities, sewage, solid wastes dumping, agricultural and industrial) of the catchment area to the river. The organic impurities by the disposal of domestic and industrial activities cause oxygen demand (COD and BOD) in the water (Al-Sanjari & Al-Tamir, 2008). In the present study, the high organic load at all stations is discharged from a highly populated area with a poor drainage system. This could be a reason for the strong positive loadings of COD and BOD. The positive loadings of Ca$^{2+}$, Na$^+$, K$^+$ and Cl$^-$ can be attributed to ion exchange on the clay minerals. It indicates a higher rate of weathering of rocks in this area. Washing out of the topsoil with its clay minerals, longer resistance of water, intensive and long-term irrigational practices and heavy use of chemical fertilizers would have caused the association of nitrate, phosphate, and potassium in the water (Al-Sanjari & Al-Tamir, 2008; Bhardwaj et al., 2010; Rao & Devedas, 2003).
The discharges of domestic and municipal wastes contribute to organic pollution to the river. Due to less water during dry seasons, the dilution effect or self-purification of the river would have decreased. TC and FC also were found with the most significant correlation due to bacterial contamination by open defecation, discharge of sewage, and overload of latrine from domestic areas. The negative loadings of pH, CO$_3^{2-}$, and PA could be attributed to high carbonates in the water. The presence of carbonate and bicarbonate ions from weathering of rocks, surface run-offs was to enhance the high pH at all stations. The utilization of CO$_2$ by algae or phytoplankton also increases the pH level in the water (Kiely, 1997).

**Cluster analysis**

The different sampling stations of selected water channels can be grouped into clusters based on the 28 WQ parameters. The dendrogram of the 21 sampling stations during winter is shown in Figure 6. Based on Euclidean distance, the HCA generated two major clusters of the stations. Cluster 1 comprises with low distance groups representing fewer impurities corresponding to 19 stations. Cluster 2 has a high intensity of WQ characteristics (PV3 and PV5). The high concentration of TDS, turbidity, TA, TH, BOD, TC, and FC were contributing the high distance of clustering of PV3 and PV5. Figure 7 shows the dendrogram of the 12 sampling stations during the summer season. Cluster 1 (CY, AY1, AY2, PB1, PB2, PV1, PG1) has similar characteristics of the water, and cluster 2 (PV2, PV3, PG2, PG3, KY1) has a high influence of Cl$^-$, TA, TC, BOD, TDS, and TH, which was attributed to a high distance of clustering. The dendrogram of the 28 measured data sets for SWM is presented in Figure 8. Cluster 1 has the maximum number of samples (22 stations) with similar characteristics of water. Cluster 2 (PV5, PV6, PG5, KY2, KY3) had a high influence on the WQ parameters. It reveals that the high concentration of TDS, COD, BOD, TH, and coliforms sharing the high clustering groups. The dendrogram of the 28 measured data sets for NEM is presented in Figure 9. Cluster 1 had a maximum number of samples (24 stations) with similar characteristics of water. Cluster 2 consisted of station PV3, PV6, PG4, PG5. The high amount of TDS, TH, CO$_3^{2-}$, COD, and coliforms were found in samples of the cluster 2.

**Table 6.** The most significant parameters of the water in four seasons.

| Season | Parameters with strong positive component loading | Parameters with strong negative component loading |
|--------|---------------------------------------------------|------------------------------------------------|
| Winter | Cl$^-$, EC, TDS, Na$^+$, TS, K$^+$, Mg$^{2+}$, PA, CO$_3^{2-}$, pH, TC, FC | - |
| Summer | EC, TDS, TS, TC, Na$^+$, Si, Ca$^{2+}$, Mg$^{2+}$, TH, PO$_4^{3-}$, FC, HCO$_3^-$, F$^-$, turbidity, Cl$^-$, COD, BOD, CO$_3^{2-}$, PA | DO |
| SWM | TA, TS, Na$^+$, TDS, TH, EC, Cl$^-$, Ca$^{2+}$, F$^-$, HCO$_3^-$, TC, FC | CO$_3^{2-}$, PA, pH |
| NEM | EC, TDS, TS, turbidity, HCO$_3^-$, COD, BOD, TC, FC, NO$_3^-$ | CO$_3^{2-}$, PA, pH, Ca$^{2+}$ |
Figure 6. Dendrogram of CA of the sampling stations in winter season.

Figure 7. Dendrogram of CA of the sampling stations in summer season.
From the above cluster analysis, it is inferred that the high impurities of sewage wastes and surface and agricultural run-offs could be the possible reason for high clustering groups of the stations in each season.

**Conclusion**

The present study was carried out to determine the WQ in Cauvery and selected distributaries of Tiruchirappalli district, Tamil Nadu. High EC, TDS, TS, turbidity, COD, BOD, and coliforms are the main characteristics for the deterioration of WQ. It was confirmed by the significant positive loadings of PCA formation in all the seasons of all stations. For this decline of WQ, sewage, surface, and agricultural run-offs are the main sources of pollutants. Maximum clustering in HCA (mainly in 3rd and 6th stations of Peruvalai and 4th and 5th stations of Panguni channels) in all the seasons is also due to the sources of the same pollutants.

The strong significant loadings were found in summer with the maximum number of variables due to the high pollution loads to the distributaries and less dilution. Thus, water from river Cauvery and its distributaries are not potable demanding immediate action. With appropriate conventional water treatment process and awareness creation among the consumers, the riverine system can be conserved for proper utility.
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