Water quality assessment of Noyyal river using water quality index (WQI) and multivariate statistical techniques

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ABSTRACT
Noyyal River is an important river that flows through the districts of Coimbatore, Tirupur, and Erode in Tamil Nadu, India. This river is the prime source of water for agricultural and domestic purposes in the above districts. This study evaluates the surface water quality of the Noyyal river and its suitability for drinking and agricultural uses. For this study, samples were collected from 27 locations along the Noyyal river from its source to sink. The water quality index (WQI) values were designated and, except for two samples out of 27, all the other samples were categorized as poor, very poor, and unfit for consumption. The parameters evaluated to assess the water quality of the Noyyal river for irrigation include Electrical conductivity (EC), Sodium adsorption ratio (SAR), Soluble sodium percentage (SSP), Residual sodium carbonate (RSC), Magnesium hazard (MH), Kelly's ratio (KR), and Permeability index (PI). USSL (U.S. Salinity Laboratory) diagram analysis helped to classify the samples 1 and 2 of the Noyyal river in the C151 and C251 category, which indicates low salinity-low sodium and medium salinity-low sodium, respectively. The rest of the samples fall under the category of very high salinity and very high sodium waters. Other indices like RSC, magnesium hazard, soluble sodium percentage, Kelly's ratio, and permeability index signified that majority of the collected samples fall in the category of unsuitable for agricultural use and they need special management practices. The Principle component analysis determined the four PCs that explained 84.88% of the total variance in the data structure. The present study concludes that we cannot use the surface water of the Noyyal river directly without treatment and strict management practices should be implemented for the sustainable use of the resource.

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Introduction
Water is the prime essential resource for all life forms. Surface water is the major source of water used for domestic, agricultural, and industrial purposes. Tamil Nadu accounts for 4% of India’s land area and hosts 6% of India’s population. But it contains only 2.5% of India’s water resources. Due to the increasing population and demand, over 95% of surface water and 80% of groundwater are already in use for human and animal consumption, irrigation, and industries. About 90% of surface water is used for irrigational purposes (TN-ENVIS, 2020). Rivers are the most substantial resources of freshwater, which are easily accessible for human use. But for the past few decades, we have also used rivers as dumping sites for human and industrial wastes. This has caused river pollution and has become one of the greatest environmental concerns. Anthropogenic activities can alter the physical, chemical, and biological composition of water so that the water becomes unsuitable for human consumption. Thus, it is essential to regularly monitor the surface water quality to maintain and save freshwater resources from degradation.

The river Noyyal originates from the Velliangiri hills of Western Ghats and flows through Coimbatore, Tiruppur, Karur, and joins the Cauvery River at Kodumudi in Erode district. The river, once considered as the sacred river of Coimbatore and Tiruppur, is now one of the heavily polluted rivers and termed as “dead river” in India (Adhilakshmi, Mariappan, & Sashirega, 2004). Many governmental and non-governmental organizations are in action to restore the Noyyal river basin to ensure water security for domestic and agricultural purposes. India is one of the world’s largest producers and exporters of textiles and garments. About 90% of India’s textile export is contributed by two major cities, namely, Tiruppur and Coimbatore. The textile manufacturing process consumes thousands of gallons of water and at the same time, it also releases an enormous amount of textile effluents. These effluents contain a high concentration of organic and inorganic compounds especially dyes which can cause serious health problems in humans. The industrial effluents discharged by the textile and the associated industries, the domestic wastes, and sewage disposal are the major sources of pollution in the Noyyal River.
The water quality index is a globally accepted approach to assess the water quality of any intended use. The present study aims to (1) assess physiochemical properties of the Noyyal river, (2) estimate the drinking water quality of the Noyyal River through Water quality indices (WQI), (3) its suitability for agricultural purposes through irrigation water quality parameters such as Soluble sodium percentage (SSP), Sodium adsorption ratio (SAR), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Kelly’s ratio (KR), and Permeability Index (PI), and (4) statistical evaluation using Correlation and Principal component analysis.

Materials and methods

Sample collection and analysis

The surface water samples for the study were collected from 27 different sites (Figure 1a) along the Noyyal river which passes through the districts of Coimbatore, Tirupur, Erode, and Karur during February and March 2020 (Figure 1b). The sampling sites were selected based on the distance. The distance between the two sampling sites was ~6 km±1 km. The water samples were collected in sterile airtight plastic bottles and labeled (L1-L27). The collected samples were stored at 4°C in an icebox and transported to the laboratory for the analysis of various physical and chemical parameters such as Appearance, Color, Odor, Turbidity, Total dissolved solids (TDS), Electrical Conductivity (EC), pH, Total Alkalinity, Total Hardness, Calcium (Ca²⁺), Magnesium (Mg²⁺), Carbonate (CO₃⁻), Bicarbonate (HCO₃⁻), Sodium (Na⁺), Potassium (K⁺), Manganese (Mn²⁺), Free ammonia (NH₃), Nitrate (NO₃⁻), Nitrile (NO₂⁻), Chloride (Cl⁻), Fluoride (F⁻), Sulfate (SO₄²⁻), and Phosphate (PO₄³⁻) using APHA (1998) standard methods. The parameters listed above, as well as the analytical methods used to measure them, are summarized in Table 1.

Drinking water quality of Noyyal river

Water quality index

The water quality index (WQI) is considered the effective and used mathematical averaging function to ensure the overall quality of water for any intended use. Horton in (1965) proposed the water quality index to analyze the quality of drinking water. Later some researchers and some countries have used different water quality parameters to define WQI such as the National Sanitation Foundation Water Quality Index (NSFWQI), Oregon Water Quality Index (OWQI) (Cude, 2001), British Columbia Water quality Index (BCWQI), Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI), Overall Index of Pollution (OIP) and Recreational water quality index (RWQI)(Shil, Singh, & Mehta, 2019). WQI used here is the weighted arithmetic index method given by Brown,McClelland,Deininger, and O’Connor (1972):

\[ WQI = \frac{\sum WnQn}{\sum Wn} \]

\( Wn \) is the unit weight factor of each parameter, \( \Sigma Wn = 1 \).

\[ Wn = \frac{K}{Sn} \]

Where,

\( K = \text{proportionality constant} \)

\( Sn = \text{Standard desirable value of the } n^{th} \text{ parameter} \)

\( Qn = \text{the sub-index of each selected parameter,} \)

\[ Qn = \frac{[(Vn - Vo)]}{[(Sn - Vo)]} * 100 \]

Where,

\( Vn = \text{Mean concentration/monitored value of the } n^{th} \text{ parameter} \)

\( Vo = \text{Actual/ Ideal values of the parameter in pure water (generally Vo = 0, except pH, because pH of the pure water is 7)} \).

Therefore, \( QpH = \frac{[(VpH-7)]}{[(8.5-7)]} * 100 \)

Irrigation water quality of Noyyal river

The criteria to assess the irrigation water quality (Table 1) are different from drinking water quality. Therefore, the suitability of Noyyal River water for irrigation purposes was evaluated by Electrical conductivity (EC), Soluble sodium percentage (SSP) (Equation 1) (Eaton, 1950), Sodium adsorption ratio (SAR) (Equation 2) (Richards, 1954), Residual Sodium Carbonate (RSC) (Equation 3) (Eaton, 1950), Magnesium Hazard (MH) (Equation 4) (Paliwal, 1972), Kelly’s ratio (KR) (Equation 5) (Kelley, 1963), and Permeability Index (PI) (Equation 6) (Doneen, 1962).

Equations

1. Soluble sodium percentage (SSP) \( \text{Na}_2O = \frac{Na^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} * 100 \)
2. Sodium adsorption ratio (SAR) \( \text{SAR} = \sqrt{\frac{Na^+}{Ca^{2+} + Mg^{2+}}} \)
3. Residual Sodium Carbonate (RSC) \( \text{RSC} = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \)
4. Magnesium Hazard (MH) \( \text{MH} = \frac{Mg^2+}{Ca^{2+} + Mg^{2+}} * 100 \)
5. Kelly’s ratio (KR) \( \text{KR} = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \)
6. Permeability Index (PI) \( \text{PI} = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+} * 100 \)
Multivariate statistical methods

Pearson correlation matrix

Pearson correlation matrix is a widely used statistical technique to evaluate the linear relationship between the variables. The correlation values range from –1 to 1, the value of −1 indicates the strong negative correlation between the variables in which they vary inversely, 1 indicates the strong positive correlation between the variables, and 0 indicates that there is no correlation between the variables (Mudgal et al., 2009).

Principle component analysis (PCA)

The principal component analysis is the multivariate statistical technique that reduces the large set of variables into principal components which are the linear combination of original variables. Hence, the large number of variables can be represented in a 2-dimensional subspace without modifying the original characteristics of the variables with the negligible loss of the data. Principal components are computed by eigenvectors of the data’s covariance matrix, where the eigenvector determines the direction in which the data is distributed, and the eigenvalues determine its magnitude. Thus, the eigenvalue greater than or equal to 1 is considered to be the most significant factor (Shrestha & Kazama, 2007).

Results

In this study, the values of physicochemical parameters of the Noyyal river have been determined to calculate the drinking water quality and the irrigation water quality, namely, electrical conductivity (EC), Sodium adsorption ratio (SAR), Soluble sodium percentage (SSP), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Kelly’s ratio (KR), and Permeability Index (PI).

Drinking water quality

The parameters considered for drinking water quality in this study are pH, Turbidity, TDS, Total hardness, Total alkalinity, Chloride, Sulfate, Calcium, Magnesium, and Nitrate (Table 2). We can categorize the WQI into five classes, namely, excellent (0–25), good (26–50), poor (51–75), very poor (76–100), and unsuitable for consumption (>100) (Brown et al., 1972).

pH

pH or hydrogen ion concentration is the important parameter of water that determines the suitability of water for various purposes such as drinking, domestic, irrigation, and industrial uses. The pH of 7 is said to be neutral, below 7 is considered acidic and above 7 is
considered as basic or alkaline. The safe pH range for any intended use is designated as 6.5 to 8.5 by BIS (2012). The pH of all the collected samples (L1-L27) ranged from 7.2 to 8.2 and is found to be slightly alkaline, which may be attributed to the release of textile effluents and sewage disposal. Other researchers observed a similar concentration of hydroxyl ions (pH) in the Noyyal river (Babu, Chinnaiyan Assistant Professor, & Chinnaiyan, 2017; Sunantha & Vasudevan, 2016).

**Turbidity**

Turbidity is the essential esthetic parameter to determine whether the water is clear or murky. Various factors like soil particles, organic matter, and biological organisms can cause turbidity. High turbidity in water will reduce the esthetic quality of water, taste, odor, and inhibit the light for aquatic organisms. The maximum permissible limit for turbidity in water is 5 NTU. The turbidity of the collected water samples shows fluctuations between 2 and 5 NTU.
is 2000 mg/L (BIS, 2012). Samples L1 and L2 recorded the TDS of 111 mg/L and 200 mg/L, respectively, which can be used for drinking with no risk and can be concluded as a freshwater source. The remaining samples (L3-L27) recorded the TDS limit, which ranged from 1247 mg/L to 1923 mg/L.

**Total hardness**

Hardness is the measure of the capacity of water to react with soap to form lather. It is determined by the concentration of calcium and magnesium ions present in water. Total Hardness (as CaCO₃) levels between 200 mg/L to 600 mg/L are considered being acceptable. The minimum and maximum recorded value of the total hardness in the collected sample is 52 mg/L and 880 mg/L, respectively. The hardness value of all the collected samples except L1, L2, and L3 are found to be more than the acceptable limit. We observed excess hardness downstream of the Noyyal River from Vellalore area of Coimbator district to Vellamangalam in Karur. This may be because of the sewage disposal and the discharge of industrial effluents into the river.

**Total alkalinity**

Alkalinity is the buffering capacity of water to neutralize acids which maintains a stable pH. Total alkalinity is the measure of carbonate, bicarbonate, and all the hydroxyl ions (calcium, magnesium, sodium, and potassium) and is expressed as calcium carbonate (CaCO₃). The tolerable limit of total alkalinity determined by the Bureau of Indian Standards (BIS, 2012) is 200 mg/L to
600 mg/L. The values of total alkalinity in the collected samples varied from 64 mg/L to 880 mg/L. The characteristic reason for the excess alkalinity may be because of the lithology of the area as the carbonate minerals get dissolved from the rocks and soils. The anthropogenic source might be because of the industrial effluents, especially textile and associated manufacturing, as they utilize salts and surfactants for the better binding of the color to the fabrics. Babu and their team in (2017), have reported a similar case that the excessive hardness and alkalinity in downstream of the Noyyal river near the Tirupur is because of the release of chemicals used by the textile and its associated industries.

**Chloride**

Chloride is a naturally occurring substance in all waterbodies. This might be because of the geological properties of the area, agricultural runoffs, wastewater from industries, and domestic sources, etc. It has no harmful effect on human health, as chloride is an essential micronutrient for life which is found as salts (NaCl and KCl) in the human body. As per the Bureau of Indian Standards (BIS, 2012), the desirable limit of chloride in water is 250 mg/L and in case of the absence of alternative sources, the maximum acceptable limit is 1000 mg/L because it can impart the taste to the water. The concentration of chloride in the collected samples varied from 8 mg/L to 480 mg/L. A report by Gayathri, Muralisanarkar, Rajaram, Muniasamy, and Santhanam (2020) also observed high levels of chloride in the Noyyal river samples which exceeded the drinking water permissible limit set by BIS.

**Sulfate**

The levels of sulfate concentration in the collected samples ranged between 0–42 mg/L and were within the limit (200 to 400 mg/L) specified by BIS. Sulfate may be leached naturally from the soils and rocks. The anthropogenic sources for sulfate in waterbodies include industrial effluents, sewage disposal, fertilizer runoffs, and so on. High levels of sulfate in the water will affect the taste and can cause laxative effects when combined with magnesium and sodium (Alan, Twort, & Brandt, 2000).

**Calcium**

Calcium is an essential part of the human diet. The presence of calcium in water is mainly because of its entry through deposits of rocks such as limestone, dolomite, and gypsum (Nayar, 2020). The calcium content in the collected samples varied from 10 mg/L to 176 mg/L and is within the prescribed limits of BIS.

**Magnesium**

Magnesium is the second most significant component in water hardness after calcium that occurs naturally in water. Magnesium has no negative impact on human and animal health. However, at levels between 30 and 100 mg/L it is nontoxic to living organisms. The magnesium levels in the study varied from 7 mg/L to 106 mg/L.

**Nitrate**

Nitrate levels ranged between and 0–19 mg/L. As prescribed by WHO (2008) the maximum permissible limit of nitrate is 50 mg/L in drinking water. But BIS allows 45 mg/L of nitrate in drinking water before treatment. The higher concentration of nitrates in the water may be because of the fertilizers used for agricultural purposes, human wastes, and industrial discharges. Jeyaraj, Indhuleka, and Arunpaul (2018) also reported that the increased levels of nitrate in the Noyyal River and its connected ponds may be because of the excessive fertilizer runoff from the agricultural fields. Nitrate is hazardous to human health, especially infants, where it can reduce the oxygen-carrying capacity of blood leading to methemoglobinemia and gastrointestinal cancers (Comly, 1945; Gilli, Corrao, & Favilli, 1984).

**Water quality index (WQI)**

The water quality index of 27 samples in the present study ranges from 36.59 to 116.61. Among the total samples, only two samples (L1 and L2) indicated good water quality. The sample from Vellalore (L4) in the Coimbatore district exceeded the WQI of 100 and indicated the water to be unfit for consumption. This is due to the elevated levels of magnesium and total hardness in the water and can be attributed to the disposal of sewage into the river. Six samples (L3, L5, L6, L7, L9, and L13) recorded poor water quality and the remaining samples (L8, L10, L11, L12, L14, L27) indicated very poor water quality. Almost all the samples of the Noyyal River collected from the Tiruppur, Erode, and Karur districts indicated very poor water quality. These data show the presence of a high level of pollutants from the textile and associated industrial effluents, sewage disposal, and agricultural runoffs, and it cannot be used for drinking with no treatment. The present study coincides with a study carried out on the Noyyal River and its connected ponds in Coimbatore by Jeyaraj et al. (2018).

**Irrigation water quality**

The concentration and type of total soluble salts in the water will determine the quality of irrigation water. The important criteria to evaluate the irrigation water quality are electrical conductivity (EC), Sodium adsorption ratio (SAR), Soluble sodium percentage (SSP), Residual Sodium Carbonate (RSC) Magnesium Hazard (MH), Kelly’s ratio (KR), and Permeability Index (PI). The parameters evaluated to
Table 3. Calculated values of physiochemical parameters to assess the irrigation water quality of Noyyal river.

| SAMPLES | EC  | SAR  | SSP  | RSC  | MH  | KR  | PI  |
|---------|-----|------|------|------|-----|-----|-----|
| L1      | 163 | 4.12 | 41.38| 1.04 | 41.18| 0.71| 45.01|
| L2      | 294 | 4.5  | 36   | 2.22 | 40.63| 0.57| 31.48|
| L3      | 2241| 23.26| 55.14| 8.72 | 37.44| 1.23| 46.41|
| L4      | 2744| 22.57| 48.73| 6.28 | 37.59| 0.96| 40.05|
| L5      | 2639| 25.18| 55.13| 15.93| 39.05| 1.23| 46.15|
| L6      | 2482| 25.59| 57.7 | 10.25| 54.55| 1.37| 46.67|
| L7      | 2513| 22.99| 52.41| 8.27 | 37.62| 1.11| 43.64|
| L8      | 2744| 24.91| 54.4 | 6.29 | 37.62| 1.2 | 45.62|
| L9      | 2618| 24.4 | 54.35| 7.02 | 39.05| 1.2 | 45.4 |
| L10     | 2681| 15.81| 43.84| 8.75 | 37.57| 0.79| 35.47|
| L11     | 2723| 25.51| 55.4 | 5.08 | 37.45| 1.25| 46.66|
| L12     | 2513| 24.5 | 55.56| 4.94 | 37.5 | 1.25| 46.83|
| L13     | 2755| 25.32| 55.21| 5.41 | 37.45| 1.24| 46.46|
| L14     | 2723| 24.91| 54.4 | 8.93 | 37.62| 1.2 | 45.61|
| L15     | 2786| 26.67| 56.85| 9.08 | 37.57| 1.32| 48.09|
| L16     | 2681| 24.91| 54.4 | 7.94 | 37.62| 1.2 | 45.62|
| L17     | 2786| 25.24| 54.11| 4.85 | 38.87| 1.18| 45.18|
| L18     | 2828| 25.87| 55.33| 7.28 | 37.62| 1.24| 46.56|
| L19     | 2744| 24.57| 53.72| 4.93 | 37.5 | 1.17| 44.97|
| L20     | 2807| 26.29| 56.14| 6.73 | 37.45| 1.28| 47.4 |
| L21     | 2729| 24.91| 54.4 | 6.95 | 37.62| 1.2 | 45.62|
| L22     | 2794| 24.81| 53.26| 6.44 | 37.56| 1.14| 44.49|
| L23     | 2832| 25.75| 55.11| 6.78 | 38.19| 1.23| 46.26|
| L24     | 2755| 24.57| 53.72| 5.27 | 37.5 | 1.17| 44.97|
| L25     | 2784| 24.81| 53.26| 7.76 | 37.56| 1.14| 44.48|
| L26     | 2763| 25.32| 55.21| 8.71 | 37.65| 1.24| 46.65|
| L27     | 1834| 18.77| 49.46| 4.35 | 39.14| 0.98| 40.63|

assess the water quality of the Noyyal river for irrigation purpose is represented in Table 3. IDW interpolation map (Figure 2) has shown spatial variations of irrigation water quality parameters of Noyyal river.

**Electrical conductivity**

The total soluble salts in irrigation waters are estimated in terms of electrical conductivity (EC). The water with an EC of less than 750 μS/cm is considered as an ideal value (Richards, 1954) and >2250 μS/cm is suitable for agricultural purposes except for some sensitive crops. Excess salt in the irrigation water will increase the salinity of the soil solution and hence the plants cannot maintain the osmotic balance. This will lead to the drooping of crops (Zamann et al., 2018). In our study, the electrical conductivity of the collected samples from the Noyyal River varied in the range from 163 to 2832 μS/cm. All the water samples except L1, L2, L3, and L27 have the EC above 2250 μS/cm indicating the salinity hazard for the crops which may need careful management practices (Table 3). The EC value of the sample collected from Siruvani falls, Coimbatore (L1) recorded 163 μS/cm. Irrespective of sodium concentration the EC less than 200 μS/cm may cause soil destruction and reduces the permeability of water (Zamann et al., 2018).

**Sodium adsorption ratio (SAR)**

The sodium adsorption ratio is used to determine the sodium hazard for the irrigation water. The SAR of 0–10 is considered being the excellent quality as prescribed by Richards (1954). Continuous use of water with SAR greater than 10 may destruct the physical structure of the soil. If the concentration of sodium concerning calcium and magnesium is excessive, then we say the soil to be sodic. (Zamann et al., 2018). The excessive salinity and the ratio of sodium in the soil reduce the infiltration of water into the soil and may eventually lead to the development of excessive weeds, rotting of seeds, inhibits the downward movement of water to the roots (Ayers & Westcot, 1985; Suarez & Lebron, 1993). In this study, we found the SAR between 4.12 and 26.67 (Table 3). Figure 3 represents the plot of sodium hazard against the salinity hazard for the rating of irrigation water in different classes. The water sample from location 1 lies between low salinity and low sodium hazard (C1-S1). Sample from location 2 fall in the category of C2-S1 showing medium salinity and low sodium hazard. The remaining 25 samples collected from different sites along the Noyyal River lie in the category of very high salinity and sodium hazard (C4-S4). This result shows that we cannot use the waters from these locations for irrigation without a proper drainage system.

**Soluble sodium percentage (SSP)**

Soluble sodium percentage is the important parameter to determine the irrigation water quality in terms of soil permeability (Nagaraju, Suresh, & Hudson-edwards, 2006). The water utilized for irrigational purposes ought to have lower concentration of sodium ion and higher concentration of calcium and magnesium ions. This is because the high sodium content may reduce the permeability of soils. The value of Soluble Sodium Percent (SSP) in our study ranges from 36 to 56.85 (Table 2). All the samples have recorded a lower range of SSP values (<60-safe, >60-Urnsafe) (Todd & Mays, 2005) showing that there is no negative effect on the permeability of the soil.
Figure 2. Spatial variations of water quality index (WQI), Sodium adsorption ratio (SAR), Soluble sodium percentage (SSP), Residual sodium carbonate (rsc), Permeability index (PI), Kelly's ratio (KR), Magnesium hazard (MH).
Residual sodium carbonate (RSC)
The concentration of carbonate and bicarbonate influences the suitability of water for irrigation (Shil et al., 2019). When the concentration of carbonate and bicarbonate ions in the water exceeds the concentration of calcium and magnesium ions, the carbonate ions precipitate the Ca$^{2+}$ and Mg$^{2+}$, thus increasing the sodium concentration in water and the soil. This may eventually lead to sodium hazard, resulting in soil salinity, destruction of soil structure and permeability, poor yield, etc. The RSC values of the collected water samples varied between 1.04 and 15.93 meq L$^{-1}$ (Table 3). Based on the RSC values, we found the sample from location 1 to be safe for agriculture, and the sample from location 2 falls in the category of medium class for irrigation. All the other samples fall in the category of unsuitable for irrigation which may increase the sodium levels in the soil.

Magnesium hazard (MH)
Most natural waters maintain the concentration of calcium and magnesium at equilibrium but they behave differently in soil systems (Ravikumar, Somashekar, & Angami, 2011). The high level of magnesium in water will deteriorate the soil structure especially the soil with high exchangeable sodium content. The magnesium hazard (MH) index to determine the effects of magnesium in irrigation water is introduced by Paliwal (1972). The risk of magnesium above 50% is adverse to crop yields. Of the 27 samples, 26 showed a magnesium ratio less than 50%, indicating suitability for irrigation, while only 1 sample falls into the unsuitable category, with MH greater than 50% (Table 3).

Kelly’s ratio (KR)
Kelly’s ratio is determined by measuring the sodium against the sum of calcium and magnesium ions. Kelly’s ratio is used to indicate the quantity of excess sodium in irrigation water. The KR < 1 is considered suitable for irrigation, KR>1 and KR<2 indicate excess sodium and sodium deficiency in water, respectively (Kelly, 1940). Kelly’s ratio in the present study varied from 0.57 to 1.37 and all the water samples, except for 5 samples (L1, L2, L4, L10, L27) are unsuitable for irrigation indicating excess sodium content according to Kelly’s index (Table 3).

Permeability index (PI)
The soil permeability is affected by the long-term use of irrigation water, which is influenced by the Na$^+$, Ca$^{2+}$, Mg$^{2+}$, and HCO$_3^-$ ions (Pillai & Khan, 2016). Doneen (1964) classified the irrigation water based on permeability as Class I (PI > 75%) as favorable for irrigation as it has maximum permeability. Class II (PI = 25–75%) moderately suitable and class III (PI<25%) is unsuitable since they have minimum permeability. According to the permeability index values, all of the samples fall under class 2 (PI ranged from 25% to 75%) signifying the water is moderately permeable (Table 3).

Statistical analysis

Pearson correlation matrix
Pearson correlation matrix was applied to check the relationship among the physicochemical parameters of the Noyyal River. The Pearson coefficient of 0.75 ≤ r < 1 indicates the strong correlation between the variables (Cohen, 1988). The results of the correlation matrix analysis showed significant positive correlation (p < .01) of Total dissolved solids (TDS) with electrical conductivity (EC), total hardness (TH), calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), sodium (Na$^+$), potassium (K$^+$) and chloride (Cl$^-$); EC with TH, Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$ and Cl$^-$; Bicarbonate with carbonate; Carbonate with Mg$^{2+}$; Calcium with Mg$^{2+}$, Na$^+$ and K$^+$; Magnesium with Na$^+$ and K$^+$; Sodium with potassium and Potassium with chloride. Total alkalinity and Total hardness are essentially associated with bicarbonates, carbonates, calcium, magnesium, sodium, and potassium and therefore showed a significant positive correlation. The variables with positive relationship at p < .05 significant level is shown in Table 4. There is no significant correlation of pH with any of the other physical and chemical parameters of the river. This clearly indicates that the source of pollution in the river cannot be controlled by definite factors (Zakaullah & Ejaz, 2020).

Principal component analysis
The PCA of water quality of Noyyal River obtained four principal components which are accountable for the total variance of 84.88% in the data structure based on the eigenvalues which are greater than 1 (Table 5). A Scree Plot determines the fraction of total variance in the data through the simple line segment plot in the descending order of eigenvalues.

In principal component analysis, the significant drop in the scree plot indicates that the eigenvalues less than 1 can be ignored without losing any important information. In this study, the scree plot graph (Figure 4) shows the significant change in the slope after the fourth eigenvalue which indicates that only 4 components are retained. The loading factors which are >0.75, 0.50–0.75, and 0.30–0.50 are classified as strong, moderate, and weak relationships, respectively.

From the results of Table 4, PC1 explained 58.49% of the total variance and had a significant contribution from the variables EC, TA, TH, HCO$_3^-$, CO$_3^{2-}$, Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$, TDS, and Cl$^-$ with a strong positive loading value of > 0.9. PC2 accounted for 10.71% of total variance has moderate positive correlation on Turbidity and Fe and moderate negative correlation with pH. PC3 had a moderate positive and negative correlation with SO$_4^{2-}$ and NO$_3^-$, respectively, with
Table 4. Pearson’s correlation matrix.

|                        | pH  | TA  | TDS | EC  | TH  | HCO$_3^-$ | CO$_3^{2-}$ | Cl$^-$ | NO$_3^-$ |NH$_4^+$ | NO$_2^-$ | Fe  | K$^+$ | Na$^+$ | Mg$^{2+}$ | Ca$^{2+}$ | SO$_4^{2-}$ | PO$_4^{3-}$ |
|------------------------|-----|-----|-----|-----|-----|-----------|-------------|--------|----------|---------|----------|-----|-------|-------|-----------|-----------|-------------|-------------|
| Turbidity              |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TDS                    | 0.19| 0.4 | 0.29| 0.28| 0.38| 0.391**   | 0.361**     | 0.26   | 0.26     | 0.349   | 0.152   | 0.228 | 0.152 | 0.173 | 0.152     | 0.152     |             |             |
| TA                     | 0.21| 0.49| 0.28| 0.28| 0.38| 0.391**   | 0.361**     | 0.26   | 0.26     | 0.349   | 0.152   | 0.228 | 0.152 | 0.173 | 0.152     | 0.152     |             |             |
| EC                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| pH                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TA                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TDS                     |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| EC                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| pH                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TA                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TDS                     |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| EC                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| pH                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TA                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TDS                     |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| EC                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| pH                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TA                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TDS                     |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| EC                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| pH                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TA                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| TDS                     |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |
| EC                      |     |     |     |     |     |           |             |        |          |         |          |     |       |       |           |           |             |             |

Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

9.56% of variance and PC4 form 6.1% of variance with strong positive correlation with NH$_4^+$ alone.

Understanding the changes in the river environment is critical for successful management and long-term sustainability. The physical and chemical characteristics of the water depict the current state of its quality and it is important to periodically track the quality of the surface water to reverse the pollution impact. This study aimed to understand the suitability of Noyyal river water for drinking and irrigational purposes. The findings of the present investigation show that the water quality of the Noyyal river is affected because of the improper use and the discharge of industrial effluents and domestic wastes. Several researchers have reported the water quality of the Noyyal river and its impact on humans, the environment, agriculture, and economic conditions. The results of drinking water quality of this study are in line with the findings of Sapna, Thangavelu, Mithran, and Shanthi (2018) and Jeyaraj et al. (2018). Various researchers have investigated the reasons for the deterioration of Noyyal river quality (Adarsh & Priya, 2020; Duraisamy & Krishnaraj, 2018; Gayathri et al., 2020; Prabha, Gogo, Mazumder, Ramanathan, & Kumar, 2017; Raganath & Priya, 2017; Shanmugavalli Elumalai, Mahalakshmi, & Sarananthan, 2014). Domestic sewage disposal and textile industries in and around the Tiruppur district contribute much to the pollution in the river. Domestic sewage from Coimbatore and Tiruppur town is discharged into the Noyyal river since the capacity of the treatment plants is less compared to the amount of sewage produced in the cities. It has been reported that the untreated sewage wastes are let into the river, which may be the prime cause for the pollution of Noyyal in the Coimbatore stretch (Subramanian, 2018a). Jeyaraj et al. (2018) in their study reported that the higher level of total dissolved solids in the river may be because of the discharge of effluents without proper treatment. Textile effluents contain a high concentration of organic and inorganic compounds. The main compositions of textile effluents are dyes, salts, surfactants, acids, binders, reducing agents, thickeners, etc. These compounds, when mixed with the freshwater system will alter the physical and chemical composition of the surface water and this may eventually affect the quality of the groundwater. As the river water is the prime source of water for domestic, agricultural, and industrial purposes, the deterioration of it can cause various health impacts, impacts on crops, aquatic habitat, and even microbial diversity, which will lead to ecological imbalance. Farmers and fishermen living in the Noyyal belt have claimed that the fish varieties have decreased dramatically, and also cultivating crops like paddy, sugarcane, turmeric, cotton, and vegetables has become
Table 5. Principle component analysis for water quality parameters of Noyyal river.

| Parameters | Component | Communalities | Extracted |
|------------|-----------|---------------|-----------|
|            | 1         | 2             | 3         | 4         |               |
| Turbidity  | .350      | .744          | .000      | .080      | .682         |
| EC         | .987      | −.052         | .095      | −.014     | .987         |
| pH         | .092      | −.096         | −.293     | −.367     | .713         |
| TA         | .924      | −.077         | −.212     | .048      | .908         |
| TH         | .981      | −.008         | −.053     | −.025     | .966         |
| HCO3       | .923      | −.062         | −.209     | .056      | .902         |
| CO3        | .926      | −.101         | −.217     | .035      | .916         |
| Ca         | .951      | .028          | −.068     | −.079     | .915         |
| Mg         | .964      | −.043         | −.038     | .031      | .933         |
| Na         | .963      | −.072         | .086      | .024      | .940         |
| K          | .985      | −.050         | .084      | −.029     | .980         |
| Fe         | .129      | .587          | .481      | −.337     | .706         |
| NH3        | −.129     | −.334         | .249      | .817      | .857         |
| TDS        | .987      | −.052         | .095      | −.014     | .987         |
| NO3        | .150      | .296          | −.761     | .250      | .751         |
| Cl         | .903      | .014          | .258      | −.080     | .890         |
| SO4        | .399      | −.261         | .720      | .142      | .766         |
| PO4        | .405      | .491          | −.050     | .269      | .480         |
| Eigenvalue | 10.53     | 1.92          | 1.72      | 1.09      |              |
| % variance | 58.49     | 10.71         | 9.56      | 6.10      |              |
| Cumulative | 58.49     | 69.2          | 78.77     | 84.88     |              |

Figure 3. Plotted values of Salinity (EC) and Sodium (SAR) hazard for classification of irrigation water quality (USSL Staff 1954, modified by Mahmoudi and Shahid (2014))
difficult, thus requiring rigorous crop management measures. (Subramanian, 2018b).

Conclusion

The present study revealed that the Noyyal river is polluted as shown by the drinking water quality index and irrigation water quality index. The study also shows that the surface water quality is fresh to brackish. The results obtained by drinking WQI analysis state that the Noyyal river from its origin remains fresh and can be used for drinking and domestic purposes without any treatment before it reaches the city limit from Poothanur in Coimbatore district. The samples collected from downstream of the Noyyal river are polluted due to the various human activities and agricultural practices. Relating to irrigation water quality, the results evidence that most of the collected samples have exceeded the limits of suitable irrigation water and the continuous use and release of water can affect the crop viability, soil structure, and groundwater resource. The correlation and principal component analysis used in the study shows that various factors such as industrial, domestic, sewage disposal, and agricultural runoffs contribute to the pollution in the Noyyal river. Over the course of three decades, as the textile industry grew, the river gradually lost its holiness and became a dead river. The present investigation strongly contends proper execution and management of effluent treatment plants and restricts any direct and indirect cause of contamination to ensure the sustainable management of freshwater resources.

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