STATISTICAL ASSESSMENT OF WATER QUALITY PARAMETERS FOR POLLUTION SOURCE IDENTIFICATION IN NOYYAL RIVER, COIMBATORE, TAMILNADU

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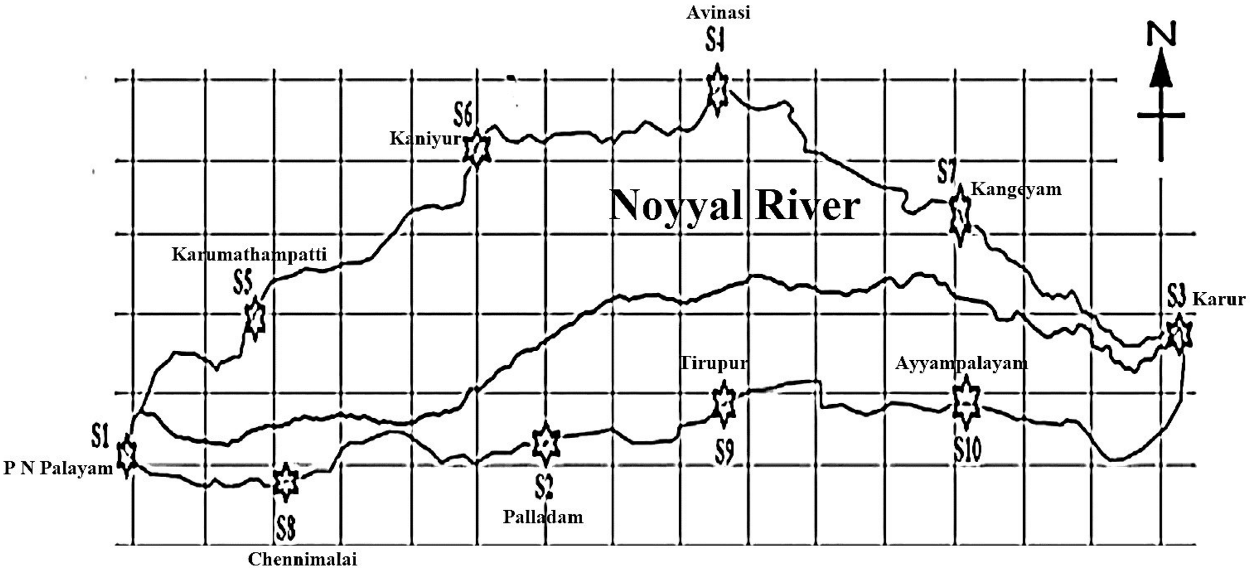
Graphical Abstract



Abstract

This study aimed to determine the extent of the water quality decrease in the Noyyal River in Tamilnadu by analyzing the seasonal change of water's physicochemical properties, identifying possible sources of pollution, and grouping the monitoring months based on shared characteristics. The measurements were taken during four different seasons. Forty percent of the water quality indices, including turbidity, DO concentration, EC, Cl concentration, TA, and COD in all seasons, were outside the acceptable limits recommended by various agencies, according to the analytical data. A 95% confidence interval's statistical analysis revealed that 52% of the contrasts differed significantly. according to the factor analysis, four factors accounted for 93.44% of the variation overall, which showed the best fit between the parameters. The significant pollution loading, primarily attributed to toxicological chemicals and industrial discharge, was reflected in Total Dissolved Solids, Biochemical Oxygen Demand, Chemical Oxygen Demand, Electrical Conductivity, Turbidity, Dissolved Oxygen, and Chloride levels. Cluster analysis revealed a seasonal variation in surface water quality, indicating contamination from rainfall or other sources. Nevertheless, seasons did impact various physicochemical characteristics, with winter recording the highest pollution values. The Noyyal River's seasonal temperature change and increased rainfall were the causes of this self-refining tendency, which goes winter < summer < pre-winter < rainy season.

Keywords: Water Quality, Characteristic Analysis, Noyyal River, Cluster analysis, Statistical model.

1. INTRODUCTION

The first necessity for human life is water. Around the world, most ancient civilizations sprang up along the banks of significant rivers. The primary uses of freshwater, including drinking and agriculture, are met by rivers. The hydrological cycle is being significantly altered by climate change and human activity, making water quality deterioration a global concern for the sustainable growth of humankind (Rakesh Sharma et al., 2021). Improper agricultural drainage from rivers and pollution caused by human activities poseserious andsevere challenges to water resources. caused mainlySurface water contamination and declining water quality are caused primarily by anthropogenic factors, including untreated industrial effluents, inadequately deposited residential trash, and agricultural runoff (Vellingiri et al., 2023). The water quality in rivers is affected by seasonal variations in natural and man-made processes, such as temperature and precipitation, which give rise to unique characteristics for each season (Amit Kumar et al., 2021). Manybuildings are built next to rivers and other bodies of water in Tamil Nadu. Surface water is contaminated when factories release untreated wastewater into rivers, either directly or indirectly. Over the past few decades, industrial effluents and municipal solid waste have significantly negatively impacted Indian river water quality (Ayyamperumal et al., 2022). One of the rivers encircling Coimbatore, the city of Tamilnadu, is the Noyyal River. This river verefaces ecological severe issues and water pollution, resulting in a biological and hydrological. A heavily inhabited area with several tanneries, oil refineries, electroplating facilities, fertilizer manufacturing facilities, dairy production facilities, and synthetic medication manufacturing enterprises surrounds this river (Krishnamoorthy et al, 2023). The thirty of the seventy-two harmful compounds found in untreated textile dyeing wastewater cannot be eliminated by treatment using the methods available today.

The people living near the Noyyal River have turned it into a dump for all kinds of solid, liquid, and chemical garbage. This means that in addition to domestic waste, the Noyyal River receives a complicated combination of numerous toxic organic and inorganic compounds from industry, which exacerbates the loss in water quality. The water condition deteriorates and the water level drops during the dry season with reduced flows compared to the wet season. Monitoring the physicochemical water quality parameters is essential for evaluating the ecosystem, hydrochemistry, ecology, and water environment as well as for restoring water quality (Ali et al, 2021). According to the Government of India's Action Plan, dredging is being done to increase river flow, generate canal circulation for Coimbatore City's transportation and satisfaction, and remove garbage from the riverbank. Additionally, the Noyyal River is shielded from unauthorized invasion. Many earlier studies (Shanmugasundharam et al., 2023; Parween et al., 2022; Perumal et al., 2023; Anh et al., 2023; Robert et al., 2023; Tharmar et al., 2022) has been conducted to analyze the surface water quality during various seasons with physicochemical properties and toxicity of water bodies. These studies used multivariate statistical techniques. Because the process of varying the quality of water is ongoing, water quality evaluation requires up-to-date data. This study therefore sought to assess the physicochemical parameters of the water from the Noyyal River as it varied over time, primarily over the seasonal cycle. To evaluate the extent of similarity and optimal alignment between water property parameters and their sources, the existence or absence of seasonal variations in these properties, and the connections among various water quality variables, the study employed diverse statistical methodologies like post hoc, correlation matrix, rotation factor varimax and cluster analyzes. These statistical techniques were instrumental in comprehensively analyzing and understanding the intricate relationships within the water quality data.

2. STUDY AREA

The Noyyal River, originating from the Vellingiri Hills in Tamil Nadu's Western Ghats, holds historical significance for Coimbatore's region, traditionally supporting agriculture and local livelihoods. It flows through various districts, primarily Coimbatore, Tiruppur, and Erode. Eventually, the river joins the Kaveri River near Noyyal village, a town in Karur district, Tamil Nadu. This confluence with the Kaveri River occurs after covering a course of approximately 180 kilometres (about 112 miles) from its origin. However, rapid urbanization, industrialization, and agricultural activities have severely deteriorated its condition. Today, the river faces a critical threat from untreated industrial effluents and agricultural runoff, significantly compromising water quality and endangering the ecosystem. This pollution not only affects aquatic life but also impacts communities reliant on the river for irrigation. Despite efforts from governmental and non-governmental entities to address the issue through wastewater treatment and sustainable practices, restoring the Noyyal River's health remains a complex challenge, demanding a delicate balance between development and environmental preservation for Coimbatore's long-term well-being.

2.1 Information about land use and land cover

is the third most significant urban area located in the western region of Tamil Nadu state, on the border with Kerala state. With a population of around 6 million, Coimbatore is one of the most populated cities in the world. Sewage treatment facilities barely cover 25% of the city's total territory. Over 50% of Coimbatore City's municipal garbage has been dumped into its waterways without a functional waste management system. The Noyyal watershed research area is a seasonal river in the Vellingiri hills in the Coimbatore district's Western Ghats. The watershed passes through the districts of Coimbatore, Tiruppur, Erode, and Karur before entering the Cauvery River in Noyyal village. Because of urbanization, industry, and population increase, the research region has an abnormally high garbage discharge rate into its rivers. It is roughly located between latitudes 10° 56′ 20′ and 11° 19′ 12′ in the north and longitudes 76° 41′ 28′ and 77° 56′ 48′ in the east. The watershed is used by humans for drinking, irrigation, and other purposes every 3 km at most, and it spans 175 km. There are 2,58,834 acres in the river's total catchment basin. The minimum and maximum temperatures range is 17.3 to 24.4°C and 29.1 to 36.6°C, respectively. Five different soil types are found in the study area: grey, red, colluvial, alluvial, and forest soils.

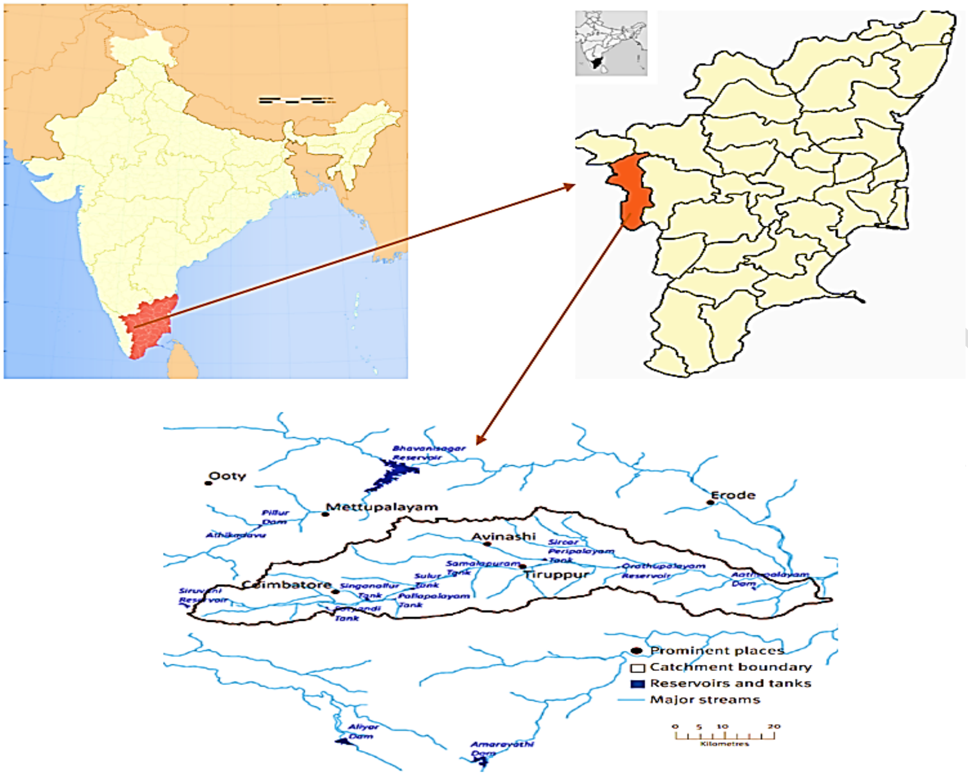


Figure 1 – Study area map of Noyyal river, Coimbatore, Tamilnadu, India.

2.2 Collection of water samples

Water samples were gathered from four distinct sites, namely Perur, Kuniyamuthur, Vellalore, and Vadavalli. Four different seasons were used to gather water samples (each around 1000 mL): Dec – Feb (Winter), Mar – May (Summer), Jun – Aug (Rain) and Sep – Nov (Pre-monsoon) respectively. Twelve sample collection sessions were conducted from December 2022 to November 2023, with a 30-day interval between each session. The water samples were obtained at midstream locations at 10 – 20 cm depth during low tide period. The collected samples were then filtered using filter paper (Whatman 41) to eliminate suspended materials, and from each filtered sample, measurements of chemical and biochemical oxygen demand (COD & BOD_5). Further, the alkaline potassium iodide was added to the samples to avoid the threats caused by fungi and pathogenic agents. After being transported to the lab and appropriately marked, the bottles were kept sealed and refrigerated until further examination.

2.3 Analytical methods

Twelve critical parameters were chosen for physicochemical water quality analysis, and listed in Table 1. An in-situ device was employed to assess the temperature, pH, and electrical conductivity (EC) of the collected sample of water. This involved measuring the respective parameters by utilizing a pH electrode, conductivity meter, and a mercury thermometer. Eriochrome Black T indicator titrated with EDTA was used to determine the TH of the water and a meter scale was used to measure the water's depth. The alkalinity of the water sample was determined by titrating $CaCO_3$, employing a methyl red (bromocresol green) indicator. Using a turbidity meter, the standard procedure, and a DO meter with a luminous DO probe, the concentrations of Cl, DO, and turbidity were measured, respectively. After being filtered and collected gravimetrically, the TSS were baked to dryness. A TDS meter was utilized to determine the TDS concentration quickly. BOD_5 was calculated using the five-day dilution technique. COD was measured using the colorimetric technique using a micro-digestion reactor. The mean value was chosen after each assay was completed in triplicate.

2.4 Water Quality Index (WQI)

In this experimental work, the physical and chemical characteristics of Noyyal River water have been analyzed from December 2022 to November 2023 at 3-month intervals at 4 locations. However, to calculate the Water Quality Index (WQI), 10 different locations were selected, and the samples were taken at a depth of 1 m. Then the characteristics of collected water samples were analyzed with water quality standards. Calculating the water quality index (WQI) of a river involves several steps to assess various water quality parameters and combine them into a single value that represents the overall water quality condition. The Water Quality Index (WQI) serves as a comprehensive rating system that evaluates the collective impact of various individual water quality parameters on the overall condition of the water. It is primarily oriented toward human consumption, providing an essential tool for assessing water quality and its suitability for drinking purposes by quantifying its quality index. In estimating the Water Quality Index (WQI), criteria specific to drinking purposes are considered. According to this approach, the weight assigned to different water quality parameters is inversely proportional to the recommended standards set for those parameters. Horton (1965) initially proposed the concept of the water quality index to evaluate the quality of drinking water. Subsequently, various researchers and countries have adopted this method for their assessments. Equation 1 can be used to calculate the WQI of the noyyal river.

$$WQI = \frac{\sum W_n Q_n}{\sum W_n} \qquad (1)$$

Here, W_n is the unit weight of each quality parameter. For water $W_n = 1$ and equation 2 can be used to calculate the unit weight of any parameter.

$$W_n = \frac{K}{S_n} \tag{2}$$

K is the constant of proportionality and S_n is the desirable value of any parameter. Equation 3 can be used to calculate the S_n concerning sub-index of each parameter (Q_n).

$$Q_n = \frac{V_n - V_o}{S_n - V_o}\, x\, 100 \tag{3}$$

V_n is the mean concentration and V_o is the actual value of the pure water parameter. (If pH = 7, $V_o = 0$). The WQI can be classified into the following categories. If the WQI value lies between 0 – 25 the water is in excellent condition and is suitable for drinking without any prior treatment. The WQI lies between 25 – 50, is categorized as in good condition, and requires a disinfection process for consumption. The water requires primary treatment before drinking if the WQI value comes in between 50 – 75 and it is in the poor category. Similarly, a secondary treatment process is required for the very poor category of water (WQI = 75 – 100) and if the value gore more than 100, it is unsuitable for drinking.

3. RESULTS AND DISCUSSION

3.1 Physicochemical properties of collected water samples

Table 1 shows the physical and chemical properties of water samples that were examined at locations S1, S2, S3, and S4 (Fig. 1) throughout different seasons. The average temperature of the water samples gathered at the four locations varied between 20°C and 28°C. Considering their seasonal fluctuation, Table 1 shows the seasonal mean temperatures for each of the four seasons as follows: (22.17 ± 0.04) °C, (26.72 ± 0.12) °C, (24.95 ± 0.03) °C, and (23.12 ± 0.11) °C. Table 2 indicates that these levels were deemed suitable for domestic activities, such as drinking, and aquatic life. The results of this study stated that the Noyyal River's temperature varied from 22.3°C to 30.9°C from March to June. The biotic community and aquatic populations may not be limited in their ability to survive by temperature variations in the Noyyal River water itself. Table 3 shows a considerable variation in seasonal temperature with a 95% confidence range. Duncan's multiple range test (DMRT) revealed that all the contrasts had p values less than 0.0001. The significance of water temperature in clean water may be diminished by aquatic life's wide tolerance to temperature changes (Muduli et al, 2021). The water temperature can significantly impact the dissolved oxygen (DO) levels in contaminated water. The average pH of the water ranged from 6.32 to 8.36 (Fig. 2), signifying a slightly alkaline to acidic nature. The Noyyal River water's pH ranges were 6.57 to 7.86 and 7.18 to 8.34, respectively, and they were roughly consistent with the values found throughout this inquiry. Regarding seasonal variations, the average pH values presented in Table 1 fell within the permissible range (Table 2) for various purposes, including residential use, recreational activities, and irrigation. For agriculture purpose and fish survival, the recommended pH range is typically between 6.5 and 8.0, while the general range for surface water systems is between 6.5 and 8.5.

Examining the effects of water acidity on fish and water insect populations might yield information about how these elements can affect duck dispersal in freshwater systems (Tyagi et al, 2021). Interestingly, there was no discernible preference for freshwater systems with a particular degree of acidity among insectivores and omnivores, despite piscivores being prevalent in water with a pH of 5.5. Wintertime pH in the current research varied somewhat, while other seasons showed a generally constant pH. Around 7 was the pH values that persisted. Water population dispersal is therefore not limited by pH, with the exception of the winter months (Dimri et al, 2021). The Noyyal River's seasonal pH values ranged from 6.74 ± 0.15 in the summer to 8.09 ± 0.11 in the winter (Table 1). Table 3 demonstrates that the pH varied significantly over the seasons. P values for every contrast were less than 0.0001, with the exception of rain vs. pre-winter. The average turbidity of the sample water obtained from the four locations diverse from 25.62 to 40.87 NTU (Fig. 2).

Table 1 – Physical and Chemical parameters of Noyyal river with mean and standard deviations (Period from Dec 2022 to Nov 2023)

Physical and Chemical Characteristics	Winter	Summer	Rain	Pre - Winter
pH	7.18 ± 0.09	6.54 ± 0.12	6.78 ± 0.18	7.52 ± 0.05
Turbidity (NTU)	38.19 ± 2.64	34.67 ± 1.18	29.17 ± 1.41	27.84 ± 1.38
Cl^- (mg/L)	101.14 ± 2.72	93.18 ± 0.41	70.14 ± 3.28	80.17 ± 3.67
Temperature °C	22.17 ± 0.04	26.72 ± 0.12	24.95 ± 0.03	23.12 ± 0.11
Total Alkalinity (mg/L)	274.16 ± 22.85	264.18 ± 3.92	208.56 ± 16.85	203.65 ± 19.58
COD (mg/L)	274.61 ± 5.18	248.37 ± 5.67	192.18 ± 6.28	228.19 ± 8.65
BOD_5 (mg/L)	46.28 ± 2.19	42.24 ± 1.92	27.16 ± 3.69	31.29 ± 2.29
DO (mg/L)	0.38 ± 0.08	0.59 ± 0.18	1.95 ± 0.21	1.64 ± 0.38

Total Dissolved Solids (mg/L)	772.64 ± 19.28	718.19 ± 9.64	521.94 ± 20.54	582.64 ± 28.62
Electrical Conductivity (µs/cm)	1328.64 ± 45.67	1249.28 ± 33.24	958.32 ± 35.49	986.26 ± 65.49
Total Hardness (mg/L)	318.56 ± 9.58	276.19 ± 7.08	206.57 ± 4.82	228.65 ± 7.81
Total Suspended Solids (mg/L)	125.64 ± 5.28	123.72 ± 4.01	89.28 ± 6.95	84.52 ± 3.53

Higher values were discovered in the current research investigation, which indicated that the Noyyal River's greatest mean turbidity was 32.46 NTU. Regarding their seasonal fluctuation, the four seasons' seasonal mean turbidity values were (38.19 ± 2.64), (34.67 ± 1.18), (29.17 ± 1.41), and (27.84 ± 1.38) NTU, in that order. Every figure is higher than the allowable limit for drinking and irrigation that has been recorded (Table 2). With the exception of two contrasts, where the DMRT estimated p values were 0.0147 and 0.0350, respectively, for rain vs winter and pre-winter vs winter, Table 3 indicates that there was no statistically significant variation in the periodic values of turbidity at a 95% assurance level. The water samples obtained at each of the four locations had mean Cl^- concentrations that fell between 60.8 and 108.2 mg/L (Fig. 2). The Noyyal River surface water has lower levels of Cl- concentration, ranging from 80.74 to 137.37 mg/L, according to the current analysis. The acceptable limits for chloride (Cl^-) content in surface water for human consumption typically range from 150 to 600 mg/L. The average values for sample stations S1, S2, S3, and S4 are shown in Table 2 and are 70.28 ± 15.46, 118.27 ± 21.47, 81.12 ± 14.28, and 82.08 ± 14.42 mg/L, respectively. These values do not meet the WHO's recommended safe range (2017a, 2017b). At site B in the winter, the Noyyal River water had the greatest seasonal Cl^- content (132.26 ± 8.47) mg/L, whereas at point S1 during the rainy season, it was the lowest (49.36 ± 10.74). According to Duncan's multiple range test (DMRT), there were no significant variations in the periodic values of chloride (Cl^-) levels, as evidenced by the lack of appreciable differences at a 95% confidence interval. Chlorinated insecticides and pollutants released by factories and synthetic mills along the river may be the causes of the chloride in the Noyyal River water (Kamboj et al., 2019). The water samples obtained at each of the four locations had mean TA values that fell between 176.4 to 292.6 mg/L (Fig. 2). The periodic mean total alkalinity concentration for each of the four seasons are presented in Table 1, and all of them exceeded the permissible limit as outlined in the standards provided in Table 2. The Noyyal River water's TA levels were found to vary from 172.57 to 294.38 mg/L; The average values of mg/L for points S1, S2, S3, and S4 were 274.16 ± 22.85, 264.18 ± 3.92, 208.56 ± 16.85, and 203.65 ± 19.58 mg/L, respectively.

DMRT revealed that, at a 95% confidence range, there was no discernible variation in the seasonal TA values (Table 3). USEPA (2012) states that a standard TA concentration greater than 100 mg/L is required. The total alkalinity values of water samples were higher than the recommended values during the pre-winter months, with a few notable exceptions. The TA increase in urban river water is probably due to oil refinery effluents, synthetic mills, pharmaceutical businesses, and companies that make antibiotics (Kisi et al., 2023). The four locations' average EC for the examined water samples fell between 756.37 and 408.56 µs/cm (Fig. 2). The average electrical conductivity (EC) values for the Noyyal River during the wet and dry seasons were 1462.61 µs/cm and 1305.87 µs/cm, respectively. The Noyyal River water's seasonal EC values, as reported by Subramanian et al. 2022, varied from 728.75 to 1980.00 µS/cm at various sample locations. In comparison, the EC values in this investigation were comparatively lower. The seasonal change, the different sample locations, and the tidal influences might all cause these variations (Verma et al, 2023). For drinking (10 µS/cm) and irrigation (2250 µS/cm) water, the periodic average of conductivity values for the Noyyal River water (1328.64 ± 45.67), (1249.28 ± 33.24), (958.32 ± 35.49), and (986.26 ± 65.49) µs/cm exceeded the permitted limits set by IS 2296 (1982) (Table 1).

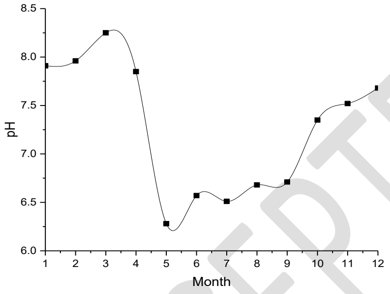
Table 2 – Water quality characteristics and its comparison with drinking, irrigation, and domestic standards

Type of property	Acceptable limits	Meet for standards at different seasons															
		Summer				Winter				Rain				Pre - Winter			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
pH	$6.5 - 8.5^{\alpha, \beta, ¥, €}$	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DO (mg/L)	$4 - 6^{\alpha}, 6^{\beta, ¥}$																
Temp. (°C)	$20 - 30^{\alpha, \beta, ¥}, 25^{€}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
COD (mg/L)	$4^{\alpha, \beta, ¥}, 200^{€}$																
BOD_5 (mg/L)	$< 6^{\beta, €}, 0.2^{¥}, 50^{\alpha}$																
Cl^- (mg/L)	$150 - 600^{\alpha, \beta}, 250^{¥, €}$																

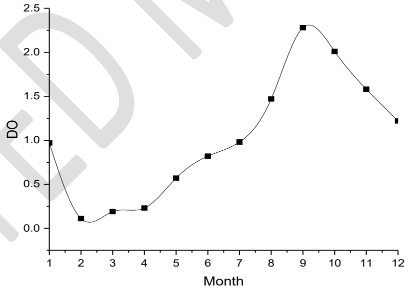
EC (µs/cm)	700^{α}, $1000^{¥, €}$																
Turbidity (NTU)	$10^{\alpha, \beta, ¥, €}$																
Total Alkalinity (mg/L)	$200^{\alpha, \beta, €}$									✓	✓			✓	✓		
Total Hardness (mg/L)	< 300^{α}, 200 - 500^{β}					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dissolved Solids (mg/L)	1000^{α}, $600^{\beta, ¥,}$ $500^{€}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Suspended Solids (mg/L)	150^{α}, $10^{\beta, ¥}$	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note: α, β, ¥ and € represents the standards of IS 10500 (2012), IS 2296 (1982), WHO (2017a, 2017b), USEPA (2012), respectively.

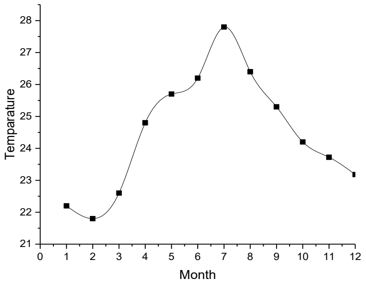
As indicated in Table 2, the water is not suitable for drinking, agriculture cultivation, internal usage, and other purposes. Except two constraints (summer vs winter & rain vs pre winter), the periodic conductivity levels provide significant constraints with other seasonal variations in DMRT analysis with 95% confidence interval. i.e., rain vs winter, prewinter vs winter, summer vs rain and prewinter vs summer seasons.



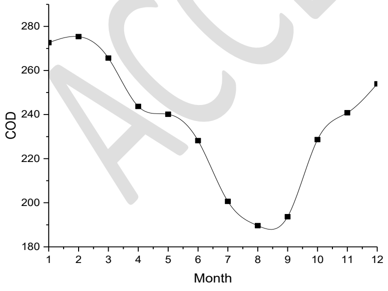
pH



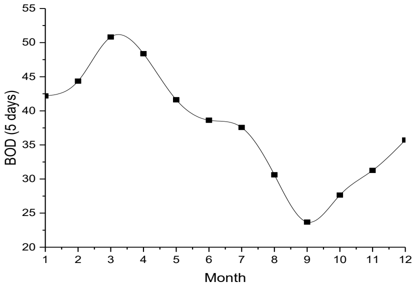
DO (mg/L)



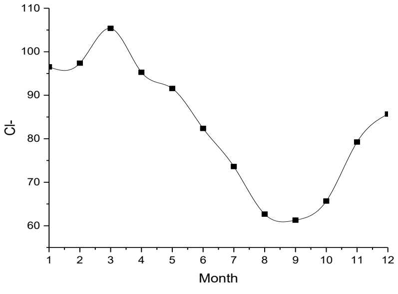
Temp. (°C)



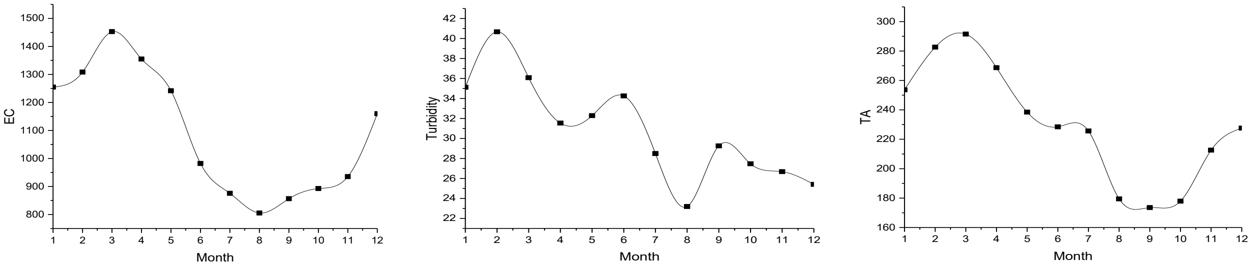
COD (mg/L)



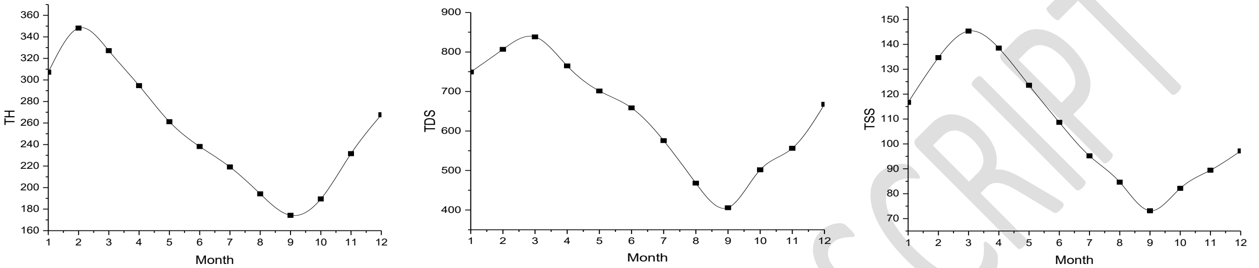
BOD_5 (mg/L)



Cl^- (mg/L)



EC (µs/cm) Turbidity (NTU) TA (mg/L)



TH (mg/L) TDS (mg/L) TSS (mg/L)

Figure 2 – Variations in physical and chemical properties of Noyyal river from Dec 2022 to Nov 2023

Due to the effect of maximum rainfall, the Noyyal River water gets diluted and reduced it neutralizes the charged particle ions in the rain vs winter season (Yadav et al., 2023). As depicted in Table 1, the total dissolved solids level of the samples collected across the four distinct seasons ranged from 407.24 to 853.57 mg/L. There were differences in the TDS content of the sample water, ranging from 187.24 to 452.34 mg/L and 537.67 to 671.54 mg/L. During the summer and winter, this research mostly showed increased TDS levels. The dry season was seen to have higher TDS. This indicates that due of the deficient winter rainfall, released toxicological chemicals may contaminate the river water quickly (Thyagarajan et al, 2021). The water from the Noyyal River has seasonal mean TDS values of 772.64 ± 19.28, 718.19 ± 9.64, 521.94 ± 20.54, and 582.64 ± 28.62 mg/L, as shown in Table 1. The observed variation in total dissolved solids (TDS) levels may be attributed to factors such as precipitation, dilution from rainfall, and increased flow (Rahman et al., 2021). It is noteworthy that the maximum limits for TDS in drinking water, according to USEPA (2012) and WHO (2017a, 2017b), are 600 mg/L, 500 mg/L, and 600 mg/L, respectively. As a result, the majority of the TDS levels were higher than allowed. The water from the Noyyal River was inappropriate for drinking and bathing at home, given that the permissible total dissolved solids (TDS) level for agriculture is 2000 mg/L. Nonetheless, it served the irrigation objective well (IS 2296 - 1982).

The Noyyal River's water quality deteriorates as a result of the high TDS load's inability to decrease the nitrogen load of urban wastewater adequately. Table 3 shows that, at a 95% confidence interval, the seasonal TDS levels differed significantly, as per DMRT. For the disparities between the winter and rainy seasons, the pre-winter and winter seasons, and the summer and rainy seasons, the p-values were less than 0.0001. In that sequence, the respective p-values for the comparisons of prewinter vs summer, summer vs winter, and rain vs pre-winter were 0.0001, 0.0321, and 0.0418. Table 4 indicates that there was a link between TDS and EC, which means that as TDS levels increase, EC values also increase and vice versa. The four collected water sample locations had mean TSS concentrations between 75 and 145 mg/L (Fig. 2). Noyyal River water has greater TSS concentrations (257–265 mg/L), according to Mohan et al. (2013). The higher concentrations of total suspended solids (TSS) in the river water may be attributed to the direct discharge of industrial effluent through pipelines, canals, open drains, and similar pathways, leading to pollution of the river water (Ayyandurai et al, 2022). Table 1 shows that the seasonal mean TSS concentrations were, in order, 84.52 ± 3.53, 89.28 ± 6.95, 123.72 ± 4.01, and 125.64 ± 5.28 mg/L. These values fell within the IS 2296 – 1982 permitted limits. As per WHO (2017a), the examined TSS values were significantly more than the drinking standard (Table 2). With the exception of two comparisons (summer vs winter and rain vs pre-winter), Table 3 reveals a significant variation in total suspended solids (TSS) levels among the seasons. The prominent variances between pre-winter vs winter, rain vs summer, and pre-winter vs summer had p values of 0.0074, 0.0062, 0.0053, and 0.0034, respectively. The four locations' mean total hardness concentration (TH) fell between 179.18 and 356.64 mg/L. The average value of sampling locations S1, S2, S3, and S4 were, in accordance with Figure 2, 228.65 ± 7.81, 206.57 ± 4.82, 276.19 ± 7.08, and 318.56 ± 9.58 mg/L.

Table 3 – Quality analysis of water in different seasons using DMRT – 95% confidence interval

Type of property	W vs R		W vs PW		W vs S		S vs R		S vs PW		PW vs R	
	p value	Prominent	p value	Prominent	p value	Prominent	p value	Prominent	p value	Prominent	p value	Prominent
pH	< 0.0001	✓	< 0.0001	✓	< 0.0001	✓	< 0.0001	✓	< 0.0001	✓	< 0.0218	✓
DO (mg/L)	< 0.0001	✓	< 0.0001	✓	0.127	×	0.0001	✓	0.0001	✓	0.3594	×
Temp. (°C)	< 0.0001	✓	< 0.0001	✓	< 0.0001	✓	< 0.0001	✓	< 0.0001	✓	< 0.0001	✓
COD (mg/L)	0.2546	×	0.4521	×	0.5175	×	0.3582	×	0.6163	×	0.3492	×

BOD$_5$ (mg/L)	0.4298	✗	0.4551	✗	0.8926	✗	0.3248	✗	0.2953	✗	0.7145	✗
Cl$^-$ (mg/L)	0.1492	✗	0.2186	✗	0.5127	✗	0.2549	✗	0.3184	✗	0.5146	✗
EC (µs/cm)	< 0.0001	✓	< 0.0001	✓	0.3152	✗	< 0.0001	✓	< 0.0001	✓	0.2514	✗
Turbidity (NTU)	0.0147	✓	0.0350	✓	0.4546	✗	0.1621	✗	0.0820	✗	0.9743	✗
Total Alkalinity (mg/L)	0.4517	✗	0.3126	✗	0.9154	✗	0.348	✗	0.2251	✗	0.9325	✗
Total Hardness (mg/L)	< 0.0001	✓	< 0.0001	✓	0.0051	✓	0.0003	✓	0.0027	✓	0.0281	✓
Total Dissolved Solids (mg/L)	< 0.0001	✓	< 0.0001	✓	0.0321	✓	< 0.0001	✓	0.0001	✓	0.0418	✓
Total Suspended Solids (mg/L)	0.0074	✓	0.0062	✓	0.7542	✗	0.0053	✓	0.0034	✓	0.8253	✗

Note: W – Winter, R – Rain, S – Summer and PW – Pre winter; Here ✓ represents the different prominent level of water in various seasons and ✗ represents the non-prominent level of water in multiple seasons

All of these numbers, with the exception of the winter season's, fell within the acceptable range as per the guidelines displayed in Table 2. Table 1 shows that the Noyyal River water's seasonal total TH was (206.57 ± 4.82) mg/L during the rainy season and (318.56 ± 9.58) mg/L during the winter. Additionally, the maximum readings at various sites in the Noyyal River were identical primarily because, the water was unfitting for drinking and other household uses. Water from the river was categorized as soft (300 mg/L) by Mathan et al, 2006. However, the Noyyal river water is categorized as hard during the rain and summer season. The total hardness concentrations were predominantly different by referring Table 3 and DMRT analysis with 95% of confidence interval. The p-values were < 0.0001, < 0.0001, 0.0051, 0.0003, 0.0027, and 0.0281 for the contrasts of rain vs winter, pre-winter vs winter, summer vs winter, and rain vs pre-winter. The complex contamination state of the Noyyal River was illustrated by the significant correlations found between hardness and other characteristics of water (Table 4).

Table 4 – Water quality characteristics and its correlation matrix

Type of property	Temp.	pH	DO	BOD$_5$	COD	EC	Cl$^-$	Total Alkalinity	Turbidity	TDS	TSS	TH
Temp.	1											
pH	-0.92^{**}	1										
DO	0.24	-0.31	1									
BOD$_5$	-0.12	0.093	-0.51^{*}	1								

COD	-0.21	0.318	-0.29	-0.38	1							
EC	-0.172	0.292	-0.78**	0.31	0.49*	1						
Cl$^-$	-0.21	0.35	-0.41	0.18	0.38	0.59**	1					
Total Alkalinity	-0.08	0.07	-0.61**	-0.78**	-0.29	0.34	-0.12	1				
Turbidity	-0.17	0.257	0.59*	-0.11	0.61**	0.62**	0.36	-0.02	1			
TDS	-0.32	0.41	-0.78**	0.21	0.62**	0.91**	0.52*	0.314	0.71**	1		
TSS	-0.08	0.148	-0.62**	0.47*	0.32	0.84**	0.67**	0.32	0.38	0.71**	1	
TH	-0.48	0.51*	-0.85**	0.41	0.56*	0.81**	0.39	0.48*	0.61**	0.89**	0.59**	1

Note: * represents the prominent correlation at 0.05 and **represents the prominent correlation at 0.01 levels in two tailed processes.

3.2 Chemical properties of collected water samples

The obtained water samples' mean DO contents ranged from 0 to 2.40 mg/L at each of the four locations (Fig. 2). The latest investigation indicated that the Noyyal River had zero DO levels all winter season. According to Haritash et al., 2016 - such a low number does not increase the chances of aquatic species surviving. The supported DO content standards are 6 mg/L for drinking water, 4-5 mg/L for amusement, 4-6 mg/L for fish and domesticated animals, and 5 mg/L for industrial uses. For such reasons, the water from the Noyyal River was practically unfit for use. The potential cause of the decline in DO might be attributed to the outflow of industrial effluent from the Coimbatore industrial region and the accumulation of municipal garbage, both of which need a greater concentration of COD and breakdown (Morhit et al, 2014). As a result, there are more anoxic conditions, less nutrients accessible, and more organic substances and pathogens are loaded into the water (Selvam et al, 2022). The seasonal DO concentrations are displayed in Table 1, all of which were substantially below the permitted levels indicated in Table 2: 0.38 ± 0.08, 0.59 ± 0.18, 1.95 ± 0.21, and 1.64 ± 0.38 mg/L, respectively. These seasonal and point-based observations suggest that the river's upper stretch had a higher DO level than its lower reach due to water flow. Alam et al. (2023) have reported that the decline in the DO level is attributed to the development and decomposition of submerged and floatingsubmerged and floating microphytes. Except for two comparisons (summer vs winter and rain vs pre-winter), the Duncan's multiple range test (DMRT) results presented in Table 3 indicated considerable variability in the seasonal dissolved oxygen (DO) values at a 95% confidence interval. However, there was no statistically significant variation in the seasonal biochemical oxygen demand (BOD_5) levels, as evidenced by the p values for the major contrasts of rain vs winter, pre-winter vs winter, rain vs summer, and pre-winter vs summer. The current study's average COD concentration varied from 192.37 to 278.61 mg/L (Fig. 2).

Municipal and industrial discharge loads might be the cause of this. Another possible cause is the elevated COD readings during the summer dry season. As a result of the water flow decreasing during this time, microbial growth rises significantly (Alnashiri et al, 2021). Furthermore, companies that produce organic chemicals, pesticides, distilleries, and dyes exacerbate the pollution caused by carbon dioxide in river water (Muthusamy et al, 2021). The seasonal mean COD values (274.61 ± 5.18, 248.37 ± 5.67, 192.18 ± 6.28, and 228.19 ± 8.65 mg/L) for seasonal variation at the four sample locations are shown in Table 1. As per WHO (2017a, 2017b), the maximum acceptable limit for COD concentration in water for drinking purposes is 4 mg/L. The irrigation standard is 250 mg/L, according to IS 2296 - 1982. We may conclude that the water from the Noyyal River was unfit for agricultural use and drinking. The Noyyal River's seasonal COD concentration was as low as 118.23 ± 21.51 mg/L during the rainy season and as high as 338.25 ± 19.31 mg/L during the winter at the report sample location. Table 3 shows that, at a 95% confidence interval, there was no discernible variation in seasonal COD levels.

3.3 Statistical methods

3.3.1 Correlation analysis using matrix

Each parameter under study's correlation coefficient (r) is displayed in Table 4 along with the significance level (p values) for each. The correlation between water temperature and pH was negative ($p < 0.01$ and $r = - 0.92$). However, there was no apparent relationship between temperature and other variables. While there was no discernible link with the other parameters, pH and TH positively correlated ($r = 0.51$ and $p = 0.05$). The temperature and turbidity of water exhibited a positive correlation with dissolved oxygen and the remaining parameters showed a negative correlation. Specifically, a significant inverse relationship was observed between DO, BOD_5, EC, TA, Turbidity, TDS, TSS and TH based on their regression values (r = 0.51, 0.78, 0.61, 0.61, 0.78, 0.71 and 0.85) associated with the p values (0.05, < 0.01, < 0.01, 0.05, < 0.01, < 0.01 and 0.01) respectively. Biochemical oxygen demand exhibited a significant positive correlation ($r = 0.84$ and $p < 0.01$) with total alkalinity and a weak positive relationship ($r = 0.45$ and $p = 0.05$) with total suspended solids. Total hardness ($r = 0.56$ and $p < 0.04$), electrical conductivity ($r = 0.49$ and $p < 0.05$), total dissolved solids ($r = 0.62$ and $p < 0.01$), turbidity ($r = 0.61$ and $p < 0.01$), and chemical oxygen demand did not show any significant negative correlation with these variables. There was an important and positive correlation found between EC and COD, Cl^-, turbidity, TDS, TSS and TH based on their regression values ($r = 0.49, 0.59, 0.62, 0.91, 0.84$ and 0.81) associated with the p values (< 0.01 for all parameters) respectively. Similarly, a positive correlation between Cl^- and TDS and TSS based on regression values ($r = 0.52, 0.67$) associated with p values (< 0.05, < 0.01), respectively. TH, DO, TA and BOD_5 show a strong association with r values ($r = 0.48, 0.61, 0.52, 0.78$) and p values (< 0.01 for all parameters). Except TDS, the turbidity exhibited a negative correlation with TH, COD, EC and DO based on regression values ($r = 0.71, 0.61, 0.52$ and 0.59) with p values (< 0.01, < 0.05, < 0.01 and < 0.01) respectively. The findings demonstrated a substantial positive connection between TDS and TSS ($r = 0.71$ and $p < 0.01$), total hardness ($r = 0.89$ and $p < 0.01$), and suspended solids ($r = 0.59$ and $p < 0.01$). Dissolved oxygen and electrical conductivity, dissolved oxygen and dissolved solids, dissolved oxygen and hardness, biochemical oxygen demand and total alkalinity, dissolved solids and hardness, and conductivity and dissolved solids were found to have significant correlations with each other in the study.

3.3.2 Factor analysis

The measured variables may be considered into a small factor and its relationship can be revealed using multivariate statistical method. A study using the varimax rotation factor was carried out in order to determine the best fit and make clear the link between the components (Table 5). Following statistical analysis, four factors were found to explain 93.44% of the total variance with eigenvalues > 1.0: factor 1 explained 50.28% of the variation, factor 2 explained 19.56%, factor 3 explained 14.93%, and factor 4 explained 8.67%. On factor 1, the variables turbidity, TDS, TH, COD, EC, and DO display strong negative loading and high positive loading, respectively (Table 5). The only parameter displaying negative loading with the other parameters was dissolved oxygen (DO), indicating that concentrations of other parameters would increase when the DO concentration decreases (Kale et al, 2020). Furthermore, DO exhibited negative loading against biochemical oxygen demand (BOD_5), whereas BOD_5 and total alkalinity (TA) demonstrated remarkably high positive loading values on factor 2. Consequently, BOD_5 will rise in response to an increase in TA and will likewise rise in response to a drop in

DO concentration. This is further supported by the noteworthy negative association that Table 4 shows between DO and BOD_5. Factor 3 had a strong positive value for pH and a high negative value for temperature. Factor 4 revealed a positive loading between the Cl and TSS concentrations, indicating that a rise in TSS concentration would also result in an increase in Cl concentration. The same sources primarily human sources are responsible for high amounts of COD, EC, BOD_5, and TA. Additionally, Table 4 shows a substantial connection between these variables, further supporting the idea that they originate from the same places.

3.3.3 Cluster analysis

The normalized data were subjected to cluster analysis using Ward's technique, using a similarity metric of squared Euclidean distances. According to Ward's technique, the squared error increase indicates how close two clusters are to one another (Tiri et al, 2017). The hierarchical cluster analysis was used to find out the tendencies for all seasons in in four different seasons. Using Ward's linkage procedure and squared Euclidean distances, the dendrogram (Fig. 3) revealed three statistically significant groups for the 12-month period from December 2022 to November 2023. August and September were the two months that made up the first cluster. All metrics had relatively greater concentrations throughout those months. October, November, July, and June made up the second cluster. Lower concentrations of water quality indicators were seen throughout these months, which correlated with the monsoon and post-monsoon seasons. This could be attributed to the significant amount of precipitation washing and diluting the environment (Rawy et al, 2023). December, January, February, March, April, and May were the months that were examined for the final cluster. These months had a somewhat greater concentration of all metrics than other months. Since winter, late winter, and summer were the main seasons throughout these months, lower water flow and greater concentrations of water characteristics frequently occurred. Surface runoff, effluent discharge, and natural flow all influence the water's quality in the winter.

Table 5 – Factor analysis by varimax rotation for physical and chemical properties of water

Type of property	Loading Factor			
	F1	F2	F3	F4
Temp.	-0.141	-0.048	***-0.928***	-0.051
pH	0.208	0.038	***0.951***	0.121

DO	***-0.713***	-0.567	-0.121	-0.237
BOD_5	-0.049	***0.915***	0.068	0.258
COD	***0.722***	-0.462	0.192	0.168
EC	***0.754***	0.315	0.059	0.489
Cl^-	0.247	-0.078	0.184	***0.923***
Total Alkalinity	0.156	***0.952***	0.028	-0.076
Turbidity	***0.859***	-0.147	0.078	0.086
TDS	***0.826***	0.253	0.217	0.369
TSS	0.423	0.359	-0.019	***0.762***
TH	***0.762***	0.395	0.324	0.196
Eigen Value (Initial)	6.196	2.476	1.584	1.009
Other Variance (%)	50.28	19.56	14.93	8.67
Cumulative Variance (%)	50.28	69.84	84.77	93.44

Note: Principal component analysis is the extraction method, and varimax with Kaiser normalization is employed as the rotation method. The boldly marked values signify the most robust connections with the corresponding component when identifying elements/parameters exhibiting similar behaviour, their sources, and the interrelations (+, -) within a component.

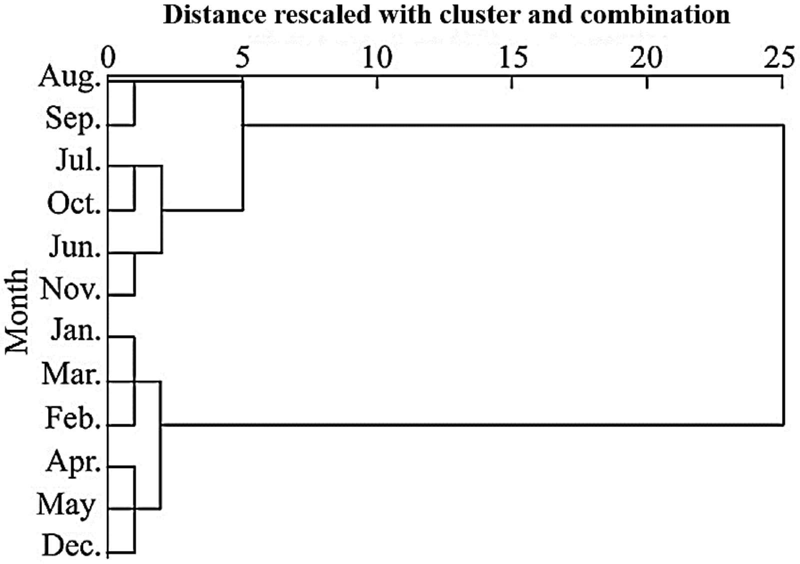


Figure 3 – Dendrogram plot of water samples in different months and their hierarchical clustering

3.3.4 Water Quality Index (WQI)

Apart from the four main stations (S1, S2, S3 and S4), six additional stations were selected to collect water samples to perform the WQI analysis. Figure 4 shows the ten different stations in the Noyyal River area. The samples were collected at every 5km intervals and preserved at less than 5°C in an icebox to avoid changes in characteristics due to temperature variations, then transported to the laboratory.

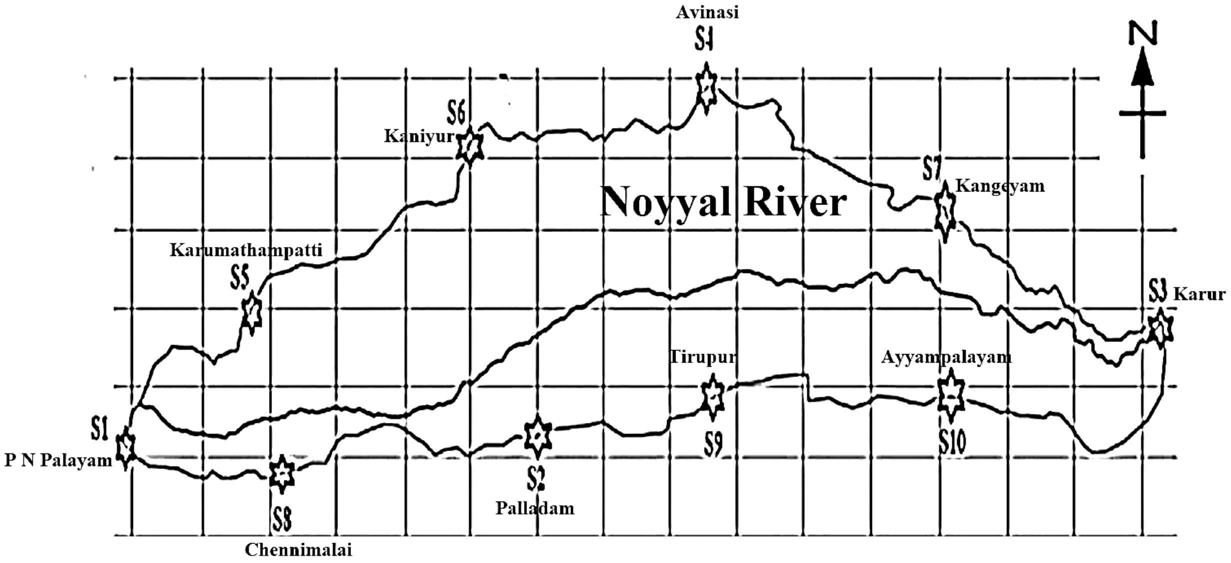


Figure 4 – Sampling locations in Noyyal River for WQI observations

Table 6 – WQI of collected Noyyal river water samples, Tamil Nadu

Sampling places	Sample No.	Temp. °C	pH	DO (mg/L)	BOD_5 (mg/L)	COD (mg/L)	EC (µs/cm)	Cl^- (mg/L)	Total Alkalinity (mg/L)	Turbidity (NTU)	TDS (mg/L)	TSS (mg/L)	TH (mg/L)	WQI (0-100) Scale	Classification
PN Palayam	S1	22.17	7.18	0.38	46.28	274.61	1328.64	101.14	274.16	38.19	772.64	125.64	318.56	33.16	Good
Palladam	S2	26.72	6.54	0.59	42.24	248.37	1249.28	93.18	264.18	34.67	718.19	123.72	276.19	29.35	Good
Karur	S3	24.95	6.78	1.95	27.16	192.18	958.32	70.14	208.56	29.17	521.94	89.28	206.57	55.61	Poor
Avinasi	S4	23.12	7.52	1.64	31.29	228.19	986.26	80.17	203.65	27.84	582.64	84.52	228.65	58.27	Poor
Karumathampatti	S5	23.57	7.18	1.18	33.48	182.64	1081.34	82.15	211.64	28.19	592.19	92.18	231.94	42.37	Good
Kaniyur	S6	24.29	7.61	1.29	32.19	181.19	1106.46	84.67	208.72	29.46	605.75	93.46	237.19	51.67	Poor
Kangeyam	S7	25.49	7.24	0.81	41.27	192.46	981.26	72.64	198.67	30.17	661.94	99.72	258.71	61.57	Very poor
Chennimalai	S8	24.38	6.97	0.92	37.29	203.14	954.37	70.49	195.77	31.28	581.64	101.69	282.12	48.34	Good
Tiruppur	S9	23.47	7.24	1.08	33.15	211.42	992.65	86.72	208.67	33.75	559.49	91.65	241.94	108.34	Unfit for consumption
Ayyampalayam	S10	24.51	6.73	0.91	36.17	201.61	1054.12	83.18	215.94	32.15	709.64	88.42	228.21	60.28	Very poor

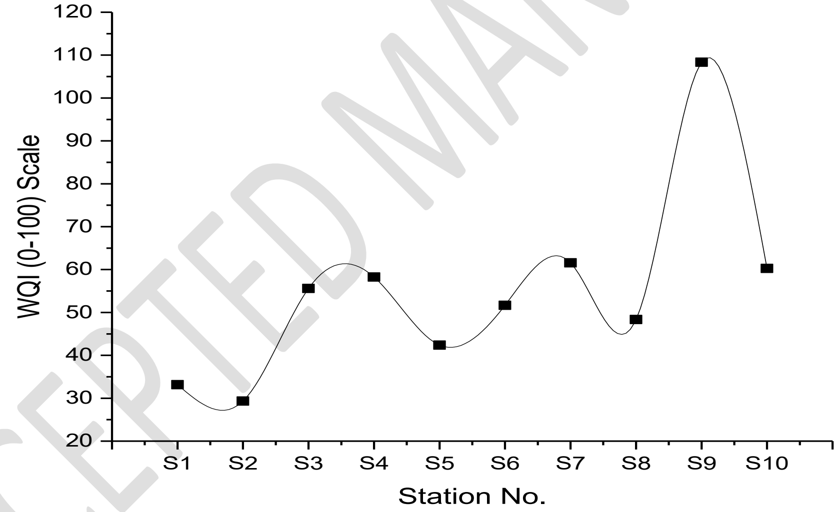


Figure 5 – WQI of Noyyal river water at different locations

Figure 5 shows the WQI of Noyyal river for 10 different stations. The 10 samples in the current investigation had Water Quality Indexes (WQI) ranging from 29.35 to 108.34. Only three samples (S1, S2, and S5) showed acceptable water quality out of all the samples. The Tiruppur (S9) sample, on the other hand, surpassed a WQI of 100, indicating that the water is not appropriate for human consumption. The increasing quantities of total solids in the water, presumably as a result of sewage dumping into the river, are most likely the cause of this high index number. According to the study, three samples (S3, S4, and S6) showed low water qualit three samples (S3, S4, and S6) showed low water quality. The other two samples (S7 and S10) showed extremely bad water quality. All of the Noyyal River's sample results showed inferior water quality, most likely due to high pollution levels from sewage disposal, agricultural runoff, textile industry effluents, and other related industries. The water cannot be drunk if it is not treated. These results align with research done by Ashwin et al. (2022) on the Noyyal River and the ponds connected to it in Coimbatore.

4. CONCLUSIONS

The degree of water contamination in the Noyyal River was assessed in this study by examining seasonal fluctuations in water quality. Anthropogenic sources were revealed to be the primary cause of the water contamination. The healthy association among several factors under investigation corroborated this conclusion. Using multivariate statistical approaches, including factor analysis, cluster analysis, and Pearson's correlation, surface river water quality data changes were evaluated seasonally. Except low DO levels, all water quality parameters achieved their maximum decreased states over the winter. The winter had higher concentrations of all parameters than the other seasons, according to the results of the seasonal cluster analysis. Significant variances in temperature, pH, total dissolved solids (TDS), and total hardness (TH), along with four significant contrasts (electrical conductivity, turbidity, and total suspended solids), were determined with a 95% confidence interval. Duncan's multiple range test (DMRT) reported that 52% of the contrasts were statistically different. Additionally, the levels of chemical oxygen demand (COD) in the Noyyal River were consistently high at every location, suggesting a significant concentration of pollutants. According to the findings, the Noyyal River's total pollution level exceeded permissible bounds for the physicochemical and chemical characteristics of the water. The water in the Noyyal River had a self-refining seasonal tendency due to the shift in seasonal temperature and the increase in rainfall. Pre-winter > summer > winter > wet season. The Noyyal River water's seasonal mean and lowest seasonal value during the rainy season, however, had mean values of turbidity (31.87 NTU), EC (1092.4 µs/cm), COD (198.61 mg/L), BOD_5 (35.27 mg/L), DO (1.19 mg/L), and chloride (86.01 mg/L) that were unfavourable for their intended applications. Owing to seasonal changes, pollution levels were probably going to fluctuate. The water quality indexes showed the examined river water was severely contaminated. The investigation found that most of the year, the water in the Noyyal

River was unfit for human consumption, irrigation, amusement, or aquatic life. To reduce the amount of pollutants building up in the Noyyal River and to avoid environmental damage, proper management of household and industrial wastes is necessary.

REFERENCES

A. Shanmugasundharam, S.N. Akhina, R.P. Adhithya, D. Satheesh Herbert Singh, S. Krishnakumar. Water quality index (WQI), multivariate statistical and GIS for assessment of surface water quality of Karamana river estuary, west coast of India, Total Environment Research Themes, 6, 100031, 2023. https://doi.org/10.1016/j.totert.2023.100031

Abirami Subramanian, Sushmitha Baskar. Water quality assessment of Noyyal river using water quality index (WQI) and multivariate statistical techniques, Water Science, 36 (1), 85-98, 2022. 10.1080/23570008.2022.2129146

Alam, A, Barkatullah, M, Kumar, A. Water Quality Status of Different Ghats of River Ganga in Patna Urban Area, Eng. Proc., 56 (85), 2023. https://doi.org/10.3390/ASEC2023-15408

Amit Kumar, A.K. Taxak, Saurabh Mishra, Rajiv Pandey. Long term trend analysis and suitability of water quality of River Ganga at Himalayan hills of Uttarakhand, India, Environmental Technology & Innovation, 22, 101405, 2021. https://doi.org/10.1016/j.eti.2021.101405

Amol Kale, Narsingrao Bandela, Jeetendra Kulkarni, Kishor Raut. Factor analysis and spatial distribution of water quality parameters of Aurangabad District, India, Groundwater for Sustainable Development, 10, 100345, 2020. https://doi.org/10.1016/j.gsd.2020.100345

Arafat Rahman, Ishrat Jahanara, Yeasmin Nahar Jolly. Assessment of physicochemical properties of water and their seasonal variation in an urban river in Bangladesh, Water Science and Engineering, 14 (2), 139 – 148, 2021. https://doi.org/10.1016/j.wse.2021.06.006

Bhagavathi Perumal, Niveditha Rajarethinam, Anusuya Devi Velusamy, Venkatesa Prabhu Sundramurthy. Water Quality Prediction Based on Hybrid Deep Learning Algorithm, Advances in Civil Engineering, 6644681, 2023. https://doi.org/10.1155/2023/6644681

Bureau of Indian Standards (BIS) – Drinking Water Specification, IS 10500 – 2012, New Delhi.

Bureau of Indian Standards (BIS) – Water Quality Standards, IS 2296 – 1982, New Delhi

Deepika Dimri, Achlesh Daverey, Ambika Kumar, Archana Sharma. Monitoring water quality of River Ganga using multivariate techniques and WQI (Water Quality Index) in Western

Himalayan region of Uttarakhand, India, Environmental Nanotechnology, Monitoring & Management, 15, 2021, 100375. https://doi.org/10.1016/j.enmm.2020.100375

El Morhit, M, Mouhir, L. Study of physico-chemical parameters of water in the Loukkos river estuary (Larache, Morocco), Environ Syst Res 3, 17, 2014. https://doi.org/10.1186/s40068-014-0017-7

El-Rawy, M, Fathi, H, Abdalla, F, Alshehri, F, Eldeeb, H. An Integrated Principal Component and Hierarchical Cluster Analysis Approach for Groundwater Quality Assessment in Jazan, Saudi Arabia. Water, 15, 1466, 2023. https://doi.org/10.3390/w15081466

Haritash, A.K., Gaur, S. & Garg, S. Assessment of water quality and suitability analysis of River Ganga in Rishikesh, India, Appl Water Sci 6, 383–392, 2016. https://doi.org/10.1007/s13201-014-0235-1

Hassien M. Alnashiri. Assessment of physicochemical parameters and heavy metal concentration in the effuents of sewage treatment plants in Jazan Region, Saudi Arabia, Journal of King Saud University – Science, 33 (8), 101600, 2021. https://doi.org/10.1016/j.jksus.2021.101600

K. R. N Ashwin, S. Arulmozhi, A. Gopalan, P. Mageshkumar, A. Rangaraj, Mukesh Panneerselvam, B. Nirmala Devi, C. Aravindhan, E. Prasath, Nyagong Santino David Ladu. Correlation, Regression Analysis, and Spatial Distribution Mapping of WQI for an Urban Lake in Noyyal River Basin in the Textile Capital of India, Advances in Materials Science and Engineering, 3402951, 2022. https://doi.org/10.1155/2022/3402951

Kisi, O, Parmar, K.S, Mahdavi-Meymand, A, Adnan, R.M, Shahid, S, Zounemat-Kermani, M. Water Quality Prediction of the Yamuna River in India Using Hybrid Neuro-Fuzzy Models, Water, 15, 1095, 2023. https://doi.org/10.3390/w15061095

Lakshmi Priya Thyagarajan, J. Jeyanthi, D. Kavitha. Vulnerability analysis of the groundwater quality around Vellalore-Kurichi landfill region in Coimbatore, Environmental Chemistry and Ecotoxicology, 3, 125 – 130, 2021. https://doi.org/10.1016/j.enceco.2020.12.002

Mariraj Mohan S, Vanalakshmi P. Assessment of water quality in Noyyal River through water quality index, International Journal of Water Resources and Environmental Engineering, 5 (1), 35 – 48, 2013. 10.5897/IJWREE12.084

Mathan, R. Physico-chemical studies of water quality of the Noyyal River, Tamil Nadu, South India. Chin. J. Geochem. 25 (1), 138, 2006. https://doi.org/10.1007/BF02840006

Muduli, P.R, Kumar, A, Kanuri, V.V. Water quality assessment of the Ganges River during COVID-19 lockdown, Int. J. Environ. Sci. Technol. 18, 1645–1652, 2021. https://doi.org/10.1007/s13762-021-03245-x

N. Krishnamoorthy, R. Thirumalai, M. Lenin Sundar, M. Anusuya, P. Manoj Kumar, E. Hemalatha, M. Mohan Prasad, Neha Munjal. Assessment of underground water quality and water quality index across the Noyyal River basin of Tirupur District in South India, Urban Climate, 49, 101436, 2023. https://doi.org/10.1016/j.uclim.2023.101436

Nguyen Tuan Anh, Le Duy Can, Nguyen Thi Nhan, Britta Schmalz, Tran Le Luu. Influences of key factors on river water quality in urban and rural areas: A review, Case Studies in Chemical and Environmental Engineering, 8, 100424, 2023. https://doi.org/10.1016/j.cscee.2023.100424

Nibedita Verma, Geeta Singh, Naved Ahsan. Water quality management by enhancing assimilation capacity with flow augmentation: a case study for the Yamuna River, Delhi, Water Science & Technology, 88 (7), 1821 – 1832, 2023. https://doi.org/10.2166/wst.2023.302

Nitin Kamboj, Vishal Kamboj. Water quality assessment using overall index of pollution in riverbed-mining area of Ganga-River Haridwar, India, Water Science, 33 (1), 65-74, 2019. 10.1080/11104929.2019.1626631

R. Ayyandurai, S. Venkateswaran, D. Karunanidhi. Hydrogeochemical assessment of groundwater quality and suitability for irrigation in the coastal part of Cuddalore district, Tamil Nadu, India, Marine Pollution Bulletin, 174, 113258, 2022. https://doi.org/10.1016/j.marpolbul.2021.113258

Ramamoorthy Ayyamperumal, Xiaozhong Huang, Fengjie Li, Zhang Chengjun, Gajendran Chellaiah, Gnanachandrasamy Gopalakrishnan, Venkatramanan Senapathi, Rajkumar Perumal, Justin K Antony. Investigation of microplastic contamination in the sediments of Noyyal River- Southern India, Journal of Hazardous Materials Advances, 8, 100198, 2022. https://doi.org/10.1016/j.hazadv.2022.100198

S. Muthusamy, K. Sivakumar, A. Shanmugasundharam, M. Jayaprakash. Appraisal on water chemistry of Manakudy estuary, south west coast, India, Acta Ecologica Sinica, 41 (5), 463 – 478, 2021. https://doi.org/10.1016/j.chnaes.2021.07.004

S. Selvam, K. Jesuraja, Priyadarsi D. Roy, S. Venkatramanan, Ramsha Khan, Saurabh Shukla, D. Manimaran, P. Muthukumar. Human health risk assessment of heavy metal and pathogenic contamination in surface water of the Punnakayal estuary, South India, Chemosphere, 298, 134027, 2022. https://doi.org/10.1016/j.chemosphere.2022.134027

Saghan Yadav, Likhita Nelapudi, Gurpinder Singh, Shushobhit Chaudhary, C. T. Dhanya, V. Arya. Impact of lockdowns and possible quantification of pollution sources on the water quality of the Yamuna River, Hydrological Sciences Journal, 68 (11), 1539-1552, 2023. 10.1080/02626667.2023.2224004

Samsad Parween, Nigar Alam Siddique, Mir Talas Mahammad Diganta, Agnieszka I. Olbert, Md Galal Uddin. Assessment of urban river water quality using modified NSF water quality index model at Siliguri city, West Bengal, India, Environmental and Sustainability Indicators, 16, 100202, 2022. https://doi.org/10.1016/j.indic.2022.100202

Shivani Tyagi, R.C. Dubey, R. Bhutiani, Faheem Ahamad. Multivariate Statistical Analysis of River Ganga Water at Rishikesh and Haridwar, India, Analytical Chemistry Letters, 10 (2), 195-213, 2020. 10.1080/22297928.2020.1756405

Sruthy Robert, Nisha Luckins, Ratish Menon. Quality deterioration of an Indian urban water source near an open dumping site, Water Practice and Technology, 18 (5), 1284–1299, 2023. https://doi.org/10.2166/wpt.2023.056

Syed Yakub Ali, Sangeeta Sunar, Priti Saha, Pallavi Mukherjee, Sarmistha Saha, Suvanka Dutta. Drinking water quality assessment of river Ganga in West Bengal, India through integrated statistical and GIS techniques, Water Science & Technology, 84 (10-11), 2997 – 3017, 2021. https://doi.org/10.2166/wst.2021.293

T. Rakesh Sharma, C. Ravichandran. Appraisal of seasonal variations in water quality of river Cauvery using multivariate analysis, Water Science, 35 (1), 49-62, 2021. 10.1080/23570008.2021.1897741

Tharmar, E.; Abraham, M.; Prakash, R.; Sundaram, A.; Flores, E.S.; Canales, C.; Alam, M.A. Hydrogeochemistry and Water Quality Assessment in the Thamirabarani River Stretch by Applying GIS and PCA Techniques. Sustainability, 14, 16368, 2022. https://doi.org/10.3390/su142416368

Tiri, A, Lahbari, N, Boudoukha, A. Assessment of the quality of water by hierarchical cluster and variance analyses of the Koudiat Medouar Watershed, East Algeria. Appl Water Sci (7), 4197–4206, 2017. https://doi.org/10.1007/s13201-014-0261-z

United States Environmental Protection Agency (USEPA), 2012. Edition of the Drinking Water Standards and Health Advisories. Office of Water, USEPA, Washington, D.C., EPA 822-S-12-001.

Vellingiri J, Kalaivanan K, Gopinath M P, Gobinath C Prabhakar Rontala Subramaniam, Sarathkumar Rangarajan. Strategies for classifying water quality in the Cauvery River using a federated learning technique, International Journal of Cognitive Computing in Engineering, 4, 187 – 193, 2023. https://doi.org/10.1016/j.ijcce.2023.04.004

World Health Organization (WHO). Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum. World Health Organization, 2017a, Geneva.

World Health Organization (WHO). UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) 2017 Report: Financing Universal Water, Sanitation, and Hygiene under the Sustainable Development Goals. World Health Organization, 2017b, Geneva.