International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133
Received: 03-07-2026, Accepted: 03-08-2026, Published: 18-08-2026
Volume 8, Issue 3, 2026, Page No. 25-30

Blueprint of river health: Monsoon hydrology drives water quality dynamics in the Chaliyar River, Western Ghats, India

Shamiyath Arayilakath*, Karumampoyil Sakthidas Anoop Das
Department of Zoology, M.E.S. Mampad College (Autonomous), University of Calicut, Malappuram, Kerala, India
Corresponding Author: Shamiyath Arayilakath
DOI: https://doi.org/10.66856/ijees.2026.8.3.8062

Abstract
This study investigated the spatio-temporal dynamics of water quality across seven sampling stations in the Chaliyar River, Western Ghats, India. Water quality dynamics were evaluated using 23 physicochemical and microbial parameters integrated with WQI and multivariate statistical analyses. Monsoon hydrology emerged as the dominant driver of water quality dynamics, with premonsoon conditions characterized by ionic enrichment and monsoon conditions by elevated turbidity, iron, organic load and microbial contamination. WQI ranged from 19.62 (Excellent) to 365.78 (Unsuitable), indicating severe monsoon deterioration followed by substantial postmonsoon recovery. Correlation and PCA identified three major hydrochemical gradients—ionic–alkalinity, nutrient–organic enrichment and redox–oxygen—reflecting the combined influence of seasonal hydrology and anthropogenic inputs. These findings highlight the pivotal role of monsoon hydrology in regulating river health and provide a scientific basis for season-specific monitoring and management of tropical river ecosystems.

Keywords: Monsoon hydrology, water quality index (WQI), hydrochemistry, microbial contamination, seasonal variability

Introduction
Water quality is fundamentally governed by physical, chemical, and biological properties that regulate aquatic ecosystem health, sustain biological productivity, and dictate potential resource utilization (Roy *et al*., 2022; Singh *et al*., 2023) [16, 17]. Multi-faceted hydro-chemical and biological evaluations provide vital baseline data required to identify pollution sources, evaluate ecological conservation status, and implement targeted ecosystem management strategies (Uthirasamy & Chitra, 2020; Pérez *et al*., 2023) [17, 19].

Kerala is endowed with extensive water resources, including 41 west-flowing and 3 east-flowing perennial rivers. However, rapid urbanization, population expansion, agricultural runoff, and untreated industrial or domestic discharge continue to degrade riverine water quality across India (Manjula & Warrier, 2019; Ahmed *et al*., 2024) [1, 9]. The physical and chemical parameters of river ecosystems fluctuate in response to meteorological conditions, local geogenic weathering, and anthropogenic inputs (Nejmi, 2006 [12]; A, 2018). Anthropogenic alterations to water quality directly impact aquatic community structures, including sensitive macroinvertebrate taxa and benthic microflora (Nandakumar, 2013; Eneh *et al*., 2024) [6, 11]. Furthermore, given that bad water quality accounts for nearly 80% of global health hazards (WHO, 1984 [20]; Bhuvaneshwari & Sivasubramanian, 2014) [5], continuous spatio-temporal monitoring is imperative to safeguard public health and preserve freshwater biodiversity (BEZGİN *et al*., 2019; Nahian *et al*., 2018) [4, 10].

This investigation provides a spatio-temporal assessment of 23 physical, chemical, and microbial parameters across the Chaliyar River network to establish the underlying drivers of riverine hydrochemistry across distinct hydrological seasons.

Materials and Methods
1. Study Area and Sampling Stations
Seven sampling stations were selected along the Chaliyar River and its tributaries, including three tributary sites and four main channel locations (Figure 1). The stations were selected to represent variations in environmental conditions and anthropogenic disturbances along the river basin. The sampling sites include Kottappuzha (T1:11.240981°N, 76.311765°E), Kuthirappuzha (T2: 11.264520° N, 76.238914°E), Kuruvanpuzha (T3: 11.311773°N, 76.199337°E), Nilambur (S1: 11.282929°N, 76.228793°E), Mampad (S2: 11.250984°N, 76.180354°E), Edavanna (S3: 11.219721°N, 76.140495°E) and Areekode (S4: 11.222924°N, 76.060039°E). These stations represent a gradient from relatively undisturbed upstream regions to downstream areas experiencing higher anthropogenic pressure.

2. Sampling Protocols and Laboratory Analyses
Triplicate water samples were collected across three distinct hydrological seasons in 2024 [1]: Pre-monsoon (March–May), Monsoon (June–September), and Post-monsoon (October–February). Field protocols and analytical procedures adhered strictly to APHA (1998, 2012) standard methods. Water temperature, pH, electrical conductivity (EC), and turbidity were measured in situ using calibrated portable probes. Dissolved Oxygen (DO) was determined via classic Winkler iodometric titration (APHA, 1998). Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Alkalinity, Total Hardness, dissolved cations (Ca2+, Mg2+), anions (Cl-, SO42-), nutrients (NH3, NO3-, NO2-, PO43-), Iron (Fe), and coliform bacteria (Total Coliform and Faecal Coliform via Most Probable Number [MPN] method) were quantified in the laboratory (Khan & Butt, 2022) [8].

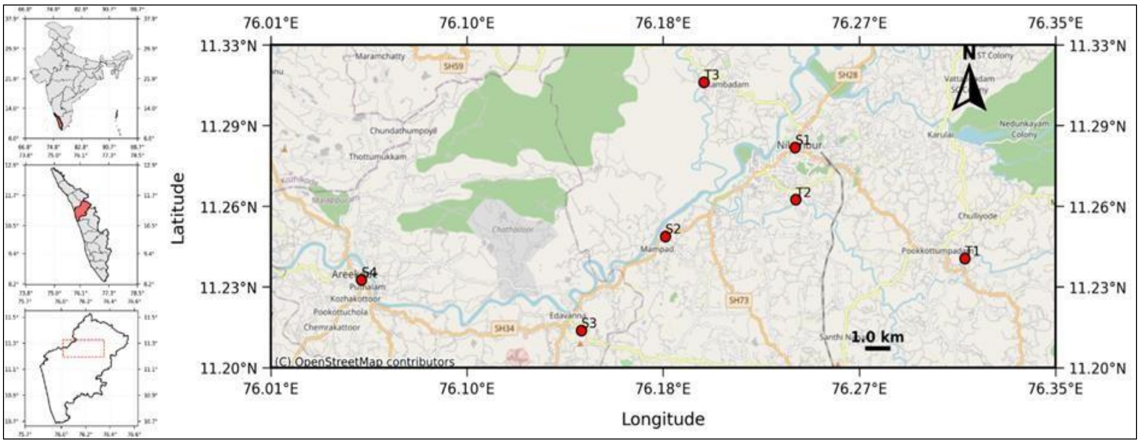

Fig 1: Location map of the sites representing three tributary (T1-T3) sites and four main stream sites (S1-S4)

3. Statistical Analysis and WQI Calculation

Data processing was carried out in R (v4.5.1; R Core Team, 2020) [15]. Non-parametric statistical routines were applied due to the non-normal distribution of the hydro-chemical variables:

Seasonal Comparisons: Kruskal–Wallis H-tests evaluated global seasonal variance. Pairwise seasonal contrasts were isolated using Dunn's post-hoc test with adjusted p-values (rstatix, FSA packages; Kassambara, 2021; Ogle *et al*., 2023) [7, 13]. Spearman's rank correlation (ρ) evaluated parameter interrelationships. Multivariate Hierarchical cluster analysis was computed using Bray–Curtis dissimilarity with Unweighted Pair Group Method with Arithmetic Mean (UPGMA) linkage. Water Quality Index (WQI) evaluated using the weighted arithmetic index method. Quality ratings (Qi) and unit weights (Wi) were derived relative to established water standard guidelines.

Results

1. Seasonal variation in physico-chemical and microbial water quality

Seasonal fluctuations were evident across the 23 measured water quality parameters (Table 1). Water temperature varied from 28.7 ± 1.3°C during the monsoon to 32.0 ± 1.9°C during the premonsoon. Electrical conductivity (120.6 ± 35.3 µS cm^{-1}), total dissolved solids (65.7 ± 13.2 mg L^{-1}), total alkalinity (46.5 ± 4.6 mg L^{-1}), total hardness (35.9 ± 9.1 mg L^{-1}), calcium hardness (27.2 ± 7.7 mg L^{-1}), calcium (10.8 ± 3.3 mg L^{-1}), nitrate (12.5 ± 18.7 mg L^{-1}) and COD (102.2 ± 87.4 mg L^{-1}) recorded their highest mean values during the premonsoon season.

In contrast, turbidity (7.70 ± 6.00 NTU), sulphate (0.74 ± 0.60 mg L^{-1}), ammonia (0.32 ± 0.27 mg L^{-1}), iron (1.90 ± 1.10 mg L^{-1}), phosphate (0.40 ± 0.17 mg L^{-1}), BOD (9.80 ± 8.40 mg L^{-1}), dissolved oxygen (7.4 ± 2.0 mg L^{-1}), total coliform (1445.2 ± 508.3 MPN 100 mL^{-1}) and faecal coliform (778.6 ± 420.3 MPN 100 mL^{-1}) reached maximum values during the monsoon period. Postmonsoon values were generally intermediate, indicating recovery towards premonsoon conditions.

The radar plot further illustrated distinct seasonal patterns, with premonsoon samples characterized by higher ionic parameters, monsoon samples associated with microbial and nutrient enrichment, and postmonsoon samples occupying an intermediate position (Figure 2).

Table 1: Seasonal variation in physico-chemical parameters of the Chaliyar River, Kerala

Parameter	Premonsoon (Mean±SD)	Monsoon (Mean±SD)	Postmonsoon (Mean±SD)
Temperature (°C)	32.0±1.9	28.7±1.3	31.0±1.4
Electrical Conductivity (µS/cm)	120.6±35.3	64.4±9.8	94.1±38.2
Turbidity (NTU)	1.75±1.24	7.7±6.0	1.57±0.67
Total Dissolved Solids (mg/L)	65.7±13.2	35.3±4.9	51.9±16.3
pH	7.3±0.4	7.2±0.2	6.9±0.4
Total Alkalinity (mg/L)	46.5±4.6	22.5±3.3	29.8±10.7
Total Hardness as CaCO3 (mg/L)	35.9±9.1	18.4±6.9	23.2±9.4
Calcium Hardness (mg/L)	27.2±7.7	13.6±3.8	20.6±9.4
Magnesium Hardness (mg/L)	8.3±3.4	4.1±5.4	0.68±0.6
Calcium (mg/L)	10.8±3.3	4.9±2.1	8.7±4.1
Magnesium (mg/L)	1.98±0.9	1.1±1.1	0.69±0.6
Chloride (mg/L)	16.3±4.3	12.7±5.0	16.7±3.6
Sulphate (mg/L)	0.16±0.13	0.74±0.6	0.19±0.15
Ammonia (mg/L)	0.25±0.14	0.32±0.27	0.17±0.05
Iron (mg/L)	0.36±0.24	1.9±1.1	0.24±0.17
Nitrate (mg/L)	12.5±18.7	2.7±2.0	0.15±0.06
Nitrite (mg/L)	1.86±1.76	0.17±0.04	0.18±0.05
Phosphate (mg/L)	BDL	0.40±0.17	0.20±0.08
COD (mg/L)	102.2±87.4	15.4±6.7	15.1±12.7
BOD (mg/L)	0.92±0.87	9.8±8.4	0.66±0.4
DO (mg/L)	5.1±0.6	7.4±2.0	6.6±1.1
Total Coliform (MPN/100mL)	180.0±344.1	1445.2±508.3	404.8±736.6
Faecal Coliform (MPN/100mL)	30.0±48.4	778.6±420.3	310.0±710.0

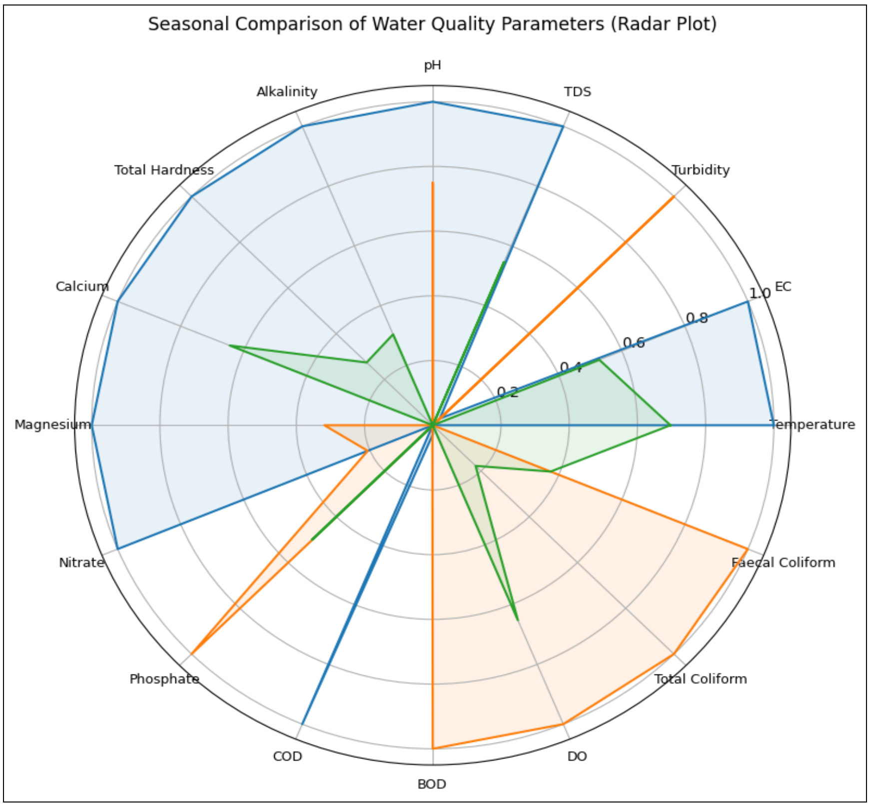

Fig 2: Seasonal comparison of water quality characteristics of the Chaliyar River using normalized radar plot analysis

2. Seasonal differences in water quality parameters

The Kruskal–Wallis test identified significant seasonal differences for 15 of the 23 measured parameters (Table 2). Temperature (H = 9.88, *p* = 0.007), total dissolved solids (H = 8.84, *p* = 0.012), total alkalinity (H = 10.21, *p* = 0.006), total hardness (H = 8.28, *p* = 0.016), calcium hardness (H = 7.84, *p* = 0.020), magnesium hardness (H = 13.44, *p* = 0.001), calcium (H = 8.38, *p* = 0.015), iron (H = 8.15, *p* = 0.017), nitrate (H = 12.88, *p* = 0.002), nitrite (H = 6.34, *p* = 0.042), phosphate (H = 5.60, *p* = 0.018), COD (H = 10.15, *p* = 0.006), BOD (H = 7.21, *p* = 0.027), dissolved oxygen (H = 7.28, *p* = 0.026), total coliform (H = 11.24, *p* = 0.004) and faecal coliform (H = 11.25, *p* = 0.004) varied significantly among seasons.

Electrical conductivity, turbidity, pH, magnesium, chloride, sulphate and ammonia showed no significant seasonal variation (p > 0.05).

Table 2: Kruskal-Wallis Test for Seasonal Variation

Parameter	Statistic	P_value	Effect_size	Significance
Temperature	9.883363	0.00714	0.437965	**
Electrical conductivity	4.477861	0.107	0.137659	ns
Turbidity	4.410342	0.11	0.133908	ns
Total Dissolved solids	8.844333	0.012	0.380241	*
pH	3.836788	0.147	0.102044	ns
Total Alkalinity	10.21099	0.00606	0.456166	**
Total Hardness as CaCO3	8.278103	0.0159	0.348783	*
Calcium Hardness as CaCO3	7.844156	0.0198	0.324675	*
Magnesium Hardness as CaCO3	13.44177	0.00121	0.635654	**
Calcium	8.378479	0.0152	0.35436	*
Magnesium	5.250814	0.0724	0.180601	ns
Chloride	3.495362	0.174	0.083076	ns
Sulphate	2.751673	0.253	0.075167	ns
Ammonia	1.120376	0.571	-0.05174	ns
Iron	8.145658	0.017	0.438976	*
Nitrate	12.87599	0.0016	0.725066	**
Nitrite	6.340127	0.042	0.620018	*
COD	10.14753	0.00626	0.581966	**
BOD	7.212121	0.0272	0.651515	*
DO	7.280148	0.0263	0.293342	*
Total Coliform	11.24055	0.00362	0.513364	**
Faecal Coliform	11.24779	0.00361	0.513766	**
Phosphate	5.603836	0.0179	0.460384	*

*Significance levels: *** p < 0.001; ** p < 0.01; * p < 0.05; ns = non-significant*

3. Pairwise seasonal comparisons

Dunn's post-hoc analysis identified significant pairwise seasonal differences for several parameters (Table 3). The strongest differences occurred between monsoon and premonsoon samples. Phosphate exhibited the highest seasonal contrast (Z = 3.95, p_adj = 0.0002), followed by magnesium hardness (Z = −3.64, p_adj = 0.0008), temperature (Z = −3.46, p_adj = 0.0016), total coliform (Z = 3.24, p_adj = 0.0036), COD (Z = −3.24, p_adj = 0.0036), iron (Z = 3.33, p_adj = 0.0026) and dissolved oxygen (Z = 2.46, p_adj = 0.042). Most postmonsoon–premonsoon comparisons were not significant.

Table 3: Summary of Significant Pairwise Seasonal Differences (Dunn's Test)

Parameter	Significant Comparison	P-adj	Significance
Phosphate	Monsoon - Premonsoon	0.0002	***
Magnesium	Postmonsoon - Monsoon	0.0008	***
Temperature	Monsoon - Premonsoon	0.0016	**
Total Coliform	Monsoon - Premonsoon	0.0036	**
DO	Monsoon - Premonsoon	0.0422	*

4. Water Quality Index (WQI)

Water Quality Index values ranged from 19.62 to 365.78 across seasons and stations (Table 4; During the premonsoon season, WQI values varied from 22.16 to 71.05, corresponding to excellent to poor water quality. Most stations were classified as good, whereas station T2 recorded poor water quality.

During the monsoon, WQI values increased markedly (25.09–365.78). Stations T3, S1, S2 and S3 were classified as unsuitable, while S4 exhibited very poor water quality. Stations T1 and T2 retained good water quality.

Postmonsoon WQI values declined substantially (19.62–47.22), with T2 and S1 classified as excellent and the remaining stations classified as good. The heatmap illustrated a pronounced increase in WQI during the monsoon followed by a reduction during the postmonsoon period.

Table 4: Seasonal and spatial variation of WQI

Station	Season	WQI	WQI_Class
T1	Premonsoon	47.44756	Good
T2	Premonsoon	71.04829	Poor
T3	Premonsoon	22.16187	Excellent
S1	Premonsoon	44.45986	Good
S2	Premonsoon	34.21765	Good
S3	Premonsoon	35.89865	Good
S4	Premonsoon	39.46636	Good
T1	Monsoon	25.2614	Good
T2	Monsoon	25.08978	Good
T3	Monsoon	365.777	Unsuitable
S1	Monsoon	308.529	Unsuitable
S2	Monsoon	105.2756	Unsuitable
S3	Monsoon	231.7525	Unsuitable
S4	Monsoon	91.80663	Very Poor
T1	Postmonsoon	34.65834	Good
T2	Postmonsoon	19.62449	Excellent
T3	Postmonsoon	36.03527	Good
S1	Postmonsoon	21.72653	Excellent
S2	Postmonsoon	47.21797	Good
S3	Postmonsoon	36.44738	Good
S4	Postmonsoon	36.26696	Good

Bray–Curtis hierarchical clustering grouped sampling sites into two major clusters (Fig. X). Samples within each cluster shared similar physicochemical characteristics, whereas separation between clusters reflected increasing dissimilarity in water quality. Samples collected under similar seasonal conditions clustered together, indicating both spatial and temporal consistency in water quality characteristics.

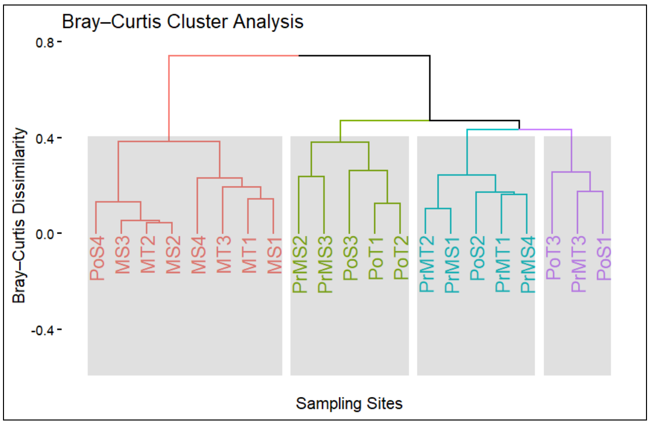

Fig 3: Bray–Curtis cluster dendrogram illustrating seasonal and spatial similarity of sampling sites based on WQI.

5. Interrelationships among water quality parameters

Spearman's rank correlation analysis revealed strong positive associations among several ionic parameters. Electrical conductivity correlated strongly with total dissolved solids (ρ = 0.83), total hardness (ρ = 0.63) and calcium (ρ = 0.65). Total dissolved solids also showed strong positive correlations with total hardness (ρ = 0.87), total alkalinity (ρ = 0.82) and calcium (ρ = 0.83). Calcium hardness was highly correlated with calcium concentration (ρ = 0.98).

Microbial indicators also displayed strong associations. Total and faecal coliforms exhibited a strong positive correlation (ρ = 0.93), while nitrate and phosphate were positively associated (ρ = 0.73). Dissolved oxygen was negatively correlated with COD (ρ = −0.52), whereas iron showed a positive relationship with ammonia (ρ = 0.54). The correlation heatmap identified three major groups corresponding to ionic, nutrient–organic and redox-related variables.

Table 3. Spearman’s rank correlation matrix for physico-chemical and biological parameters of the Chaliyar River.

The matrix presents Spearman correlation coefficients (ρ) based on pairwise complete observations. Significant correlations (*p* < 0.05) are shown. Strong positive associations indicate common geogenic or anthropogenic sources, while negative relationships highlight contrasting environmental gradients.

Figure 4. Heatmap showing Spearman’s rank correlation coefficients (ρ) among physico-chemical and microbial parameters of the Chaliyar River.

6. Principal Component Analysis

The first two principal components explained 54.49% of the total variance, with PC1 accounting for 37.28% and PC2 accounting for 17.21%. Together, the first four principal components explained 77.53% of the overall variation.

The PCA biplot demonstrated distinct seasonal clustering. Premonsoon samples were associated with electrical conductivity, total dissolved solids, hardness, alkalinity, temperature and COD. Monsoon samples were associated with turbidity, nutrients, microbial indicators, BOD and iron, whereas postmonsoon samples occupied an intermediate position between the two seasonal groups. The scree plot indicated a sharp decline in eigenvalues after the second component, suggesting that PC1 and PC2 adequately summarized the dominant patterns in the dataset.

Figure 5. Spatio-temporal distribution of water quality parameters based on principal component analysis (PCA). The PCA biplot illustrates relationships among sampling sites, seasons, and environmental variables in the Chaliyar River.

Figure 6. Scree plot showing the percentage of variance explained by successive principal components of water quality parameters.

Discussion

Seasonal hydrology emerged as the primary driver of water quality variation in the Chaliyar River, with monsoonal rainfall strongly influencing both physicochemical and microbial characteristics. Premonsoon conditions were characterised by elevated electrical conductivity, total dissolved solids, alkalinity and hardness, reflecting concentration effects under reduced river discharge. In contrast, the monsoon season was associated with increased turbidity, iron, phosphate, biochemical oxygen demand and microbial contamination, while postmonsoon conditions indicated recovery towards improved water quality. The significant seasonal differences detected by the Kruskal–Wallis and Dunn's post-hoc analyses, together with the marked increase in WQI during the monsoon, demonstrate the dominant influence of seasonal hydrological processes on river water quality.

Spatial differences among sampling stations indicate that seasonal effects are further modified by local anthropogenic influences. Stations exhibiting poor or unsuitable WQI during the monsoon were associated with greater pollutant loading, whereas upstream stations generally maintained better water quality. The Bray–Curtis clustering supported this pattern by grouping sampling sites according to similarities in water quality characteristics, suggesting that hydrological variability operates alongside site-specific environmental pressures.

Multivariate analyses further clarified the processes governing water quality. Strong correlations among electrical conductivity, total dissolved solids, hardness, alkalinity and calcium identified an ionic–alkalinity gradient associated with mineral weathering and concentration during low-flow conditions. A second gradient linking phosphate, nitrate and microbial indicators reflected nutrient enrichment and external pollutant inputs, whereas the inverse relationship between dissolved oxygen and organic load highlighted oxygen depletion associated with organic matter decomposition. Principal Component Analysis reinforced these findings by clearly separating premonsoon samples characterised by ionic enrichment from monsoon samples dominated by turbidity, nutrients and microbial contamination, with postmonsoon samples representing an intermediate recovery phase.

Overall, the study demonstrates that the Chaliyar River retains considerable capacity for postmonsoon recovery despite pronounced seasonal deterioration during the monsoon. However, recurring runoff-driven pollution and local anthropogenic inputs may progressively reduce this resilience if left unmanaged. Continuous seasonal monitoring combined with effective control of domestic wastewater, catchment runoff and other diffuse pollution sources will be essential for maintaining the ecological integrity and long-term sustainability of the river.

Conclusion

This study identifies monsoon hydrology as the dominant control on water quality dynamics in the Chaliyar River. Seasonal hydrochemical variability, microbial contamination, and WQI collectively indicate that monsoon-driven runoff, coupled with localized anthropogenic pressures, shapes river health. The findings underscore the importance of integrated monitoring and season-specific management strategies for the conservation of tropical river ecosystems.

References

1. Ahmed M, *et al*. Hydrological controls on riverine water quality and biodiversity in tropical catchments. Journal of Environmental Management,2024:310:114720.
2. APHA. Standard Methods for the Examination of Water and Wastewater. 20th ed. American Public Health Association,1998.
3. APHA. Standard Methods for the Examination of Water and Wastewater. 22nd ed. American Public Health Association,2012.
4. Bezgin N, *et al*. Public health implications of bacterial and chemical water pollution in river networks. Environmental Monitoring and Assessment,2019:191(4):215.
5. Bhuvaneshwari R, Sivasubramanian V. Impact of industrial effluents on freshwater ecosystems and public health. International Journal of Environmental Sciences,2014:4(5):890–898.
6. Eneh C, *et al*. Integrating physicochemical analysis and biomonitoring for freshwater health assessment. Ecological Indicators,2024:148:110052.
7. Kassambara A. rstatix, pipe-friendly framework for basic statistical tests. R package version 0.7.0,2021.
8. Khan A, Butt M. Analytical protocols for physical and biological water quality determination. Water Resources Research,2022:58(2):e2021WR0312.
9. Manjula P, Warrier CU. Urbanization and industrialization impacts on river basins of Kerala, India. Environmental Earth Sciences,2019:78(12):350.
10. Nahian MA, *et al*. Spatial and temporal variation of water quality parameters in riverine networks. Environmental Science and Pollution Research,2018:25(18):17890–17902.
11. Nandakumar S. Nutrient alterations and benthic macroinvertebrate distribution in tropical streams. Freshwater Biology,2013:58(8):1640–1652.

12. Nejmi M. Meteorological and chemical controls on aquatic physical properties. Hydrobiologia,2006:560(1):123–134.
13. Ogle DH, *et al*. FSA, Fisheries Stock Analysis. R package version 0.9.4,2023.
14. Pérez L, *et al*. Multi-parametric evaluation of aquatic ecosystems for conservation and intervention planning. Conservation Biology,2023:37(3):e14012.
15. R Core Team. R, a language and environment for statistical computing. R Foundation for Statistical Computing,2020.
16. Roy S, *et al*. Physicochemical parameters as key drivers of aquatic biological productivity. Limnology,2022:23(1):45–58.
17. Singh P, *et al*. Ecosystem health assessment of river basins using spatio-temporal indicators. Water Research,2023:229:119410.
18. Sukanya S, Joseph S. Water quality degradation in western flowing rivers of Kerala due to anthropogenic pressures. Environmental Challenges,2020:1:100005.
19. Uthirasamy S, Chitra J. Assessment of pollution loads and conservation strategies for tropical aquatic systems. Journal of Cleaner Production,2020:265:121820.
20. WHO. Guidelines for Drinking-Water Quality. World Health Organization,1984.
21. Zohrabi M, *et al*. Long-term spatio-temporal water quality trends under changing hydrological regimes. Hydrological Processes,2024:38(2):e14810.