



ORIGINAL RESEARCH PAPER



## CLIMATE-DRIVEN VARIATION IN PHYSICOCHEMICAL CHARACTERISTICS AND WATER QUALITY OF THE VEDGANGA RIVER, MAHARASHTRA, INDIA

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### Abstract:

The present study evaluated the seasonal and spatial variations in the physicochemical characteristics of the Vedganga River, Kolhapur District, Maharashtra, during January–December 2024. Water samples were collected from four sites—Gargoti, Kur, Murgud, and Bastawade—during summer, monsoon, and winter seasons. Parameters analyzed included temperature, pH, electrical conductivity, turbidity, total dissolved solids, nitrate, phosphate, dissolved oxygen, biochemical oxygen demand, dissolved carbon dioxide, alkalinity, and total hardness using standard methods. Results showed significant seasonal and spatial variations in water quality. Monsoon samples exhibited higher turbidity and nutrient concentrations due to runoff from agricultural lands and settlements. The upstream Gargoti site maintained better water quality with higher dissolved oxygen and lower nutrient levels, whereas downstream sites recorded increased dissolved solids, nutrients, and organic matter. Principal Component Analysis identified nutrient enrichment and ionic concentration as major factors influencing water quality. Water Quality Index values indicated water quality ranging from excellent to moderate across the study area.

**Keywords:** Climate Variability, Physicochemical Parameters, Principal Component Analysis, Vedganga River, Water Quality Assessment.

### Introduction

Rivers are among the most important freshwater resources and play a vital role in sustaining ecological balance, supporting biodiversity, and providing water for domestic, agricultural, and industrial purposes. However, increasing human activities and environmental changes have significantly affected river water quality in many regions of the world. The assessment of physicochemical characteristics of river water is widely used to

understand the ecological condition of aquatic systems and to evaluate their suitability for various uses (1, 2). Parameters such as temperature, pH, dissolved oxygen, turbidity, nutrients, and dissolved solids provide important information about the chemical composition and overall health of river ecosystems (3).

Water quality in river systems is influenced by both natural processes and anthropogenic pressures. Land use changes, urbanization, agricultural runoff, and discharge of untreated wastewater can significantly alter the physicochemical properties of river water (4, 5). These factors often lead to increased nutrient concentrations, organic pollution, and changes in oxygen dynamics, which may affect aquatic biodiversity and ecosystem functioning. Monitoring such parameters is therefore essential for understanding environmental conditions and implementing effective water resource management strategies.

In recent years, climate change has emerged as an important factor influencing river water quality. Changes in rainfall patterns, temperature, and hydrological processes can modify nutrient transport, sediment dynamics, and pollutant distribution in river basins (6). Increased rainfall intensity may enhance surface runoff and accelerate the transport of nutrients and contaminants from surrounding catchments into rivers, while rising temperatures can influence biological activity and oxygen availability in aquatic systems (7). These interactions between climatic variability and watershed processes are increasingly recognized as key drivers of changes in river water chemistry and ecological conditions.

Several studies have highlighted the combined influence of climate change and anthropogenic nutrient enrichment on freshwater ecosystems. For example, nitrogen enrichment from agricultural activities together with climatic variations can significantly affect nutrient cycling and biodiversity in aquatic environments (8). Long-term studies have also shown that river inflows and climatic variability can influence oxygen dynamics and other physicochemical conditions in freshwater systems (9). At a broader scale, research on river basins across India indicates that hydrological processes are highly sensitive to climatic variations, which can further affect water availability and quality (10). These interactions highlight the importance of integrating climate considerations into water quality assessments. River basins in India are increasingly experiencing pressures from population growth, agricultural expansion, and changing climatic conditions. Such pressures can alter hydrological processes and influence nutrient and sediment transport within catchments (11). Therefore, evaluating physicochemical characteristics of rivers under varying seasonal conditions is important for understanding the current status of water quality and identifying potential environmental risks.

The present study aims to assess the physicochemical characteristics of the Vedganga River in the Kolhapur district, Maharashtra. The study focuses on evaluating seasonal variations in water quality parameters at four selected sites and examining how climatic factors and local environmental conditions influence the hydrochemical characteristics of the river. The findings of this study are expected to provide baseline information for river water quality management and contribute to a better understanding of climate-related influences on freshwater ecosystems.

## **Materials and Methods**

### **A. Study area**

The present study was conducted on the Vedganga River in the Kolhapur district, Maharashtra, India. The river originates in the Western Ghats (Patgaon) and flows through agricultural and semi-urban regions before joining the Dudhaganaga River system at Barwad. The area experiences a tropical monsoon climate with distinct summer,

monsoon, and winter seasons. Agricultural activities, settlements, and seasonal rainfall influence the water quality of the river.

Four sampling sites were selected along the river to represent different sections of the river: Gargoti (16.312166, 74.133330) (Site I), Kur (16.375062, 74.148066) (Site II), Murgud (16.405223, 74.189388) (Site III), and Bastawade (16.443445, 74.274471) (Site IV). These locations were chosen based on accessibility and surrounding land-use patterns.

#### **B. Sample collection**

Water samples were collected seasonally during summer, monsoon, and winter to evaluate seasonal variations in water quality. At each site, surface water samples were collected from approximately 20–30 cm below the water surface using clean polyethylene bottles. The bottles were rinsed with river water before sample collection. Samples were properly labelled and transported to the laboratory for further analysis. Field parameters such as temperature and pH were measured at the sampling site.

#### **C. Physicochemical Analysis**

Physicochemical parameters were analyzed using standard procedures described in Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WEF, 1998; APHA/AWWA/WEF, 2005). The parameters analyzed included temperature, pH, electrical conductivity (EC), turbidity, phosphate ( $\text{PO}_4^{3-}$ ), total dissolved solids (TDS), dissolved oxygen (DO), nitrate ( $\text{NO}_3^-$ ), biochemical oxygen demand (BOD), dissolved carbon dioxide ( $\text{CO}_2$ ), alkalinity, and total hardness.

Temperature was recorded using a thermometer, while pH and EC were measured using portable digital meters. Turbidity was measured with a turbidity meter, and TDS was estimated using standard conductivity methods. Dissolved oxygen was determined using the Winkler method, and BOD was measured after five days of incubation. Nutrient parameters such as nitrate and phosphate were determined using standard spectrophotometric methods, while alkalinity and total hardness were analyzed using titrimetric methods. All analyses were performed in triplicate, and average values were used for interpretation.

#### **D. Water Quality Index (WQI)**

The overall water quality of the river was evaluated using the Water Quality Index (WQI). Selected parameters, including pH, DO, BOD, nitrate, phosphate, turbidity, and TDS were used to calculate the index. The WQI values were classified into different categories to determine the general status of water quality at each sampling site.

#### **E. Climate–Water Quality Sensitivity Index (CWQSI)**

To assess the influence of climatic variability on water quality, a Climate–Water Quality Sensitivity Index (CWQSI) was calculated. This index combines rainfall intensity, temperature variation, and selected nutrient parameters to evaluate the sensitivity of river water quality to climatic conditions.

#### **F. Statistical analysis**

Statistical analysis of the data was carried out using PAST software to examine spatial and seasonal variations in water quality parameters. Principal Component Analysis (PCA) was used to identify major factors influencing water quality. Graphs and figures such as heatmaps and scatter plots were prepared using OriginPro software to present the results clearly.

**Table 1: Seasonal variation in physicochemical characteristics of water at different sampling sites along the Vedganga River, Kolhapur district**

Sites	Season	Temp	pH	EC	Turb	PO <sub>4</sub>	TDS	DO	NO <sub>3</sub>	BOD	Dissolved CO <sub>2</sub> (mg/L)	Alkalinity (mg/L)	Total Hardness (mg/L)
<b>Site I – Gargoti</b>	Summer	24 ±0.24	7.5 ±0.10	0.32 ±0.02	0.08 ±0.02	0.02 ±0.01	180 ±6	7.0 ±0.35	1.2 ±0.10	0.25 ±0.05	2.8 ±0.30	85 ±4	110 ±5
	Monsoon	22.5 ±0.28	7.6 ±0.12	0.30 ±0.02	0.22 ±0.03	0.05 ±0.01	165 ±5	6.6 ±0.30	1.6 ±0.12	0.40 ±0.06	3.5 ±0.35	80 ±4	105 ±5
	Winter	23 ±0.22	7.4 ±0.08	0.28 ±0.02	0.10 ±0.02	0.02 ±0.01	150 ±5	7.5 ±0.40	1.0 ±0.08	0.20 ±0.04	2.5 ±0.25	75 ±3	98 ±4
<b>Site II – Kur</b>	Summer	24.5 ±0.26	7.8 ±0.12	0.44 ±0.03	0.18 ±0.02	0.10 ±0.02	260 ±8	5.8 ±0.30	3.2 ±0.22	1.80 ±0.18	6.2 ±0.50	115 ±6	160 ±7
	Monsoon	22.5 ±0.30	7.9 ±0.15	0.42 ±0.02	0.40 ±0.04	0.18 ±0.03	230 ±7	5.2 ±0.28	4.6 ±0.30	2.40 ±0.22	8.5 ±0.60	110 ±5	150 ±6
	Winter	23 ±0.24	7.7 ±0.10	0.40 ±0.02	0.22 ±0.02	0.08 ±0.02	210 ±6	6.0 ±0.32	2.6 ±0.18	1.40 ±0.15	5.8 ±0.45	100 ±5	140 ±6
<b>Site III – Murgud</b>	Summer	24 ±0.22	8.1 ±0.12	0.52 ±0.03	0.28 ±0.03	0.20 ±0.03	320 ±10	4.6 ±0.25	4.2 ±0.28	2.80 ±0.25	10.5 ±0.70	150 ±8	210 ±10
	Monsoon	23 ±0.26	8.2 ±0.15	0.50 ±0.03	0.55 ±0.05	0.32 ±0.05	290 ±9	3.9 ±0.22	6.5 ±0.40	3.60 ±0.30	13.8 ±0.90	165 ±9	225 ±12
	Winter	24 ±0.24	8.0 ±0.10	0.48 ±0.02	0.30 ±0.03	0.15 ±0.02	260 ±8	4.9 ±0.28	3.8 ±0.24	2.20 ±0.20	9.2 ±0.60	140 ±7	195 ±9
<b>Site IV – Bastawade</b>	Summer	25 ±0.30	8.0 ±0.15	0.48 ±0.03	0.22 ±0.03	0.14 ±0.02	280 ±9	5.0 ±0.28	3.4 ±0.22	1.90 ±0.18	7.8 ±0.55	125 ±6	175 ±8
	Monsoon	23.5 ±0.32	8.1 ±0.12	0.46 ±0.02	0.48 ±0.05	0.22 ±0.03	250 ±8	4.5 ±0.25	4.8 ±0.30	2.60 ±0.24	9.6 ±0.65	135 ±7	185 ±9
	Winter	24 ±0.22	7.9 ±0.10	0.44 ±0.02	0.26 ±0.03	0.10 ±0.02	225 ±7	5.4 ±0.30	3.0 ±0.20	1.60 ±0.15	6.5 ±0.50	120 ±6	165 ±7

Table 1 presents the seasonal variation in physicochemical parameters of the Vedganga River at four sampling locations during summer, monsoon, and winter. Water temperature exhibited only minor seasonal fluctuation across the study sites, ranging from  $22.5 \pm 0.28$  °C to  $25 \pm 0.30$  °C. The pH values remained slightly alkaline (7.4–8.2) throughout the study period, indicating a stable buffering capacity of the river system. Electrical conductivity (EC) and total dissolved solids (TDS) displayed a gradual increase from the upstream site (Gargoti) toward the midstream and downstream locations, with the highest values recorded at Murgud, suggesting higher mineral and ionic content in this section of the river.

Seasonal changes were also evident in turbidity and nutrient concentrations. Turbidity values increased during the monsoon season at all sites, likely due to increased runoff and sediment input. Similarly, nitrate ( $\text{NO}_3^-$ ) and phosphate ( $\text{PO}_4^{3-}$ ) concentrations were comparatively higher during monsoon, particularly at Site III (Murgud), indicating the influence of catchment runoff and possible anthropogenic inputs. Dissolved oxygen (DO) concentrations showed an opposite pattern, with higher values observed at the upstream site (Gargoti) and comparatively lower levels at the midstream sites, especially during monsoon. This decline in DO was accompanied by an increase in biochemical oxygen demand (BOD), reflecting greater organic load and microbial activity in downstream sections.

Dissolved carbon dioxide, alkalinity, and total hardness also exhibited increasing trends from upstream to downstream sites, with peak values recorded at Murgud during the monsoon season. These patterns suggest that both natural hydrological processes and human activities contribute to spatial differences in water chemistry along the river. Overall, the results indicate that the upstream section maintains relatively better water quality, whereas the midstream region experiences higher nutrient enrichment and organic load, particularly during the monsoon period.

**Table 2: Seasonal variation of the Climate–Water Quality Sensitivity Index (CWQSI) and sensitivity levels at different sampling sites of the Vedganga River**

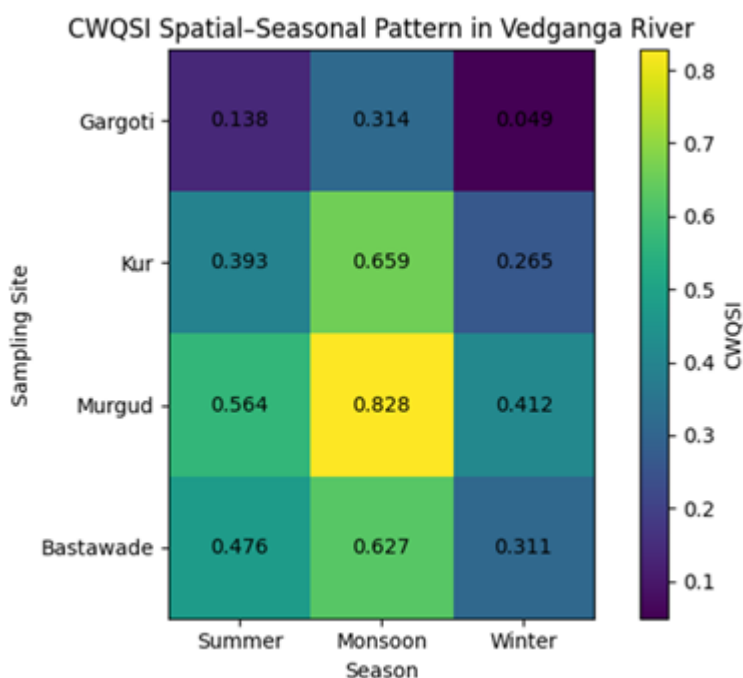
Sites	Seasons	CWQSI	Sensitivity Level
Gargoti	Summer	0.138	Low
	Monsoon	0.314	Moderate
	Winter	0.049	Very Low
Koor	Summer	0.393	Moderate
	Monsoon	0.659	High
	Winter	0.265	Moderate
Murgud	Summer	0.564	High
	Monsoon	0.828	Very High
	Winter	0.412	Moderate
Bastawade	Summer	0.476	Moderate
	Monsoon	0.627	High
	Winter	0.311	Moderate

(CWQSI Classification: - 0.00 – 0.25 Low; 0.26–0.50 Moderate; 0.51 – 0.75 High; 0.76 – 1.00 Very high)

The calculated Climate–Water Quality Sensitivity Index (CWQSI) (table 2) demonstrated noticeable seasonal and spatial differences in the Vedganga River. The minimum sensitivity value was observed at Site I (Gargoti) during winter (CWQSI = 0.049), suggesting that climatic factors exert relatively limited influence on water quality during this period. In contrast, the maximum sensitivity was recorded at Site III (Murgud) during the monsoon season (CWQSI = 0.828). This elevated value indicates a strong impact of climatic conditions, particularly rainfall-induced surface runoff, which contributes to increased nutrient influx and reduced oxygen availability in the water.

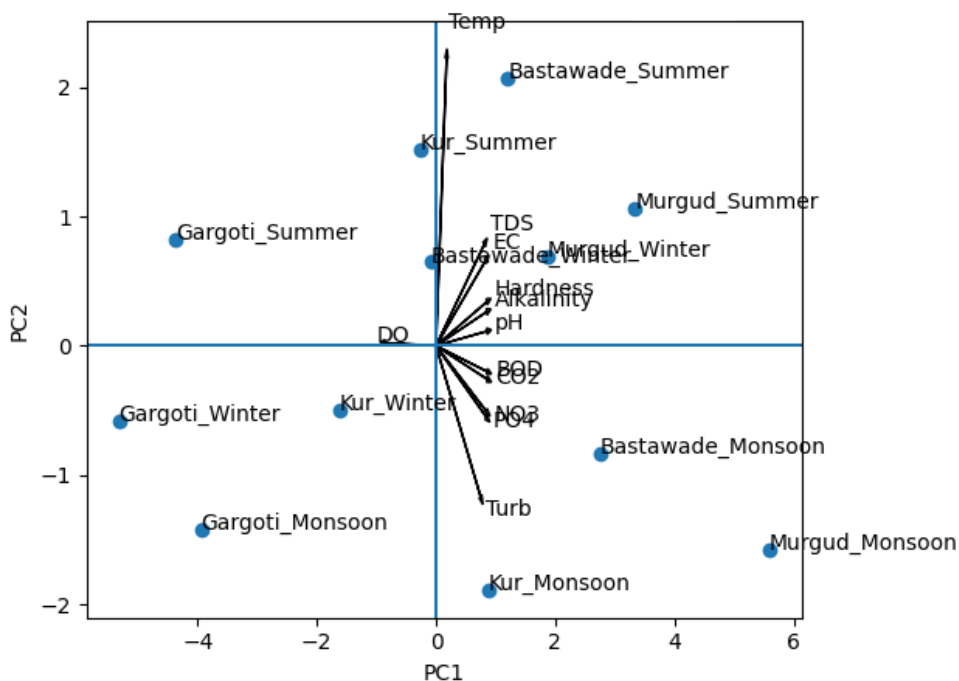
The upstream section of the river generally showed low to moderate sensitivity, reflecting comparatively stable water quality conditions. However, the midstream and downstream sites displayed moderate to very high sensitivity, especially during the monsoon months. Higher CWQSI values at Kur, Murgud, and Bastawade during the rainy season indicate that intense precipitation promotes the transport of nutrients such as nitrate (NO<sub>3</sub><sup>-</sup>) and phosphate (PO<sub>4</sub><sup>3-</sup>), increases turbidity, and elevates biochemical oxygen demand (BOD). At the same time, these processes contribute to a decline in dissolved oxygen concentrations.

The spatial distribution of CWQSI values suggests that Murgud represents a climate-sensitive hotspot along the Vedganga River. At this location, the combined effects of rainfall variability, temperature fluctuations, and local anthropogenic activities play a significant role in shaping the observed water quality characteristics.



**Figure 1: Spatial–seasonal heatmap of the Climate–Water Quality Sensitivity Index (CWQSI) along the Vedganga River**

The heatmap highlights a clear spatial gradient in climate sensitivity, with relatively low CWQSI values at the upstream site (Gargoti) and progressively higher sensitivity toward the midstream region. The highest CWQSI values during monsoon at Murgud indicate that this site of the river is particularly vulnerable to rainfall-driven runoff and associated nutrient enrichment.



**Figure 2: Principal Component Analysis (PCA) Biplot of Physicochemical Parameters in the Vedganga River**

Principal Component Analysis (PCA) was used to understand the variation in physicochemical parameters and the distribution of sampling sites along the Vedganga River (Fig. 2). The results indicated clear spatial and seasonal patterns in water quality. The first principal component (PC1) showed strong contributions from parameters associated with ionic concentration and nutrient enrichment, such as total dissolved solids (TDS), electrical conductivity (EC), alkalinity, total hardness, nitrate, phosphate, and biochemical oxygen demand (BOD). These parameters largely explained the spatial differences in water quality among the sampling locations.

Samples collected from the midstream and downstream sites, particularly from Murgud and Bastawade during the monsoon season, were positioned on the positive side of PC1. This distribution suggests higher levels of nutrients and organic matter at these locations, likely influenced by runoff and local anthropogenic activities. The second principal component (PC2) was mainly related to temperature and turbidity, indicating the role of seasonal environmental changes in influencing water characteristics. In contrast, samples from the upstream site at Gargoti formed a separate cluster, reflecting comparatively better water quality conditions with lower nutrient and organic load.

**Table 3: Water Quality Index (WQI) values and status of the Vedganga River at different sampling sites**

Sites	Average WQI	Water Quality Status
Site I – Gargoti	42.5	Excellent
Site II – Kur	78.3	Good
Site III – Murgud	118.6	Poor
Site IV – Bastawade	95.4	Good

The Water Quality Index (WQI) values indicate noticeable spatial variation in water quality along the Vedganga River. The upstream site at Gargoti recorded the lowest WQI value (42.5), classifying the water as excellent and suggesting minimal pollution influence. In contrast, the midstream site at Murgud exhibited the highest WQI value (118.6), indicating poor water quality conditions likely associated with increased nutrient input, organic load, and anthropogenic activities. The Kur and Bastawade sites showed intermediate WQI values (78.3 and 95.4, respectively), falling under the good water quality category. The results suggest that water quality gradually deteriorates from upstream to midstream sections, with partial improvement observed downstream.

These results demonstrate clear spatial and seasonal variations in the physicochemical characteristics of the Vedganga River. Upstream locations, particularly Gargoti, generally exhibited better water quality conditions characterized by higher dissolved oxygen levels and lower nutrient and organic load. In contrast, the midstream and downstream sections showed relatively elevated concentrations of nutrients, turbidity, and biochemical oxygen demand, especially during the monsoon season. Multivariate analysis further highlighted the influence of ionic enrichment and nutrient inputs on spatial variation, while seasonal factors such as rainfall and temperature contributed to temporal changes in water quality. The Water Quality Index and Climate–Water Quality Sensitivity Index results also indicated that certain sections of the river, particularly around Murgud, experience greater environmental stress. These findings provide important baseline information on the hydrochemical characteristics of the Vedganga River and highlight the role of climatic variability and local influences in shaping water quality patterns along the river system.

### **Discussion**

The results of the present Study indicate clear spatial and seasonal differences in the physicochemical characteristics of the Vedganga River. Such variations are typical in river ecosystems where climatic factors, hydrological conditions, and human activities collectively influence water quality. Seasonal changes in parameters such as temperature, turbidity, nutrients, and dissolved oxygen are often associated with variations in rainfall, runoff, and catchment processes (15, 16). In this study, higher turbidity, nitrate, and phosphate concentrations during the monsoon season suggest that rainfall-driven runoff transports sediments and nutrients from surrounding agricultural areas and settlements into the river channel.

Similar observations have been reported in studies of rivers in the Kolhapur region. Investigations conducted on the Dudhganga River have shown that anthropogenic pressures, including agricultural practices and local land-use activities, can significantly influence water quality conditions (17). Monitoring studies in the Dudhganga catchment also reported differences in physicochemical parameters between upstream and downstream sections, indicating the role of watershed characteristics and human activities in controlling river water chemistry (18). The comparatively better water quality observed at the upstream site (Gargoti) in the present study follows a similar pattern, as headwater regions often experience lower pollution levels due to limited anthropogenic disturbance.

The increasing trend of electrical conductivity, total dissolved solids, alkalinity, and hardness from upstream to downstream sections indicates a gradual accumulation of dissolved minerals and possible anthropogenic inputs along the river course. Comparable findings have been documented in the Panchganga River basin in Kolhapur district. Studies on this river have reported elevated concentrations of dissolved solids and nutrients, mainly associated with domestic wastewater discharge, agricultural runoff, and urban activities (19, 20). Further

research on the Panchganga River has also demonstrated that downstream locations often experience higher pollutant loads compared to upstream areas due to cumulative impacts of human activities along the river course (21). These patterns are commonly observed in rivers flowing through urbanized and agricultural landscapes. The reduction in dissolved oxygen levels accompanied by an increase in biochemical oxygen demand at certain locations in the present study suggests the presence of organic pollution and enhanced microbial decomposition. Such conditions are frequently linked with the discharge of untreated domestic sewage and organic matter into river systems (22). Similar relationships between dissolved oxygen depletion and organic loading have been reported in the Yamuna River, where wastewater discharge from urban areas has significantly affected water quality (23). Changes in oxygen dynamics are particularly important because they directly influence aquatic life and the ecological stability of river ecosystems.

The analysis of the Climate–Water Quality Sensitivity Index (CWQSI) further indicates that rainfall and seasonal climatic variations play a crucial role in determining water quality patterns in the Vedganga River. Increased rainfall during the monsoon season enhances surface runoff, which can transport nutrients, sediments, and other pollutants from the catchment into the river system. Similar findings have been reported in studies examining the relationship between climate variability and river water quality, where rainfall intensity and hydrological changes influence nutrient transport and pollutant distribution (24). Global studies have also emphasized that climatic factors, including rainfall variability and temperature changes, are important drivers of water quality dynamics in river systems (5).

Nutrient enrichment, particularly involving nitrate and phosphate, is often associated with agricultural runoff, fertilizer application, and domestic wastewater inputs. Elevated concentrations of these nutrients can contribute to eutrophication and ecological imbalance in freshwater ecosystems (25). Similar trends of nutrient enrichment and water quality deterioration have been observed in several river systems worldwide, highlighting the combined effects of anthropogenic activities and natural environmental processes (26, 27).

The findings of this study align with previous research conducted in rivers of Maharashtra and other parts of the world, demonstrating that both climatic variability and human activities significantly influence river water quality. The observed spatial pattern in the Vedganga River, where upstream locations exhibit relatively better conditions while midstream and downstream areas show higher nutrient and organic loads, reflects a common trend in river basins affected by agriculture and urbanization. These results highlight the importance of sustainable watershed management and effective pollution control strategies to protect river ecosystems under changing climatic conditions.

### **Conclusion**

This study assessed the seasonal and spatial variation in physicochemical characteristics of the Vedganga River in Kolhapur district, Maharashtra. The results revealed clear differences in water quality among sampling sites and seasons. Upstream locations showed comparatively better water quality, while midstream and downstream sites exhibited higher levels of nutrients, dissolved solids, and organic load. Lower dissolved oxygen levels at some sites further indicate the influence of anthropogenic activities on river water quality.

Seasonal changes were strongly influenced by monsoon rainfall, which increased surface runoff and contributed to higher turbidity and nutrient transport into the river system. The Climate–Water Quality Sensitivity Index (CWQSI) highlighted that the midstream region, particularly around Murgud, is more sensitive to climatic

variability and nutrient enrichment. The Water Quality Index (WQI) also indicated a gradual decline in water quality from upstream to downstream sections.

These findings demonstrate that both climatic factors and human activities play an important role in shaping water quality patterns in the Vedganga River. Continuous monitoring and improved watershed management are therefore essential for maintaining river health and ensuring sustainable water resources under changing climatic conditions.

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