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SEASONAL VARIATIONS IN PHYSICOCHEMICAL CHARACTERISTICS OF THE VARUNA RIVER: A CASE STUDY AT VARANASI, INDIA

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Keywords

Varuna River, pollution, Varanasi, River pollution, physicochemical parameters

Abstract

The current study analyses a seasonal change in various physicochemical parameters of Varuna River at Varanasi during pre-monsoon, monsoon and post-monsoon seasons. Important parameters are pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand

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(COD), turbidity, and total dissolved solids (TDS) were studied to assess changes in water quality over time under different hydrological conditions. The results indicate different seasonal trends which were predominantly controlled by monsoonal rains, surface runoffs, dilution processes, and the incessant anthropogenic contributions. The high value of BOD and COD in the pre-monsoon season suggests that organic pollution burden is much higher in the low-flow environment in the pre-monsoon period than in the high-flow period as indicated by higher turbidity of the water in the season. The increase in the dissolved oxygen during monsoon and post monsoon implies that recovery was partial, as more flow and natural aeration occurred. Altogether, the identified seasonal changes demonstrate a joint effect of natural activities and human actions on the water quality of the Varuna River, which makes it necessary to monitor the situation in the river seasonally and implement effective methods of pollution control.

INTRODUCTION

The Varuna River is one of the major tributaries of the Ganga River and flows in the northern region of the Varanasi district in the state of Uttar Pradesh (India). The river is originated in the area of Phulpur (Prayagraj district) and flows through an urban and peri-urban terrain and finally meets the Ganga near Varanasi. Thus, it is a small river which is a tributary of river Ganga. This river basin is located on the Middle Ganga Plain and has alluvial soils and a monsoon-based hydro regime (Central Water Commission, 2018).

The Varuna River has ecological, cultural, and socio-economic significance for the city of Varanasi; however, it is being polluted due to anthropogenic interference arising from rapid urbanization, population growth, and inadequate wastewater management infrastructure (Singh, 2025; Kantamaneni, 2025).

The water quality of the river Varuna is moderately polluted. River Varuna receives untreated/partially treated domestic sewage through different pipes and storm channels of urban area, whereas in some part of its course, it receives urban surface runoff containing various organic matter and fertilizers from nearby agricultural land. Dissolved solids are also leached in the rainy season (Kumar and Agrawal, 2025). Therefore, in pre-monsoon season, due to less amount of river water, the dilution capacity of the river for such quality of water is greatly restricted.

Other stressors such as land use changes associated with banks development, changes in flow regime and seasonality of water availability have further added to the variance pressure on the Varuna. This combination of issues has continued to degrade water quality, particularly under periods of low flow and increased stress upon the river ecosystem, integrity and functionality (CPCB, 2020; Kumar et al., 2015).

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The Varuna river as with many other rivers of India, flowing through urban and semi-urban settings, is highly seasonally dynamic in terms of water quality. Principal drivers of this dynamic include monsoonal rainfall and rapid changes in river discharge, as well as the increasingly significant pressures humans are placing on the rivers in terms of discharge of domestic sewage, urban runoff, and excessive use of fertilizers and pesticides. (Arvind et al, 2021; Hassan et al, 2017; Singh, 2025). The monsoon regime of the climate has a strong impact on the hydrological conditions, which affect the dilution capacity, sediment transport, and loading of pollutants in the river systems (Kumar et al, 2015).

Some of the common physicochemical indicators of river water quality are pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity and total dissolved solids (TDS) (Chapman, 2021). Dissolved oxygen indicates the potential of a river to maintain aquatic life. BOD and COD show the state of organic pollution and oxidable substances in the river. Turbidity and TDS are able to give us the idea of the sediment load and dissolved ionic content, which is usually higher during the periods of the monsoon-induced runoff (Gorde and Jadhav, 2013). The American Public Health Association has standardized protocols of analytical methods of these parameters, which are currently the standard of water quality studies in the world (APHA, 2022).

Physicochemical parameters should be monitored seasonally and it helps to determine the trends of pollution linked to the hydrological cycles and human activities. The water quality of river Varuna is moderately polluted because of sewage, industrial wastes, using of excessive fertilizers etc (Singh, 2025; Kumar and Agrawal, 2025). Hence, timely assessment is then necessary to comprehend changes in the riverine environment over time and to determine when the stress due to pollution is maximized. The differences that are experienced during pre-monsoon seasons, during the monsoon seasons and during the post-monsoon seasons are utilized to separate between natural dilution effects and the long term anthropogenic effects. These evaluations are essential in river administration, constructions of plans to reduce pollution and development of evidence based conservation strategies of the urban rivers such as the Varuna.

The aim of the current research is to determine the seasonal variation of pre-monsoon, monsoon, and post-monsoon seasons on the physicochemical parameters such as pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, and total dissolved solids (TDS) of the Varuna River at Varanasi.

MATERIALS AND METHODS

Study Area

The study area was restricted only in Varanasi district to observe the impact of urbanization on water quality of the Varuna River.

Sampling Design

To determine seasonal changes in hydrology, three different seasons were chosen to sample the water. Three months viz. May, July and November were chosen for pre-monsoon, monsoon and post-monsoon seasons, respectively. To get the representative water quality conditions per period, seasonal composite sampling was adopted.

Sample collection

All the samples were collected from Chauka Ghat, Varanasi in the three months (May, July and November) of a year. The water samples were sampled using the grab sampling method. A collection of samples was conducted in clean 1 ltr plastic bottles with a proper rinsing of the bottles before sampling to eliminate any contamination. The samples were then transported to the laboratory where they were analysed in accordance with the standard procedures.

Physicochemical Parameters to be analysed and their analytical methods

Water quality was evaluated using the following aspects of physicochemical parameters:

- **pH-** through a calibrated digital pH meter by the procedure established by EPA method 410.4 (NEMI, 1982)
- **Dissolved Oxygen (DO)-** iodometric method also known as Winkler Titration (Helm et al, 2012)
- **Biochemical Oxygen Demand (BOD)-** five-day incubation method (BOD_5) (Rono, 2017). This measures the amount of oxygen consumed by bacteria while decomposing organic matter at 20°C. It is the standard metric for determining the organic pollution load in a river. The BOD5 (mg/L) of water samples was determined by getting the variation between dissolved oxygen (DO) on day one and day five.

Calculation for BOD5 (mg/L) was then determined by the following formula:

BOD (mg/L) = (D1-D2)/P

Where, D1=DO (mg/L) value in initial sample

D2=DO (mg/L) value in final sample

P=decimal volumetric fraction of sample used (ml of sample/300 ml).

- **Chemical Oxygen Demand (COD)-** open reflux method by EPA method 410.4 (NEMI, 1975). This uses a strong oxidizing agent (potassium dichromate) to break down everything—even substances that bacteria can't digest. The "open reflux" part ensures that volatile organic compounds are fully oxidized under heat, giving you a complete picture of the chemical pollutants. his involves heating the sample with potassium dichromate ($K_2Cr_2O_7$) in an open vessel to oxidize organic matter

- **Turbidity-** nephelometric procedure using Turbidimeter (or, nephelometer) (Brown et al, 2005)
- **Total Dissolved Solids (TDS)-** through the gravimetric procedure established by EPA procedure established by Fishman and Friedman, 1989. This involves filtering the sample, evaporating the water, and weighing the dried residue (dried at 105°C).

The formula for calculation :

$$\textbf{TDS (mg/L)} = \textbf{(1000/ V) x M}$$

Where: V = The volume of the sample you used (in mL).

M= The mass of the dry residue remaining in the dish (in mg).

While TDS meters (which measure electrical conductivity) are common for quick checks, the gravimetric method is the definitive way to measure the actual mass of dissolved minerals and salts.

All raw data was recorded in the Microsoft excel sheet and calculation of mean and standard deviation are done in excel.

RESULT AND DISCUSSION

The physio-chemical characteristics of the Varuna River for Pre-monsoon, Monsoon and Post-monsoon seasons are presented in the Table no. 1 along with standard deviations.

Table 1: Seasonal Variation in Physicochemical Parameters of the Varuna River

Parameters	Unit	Pre-monsoon (Mean ± SD)	Monsoon (Mean ± SD)	Post-monsoon (Mean ± SD)
pH	—	8.1 ± 0.2	7.5 ± 0.3	7.8 ± 0.2
Dissolved Oxygen (DO)	mg/L	3.2 ± 0.6	6.1 ± 0.7	5.0 ± 0.5
Biochemical Oxygen Demand (BOD)	mg/L	7.8 ± 1.1	4.2 ± 0.8	5.6 ± 0.9
Chemical Oxygen Demand (COD)	mg/L	42 ± 6	28 ± 5	35 ± 6
Turbidity	NTU	32 ± 5	96 ± 14	48 ± 7
Total Dissolved Solids (TDS)	mg/L	620 ± 85	410 ± 70	520 ± 78

Seasonal variation in pH

The pH of the Varuna River remained within the slightly alkaline range throughout the study period, varying from 7.5 ± 0.3 during the monsoon to 8.1 ± 0.2 in the pre-monsoon season, and moderate in the post-monsoon phase. The same seasonal stability in the pH with marginal dilution through monsoons has also been observed in urban rivers in the north of India (Kumar et al., 2021; CPCB, 2022). This relatively narrow fluctuation indicates a moderately stable acid–base regime. However, there is a clear seasonal modulation driven by different hydrological and biological processes.

The higher pH observed during the pre-monsoon period is due to reduced river discharge as well as reduced water flow, which favours growth of phytoplankton. These phytoplankton take up CO_2 from water during photosynthesis which increases pH of the water. In addition to this, the concentration of bicarbonates and other alkaline salts during low water quantity and reduced flow further contributes to the observed rise in pH.

In contrast, during the monsoon season, the slightly acidic to neutral rainwater lowers the overall alkalinity of the river water. Also, increased flow conditions hamper growth of phytoplankton reducing photosynthesis. These conditions, in turn, reduce pH.

The post-monsoon period exhibits a partial rebound in pH, indicating a gradual return toward pre-monsoon conditions as the water flow and quantity reduces and phytoplankton growth starts beginning again.

The seasonal trends in use are also supported by recent research works on urban rivers in the Ganga basin, which emphasizes that during the dry seasons, tributaries become fragile to the accumulation of pollution, and during the monsoon seasons, they become vulnerable to degradation caused by sediments (Singh et al., 2020; Sharma et al., 2021; Mishra et al., 2023). The results highlight the fact that only temporary relief is given by the monsoonal dilution, but deep sources of pollution pose a consistent pressure on the river health throughout the year.

Seasonal variation in level of Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is a most significant parameter for getting an idea of ecological condition of a river. In our observation, the lowest DO concentration was recorded during the pre-monsoon season (3.2 ± 0.6 mg/L), followed by a significant increase during the monsoon (6.1 ± 0.7 mg/L), and a moderate decline in the post-monsoon period (5.0 ± 0.5 mg/L).

During pre-monsoon, higher temperatures decrease oxygen solubility, while the accumulation of domestic sewage and organic matter enhances microbial decomposition, which fasten oxygen consumption. As a result, DO becomes low, significantly.

In contrast, the DO increases during monsoon season because the rainwater is rich in oxygen as well as the hight water movement and turbulence engulfs the atmospheric oxygen. Various researchers have reported similar seasonal improvements in oxygen dynamics in other polluted tributaries of the Ganga basin (Singh et al., 2020; Mishra et al., 2023).

During post-monsoon time, the water flow starts declining and sewage organic matter and starts increasing in amount. Now the gradual beginning of decomposition of the sewage organic matter lead to mild reduction in DO level.

Thus, the data clearly shows there is an inverse relationship between dissolved oxygen and organic pollution load. These findings are consistent with flow-dependent variability reported in urban river systems across India (Shukla et al., 2021; CPCB, 2023).

Seasonal variation in Organic Load (BOD & COD)

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) both showed a seasonal pattern of variation and thus can be used to determine the organic as well as the pollution load of organic and chemical pollutants on the Varuna River. The values of BOD showed maximum in pre-monsoon season (7.8 ± 1.1 mg/L) and minimum in monsoon season (4.2 ± 0.8 mg/L) while in post-monsoon season it was 5.6 ± 0.9 mg/L. The values of COD also showed maximum in pre-monsoon season (42 ± 6 mg/L) and minimum in monsoon season (28 ± 5 mg/L), while in post-monsoon season it was 35 ± 6 mg/L.

The BOD, which measures the oxygen required by aerobic microorganisms for the breakdown of organic material, indicated substantial amounts of organic pollution in the Varuna during pre-monsoon season. The reduced river flow during pre-monsoon also meant a reduced dilution capacity to counteract the pollution load, while domestic sewage, agricultural effluent and other anthropogenic sources found unabated entry into the Varuna's waters (Singh, 2025). In addition, high temperature favoured increased metabolic activity of microbes hence increased oxygen consumption. Further, high COD levels during this time frame contained both biodegradable and non-biodegradable oxidizable material including organic and inorganic compounds typical of wastewater. These elevated levels were concentrated during low-flow conditions.

Reductions in BOD and COD observed during the monsoon season are largely attributed to dilution and flocculation by increased hydrological flux. Enhanced flow also serves to transport these pollutants downstream. Turbulent flow increases aeration and aids in degradation processes required to reduce oxygen demand. Such reductions in flux of pollutants during high-flow events are characteristic of urban rivers and were observed in this study (Verma et al., 2022; Mishra et al., 2023; Aravind, 2021).

Post-monsoon BOD and COD showed a moderate increase for reasons of decreasing discharge and increased pollution as against pre-monsoon. However, the concentrations were significantly lower than those recorded pre-monsoon. There is partial recovery of the river system in terms of changes in seasonal flow and related variations in BOD and COD. These variations are flow-dependent and are typical of many Indian rivers. (Shukla et al., 2021; CPCB, 2023; Lokhande, 2021).

Dynamics of Physical Parameters (Turbidity & TDS)

Like other parameters, Turbidity and TDS also showed seasonal trends. In our observation, the turbidity increased sharply during the monsoon (96 ± 14 NTU) due to surface runoff, erosion, and sediment resuspension, while remaining lower in pre- and post-monsoon periods. In contrast, TDS was highest in pre-monsoon (620 ± 85 mg/L), decreased during monsoon (410 ± 70 mg/L) due to dilution by high water discharge, and rose again in post-monsoon (520 ± 78 mg/L) as river flow reduces. These pattern shows how water quantity controls water quality in various seasons as in other rivers (Giri, 2024).

Table 2: Summary of the Varuna River dynamics:

Parameter	**Trend**	**Primary Driver**
DO	Monsoon > Post > Pre	Temperature & Re-aeration
BOD / COD	Pre > Post > Monsoon	Concentration of organic matter /Dilution effect
Turbidity	Monsoon > Post > Pre	Siltation & Surface Runoff
TDS	Pre > Post > Monsoon	Dilution by rainwater

CONCLUSION

Analysis of trends of the above mentioned parameters and inputs from other researchers clearly summarises that the water quality improves during monsoon season due to dilution and increased river flow. However, the pre-monsoon period represents most polluted phase and post-monsoon phase is intermediate in pollution but later pollution load increases again. Although the river shows some natural self-purification, pollutant inputs exceed its assimilative capacity, especially during pre-monsoon periods, largely due to continuous discharge of sewage, agricultural runoff, and other human activities.

These findings stress the need of framing and implementing a plan for water quality management like waste water treatment, sewage purification, monitoring anthropogenic activities/rituals followed by a periodic strict monitoring. With these, public awareness remains a key aspect in Varuna river conservation.

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CONFLICTS OF INTEREST

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