Proceedings of the 11th World Congress on New Technologies (NewTech'25)
Paris, France - August, 2025
Paper No. ICEPR 165
DOI: 10.11159/icepr25.165

Seasonal Assessment of Water Quality in the Godavari River Basin

Pratyusha Tatavarthi[1], Prabhakar Singh[1], Vignesh Reddy Gandu[1], Dewanshi Dahake[2], Adarsh Reddy Vangala[1], Keerthi Katam[1*]
[1]Department of Civil Engineering, École Centrale School of Engineering, Mahindra University, Telangana, India
Prathyusha22pcie001@mahindrauniversity.edu.in; cougar.singh@gmail.com; se21ucie017@mahindrauniversity.edu.in; se21ucie001@mahindrauniversity.edu.in; Keerthi.katam@mahindrauniversity.edu.in
[2]Department of Biology, Indian Institute of Science Education and Research, Bhopal, India
dewanshidahake@gmail.com

Abstract – Seasonal variations in water quality play a vital role in assessing the ecological and environmental behaviour of river systems, explicitly in agriculture-dominant regions like the Godavari river basin in Andhra Pradesh, India. The study focuses on evaluating spatiotemporal variations for key physicochemical parameters like pH, salinity, dissolved oxygen (DO), alkalinity, hardness, total solids (TS), chlorides, and optical density at 254 nm (OD254) during the three distinct hydrological seasons- pre-monsoon, monsoon, and post-monsoon. Water samples were collected from strategically selected eight sites (named S1 to S8) along the river from Polavaram to Dowleswaram and were tested following standard laboratory procedures. The findings showed notable seasonal variations driven by anthropogenic activities, agricultural runoff, and monsoonal rainfall. While the greater amounts of chlorides during the pre-monsoon suggest pollutant deposition under low-flow circumstances, increased total solids during the monsoon were caused by surface runoff. Moderate levels of the majority of indicators in post-monsoon waters displayed the role of sedimentation and dilution. Site S2 was always recognized as an outlier based on Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA), reflecting perennial pollution mostly due to organic content throughout the year. The results highlight the need to conduct ongoing seasonal monitoring to understand the changes in water quality, and can help in guiding regional water management plans. The research highlights the need to practice integrated watershed management techniques in areas experiencing significant agricultural and industrial expansion to protect rivers.

***Keywords*:** HCA, PCA, pre-monsoon, monsoon, post-monsoon, Water quality

1. Introduction

River water is the fundamental source of water for agriculture, industrial activities, and domestic use. It plays a vital role in supporting life and sustaining the ecosystem. The dynamic nature of the river makes it an essential source of surface water, especially in agriculture-dependent countries like India [1]. Nevertheless, due to expansion in the industrial sector, agricultural advances, and urbanization, the quality of river water was highly altered. In addition to safeguarding human health, water quality monitoring is crucial for preserving ecological stability and promoting sustainable development. Because of its vast drainage basin, reliance on agriculture, and socioeconomic significance, the Godavari River is extremely important in southern India [2].

Godavari River is essential to Andhra Pradesh's economy, aquaculture, agriculture, and potable water supply, especially in the East and West Godavari areas [3]. The increase in the population has increased the demand for water resources, thereby depleting the quality of water resources. Increased use of fertilizers, pesticides, domestic sewage discharge, and effluents from both major and small-scale enterprises has led to a decline in water quality in many sections of the river [4]. During the non-monsoon and monsoon seasons, seasonal fluctuations caused by runoff, dilution, and increased sediment transit have a major impact on the physical and chemical features of river water [5]. Water quality is generally evaluated by studying the physical, chemical, and biological parameters [6]. Dissolved oxygen (DO), pH, and Total Solids (TS) are the significant parameters for understanding water quality [7]. For instance, Total Dissolved Solids (TDS) gives information on the mineral content and salinity, pH shows how acidic or basic the water is, and DO shows the level of organic pollution and the presence of both biodegradable and non-biodegradable contaminants.

During the pre-monsoon season, because of the slower river flow and lower water levels, there is a greater concentration of pollutants because of the limited ability for dilution [8]. On the other hand, higher rainfall and runoff during the monsoon season, in combination with land use patterns and watershed management techniques, can both dilute existing pollutants and introduce new ones via surface runoff. The post-monsoon season is a crucial transitional time when sedimentation takes place and water bodies start to recover from monsoonal effects, making it important to study the water quality post-rains [9]. Therefore, it is necessary to study the seasonal variations of water quality to understand the state of the river system and potential dangers to the ecosystem.

Within a portion of the Godavari River basin, this study examines the geographical and temporal variation in important physicochemical water quality indicators during three different hydrological seasons: pre-monsoon, monsoon, and post-monsoon. Samples taken throughout each season were subjected to laboratory testing, and data were gathered from several sampling sites. The aim of the study is to evaluate the seasonal variability in key water quality indicators and analyze trends that can guide water resource management. In an area that is heavily reliant on surface water for a variety of purposes, this study intends to support continued efforts in river basin monitoring, sustainable water use, and pollution control.

2. Study Area

The east and west Godavari regions are mostly agricultural areas that rely largely on surface water from the Godavari River (Fig.1) and its network of canals for irrigation, paddy fields, aquaculture ponds, and banana plantations, all of which are water-intensive [10]. Seasonal rainfall from the southwest monsoon has a considerable impact on river discharge, dilution, and the movement of numerous biochemical elements in the water. The sampling sites chosen run along the district's river and canal systems, and include areas with various land use patterns such as agricultural zones, rural communities, and semi-urban discharge points. These locations were chosen to reflect the impact of both point and non-point sources of pollution. Anthropogenic activities, return flows from paddy fields, aquaculture effluents, and household sewage outflows all have a substantial impact on water quality. The climate in the research region is tropical, with high humidity and mean annual temperatures ranging from 24°C to 38°C. The monsoon season normally lasts from June to September, with a comparatively dry post-monsoon period from October to December, and a pre-monsoon season from March to May. These climatic fluctuations have a substantial impact on surface water availability, dilution potential, and microbiological and chemical activities in the aquatic system.

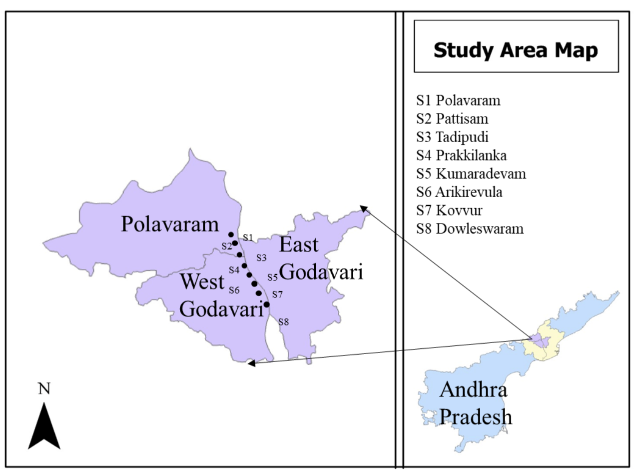

Fig. 1: Map showing the location of the sampling points and outline of the study area

Figure 1 represents the map showing the location of the sampling points and the outline of the study area. The sampling sites are located in the lower portions of the Godavari Basin, where the river slows and deposits sediments, resulting in extended residence time for toxins and higher interaction between water and sediment [11]. Lower velocities during the post-monsoon and pre-monsoon periods may also increase eutrophication and biological activity [12]. The geographic coordinates of the sites are summarised in Table 1.

Table 1: Geographic coordinates of the sites

Site Number	Location Name	Latitude	Longitude
S1	Polavaram	17.24	81.646
S2	Pattisam	17.21	81.640
S3	Tadipudi	17.16	81.661
S4	Prakkilanka	17.13	81.667
S5	Kumaradevam	17.06	81.71
S6	Arikirevula	17.05	81.72
S7	Kovvur	17.01	81.740
S8	Dowleswaram	16.93	81.78

3. Methodology

The study was carried out in Andhra Pradesh's Godavari River basin, which is mostly an agricultural area with significant irrigation, household, and industrial uses for the river water. Based on observed pollution levels, closeness to agricultural areas, and human populations, eight sampling sites were carefully chosen throughout the river route. Sampling was done during three seasons, Pre-Monsoon (July 2024) a dry-season scenario with limited flow and elevated solute concentrations, Monsoon (September 2024) illustrating the time of greatest precipitation and its effects on erosion, runoff, and suspended particles and Post-Monsoon (December 2024) showing that water quality has stabilized following rainfall, with dilution and sedimentation impacts becoming less significant. Water samples were collected according to standard procedures. To prevent surface contamination, samples were taken 20–30 cm below the surface with the help of clean, sterilized plastic bottles. Within 24 hours after being collected, all samples were brought to the lab for examination and kept at 4°C.

Parameters such as pH, Salinity, and DO were measured on site using a handheld water quality meter (Make: TOA DK; Model: WQC-30), and the laboratory analysis for Hardness, Alkalinity, Total Solids, and Chlorides was carried out following standard methods for water and wastewater [13]. The accuracy of the data was ensured by doing each analysis in triplicate. Prior to use, all instruments and glassware were calibrated, and blanks and common reference materials were used to maintain quality control.

Principal component analysis (PCA) was carried out to understand the influential parameters and the correlation between them. PCA is an orthogonal linear transformation that transforms the variables to a new coordinate system in such a way that the highest variance projected by any variable falls in the first coordinate, the second highest variance falls in the second coordinate, and so on [14]. The principal component gives information on the most influential parameters, which gives details of the overall data set, allowing data reduction while reducing the loss of original information [15]. Hierarchical Cluster Analysis (HCA) was further carried out to support the findings from PCA. The statistical analysis was performed using Origin Pro software.

4. Results and Discussions

The pH levels are between 6.87 and 8.20 in all seasons, which is within the permissible range for freshwater systems. Pre-monsoon pH readings were usually higher (mean ≈ 7.95), peaking at S4 (8.20), suggesting alkaline conditions that may have been caused by decreased bicarbonate ion movement, evaporation, and concentration. On the other hand, post-monsoon pH fell to its lowest point at S4 (6.87), most likely as a result of increased microbial activity that contributed to organic acids and dilution from rainfall and runoff. Although somewhat lower than the pre-monsoon, the monsoon season's pH readings (7.54–8.06) remained alkaline, indicating that enhanced runoff has a moderating influence on pH levels. These findings were similar to previous literature [16]. The seasonal pattern indicates that the acid-base state of the river system is influenced by hydrological dilution and biogeochemical activities [17]. All samples and seasons showed a constant low salinity of 0.01%, indicating that the Godavari River is a freshwater [18]. The changes in the salinity suggest that saltwater intrusion is frequently observed in rivers that are impacted by tides or as a result of groundwater pumping. Both of these are not a significant issue in the areas that were examined [19]. It also shows that there were no notable industrial saline discharges during the research period.

One important measure of the health of aquatic ecosystems is dissolved oxygen. There were noticeable seasonal fluctuations in DO concentrations. The pre-monsoon period had the lowest DO levels (2.00–2.97 mg/L), and some locations (such as S6 and S8) were getting close to hypoxic conditions, which can result in dead zones for the ecosystem [20]. These might be caused by organic pollution, thermal stratification, and decreased re-aeration as a result of low flow. Monsoon values increased to 6.30 mg/L at S3, indicating a considerable improvement. High DO levels were caused by increased aeration, turbulent flow, and organic matter dilution after intense rains [21]. Following the monsoon, DO decreased somewhat (3.3–4.2 mg/L), most likely as a result of less turbulence in water bodies and the breakdown of stored organic waste. The temporal trends highlight the river system's susceptibility to oxygen depletion, particularly during dry spells, which can have a negative impact on aquatic life.

Seasonal variations were significant in total solids, which include both suspended and dissolved materials. During the pre-monsoon, low dilution capacity, evaporative concentration, and agricultural runoff are the reasons for the highest concentrations (up to 6.24 g/L at S3). In the monsoon, significant decrease (down to 0.16 g/L), mostly as a result of increased flow and dilution from rainfall. Intermediate values (up to 5.2 g/L) during the post-monsoon indicate that sediments may have been re-suspended, maybe as a result of groundwater flow or bank erosion. The high values in the pre- and post-monsoon periods may hinder turbidity-sensitive aquatic activities, including photosynthesis, and these changes reflect seasonal sediment dynamics [22].

Natural organic matter, particularly aromatic chemicals like fulvic and humic acids, can be identified by OD254 [23]. Moderate pre-monsoon levels (0.052–0.113) show a background of organic matter from natural debris and small inflows of garbage. During the monsoon, high amounts of labile organic matter are introduced via storm water runoff, agricultural leachates, and urban drainage, which is probably why peaks were seen at S2 (0.222) and S3 (0.173). In the post-monsoon season, Stabilization took place (0.1–0.2), but consistently high levels imply either insufficient flushing or continuous organic inputs, maybe from wastewater or decomposing vegetation [24]. These readings, especially in slower-flowing passages, indicate a possible danger of oxygen deprivation and microbial development.

Calcium and magnesium levels, which measure water hardness, demonstrated notable seasonal fluctuation. Before the monsoon, moderate hardness (46–96 mg/L) was observed with little leaching, and base flow played a role. The monsoon season noticeable rise (up to 153 mg/L at S3), most likely brought on by upland floods, erosion of catchment rocks, and mineral leaching caused by runoff. After the monsoon persistently high (77.7–120 mg/L), indicating a gradual release from mineralized soil and a recovery of groundwater. Although the hardness levels stayed within reasonable bounds, they clearly show a mineral-rich post-monsoon nature that might influence the expansion of irrigation systems and residential applications [25].

Because of little human input and little water movement, chlorides showed seasonal enrichment and the lowest concentrations (16.66–24.99 mg/L) before the monsoon. Monsoon peak levels (66.6 mg/L at S2) may be caused by home sewage, flood mobilization of soil salts, and runoff from both urban and rural areas. Higher values (up to 29.9 mg/L) were sustained post the monsoon, indicating limited dilution and possible human effects (e.g., fertilizers, detergent residues). If left uncontrolled, elevated chloride levels might endanger crop output and the flavour of drinkable water.

The most notable fluctuation was in alkalinity, which represents the water's buffering ability. Strong buffering, probably caused by accumulated bicarbonates and carbonates, driven by evaporation and concentration effects, is indicated by the exceptionally high pre-monsoon levels (up to 945 mg/L at S5). During the monsoon, a significant decrease was observed (down to 86.6 mg/L) as a result of ionic concentrations being diluted. Alkalinity recovered (232–355 mg/L) post the monsoon, which may have been caused by base flow and groundwater contributions. Extremely high alkalinity can alter metal solubility and the balance of aquatic ecosystems, even while it increases resilience to pH swings [26]. Station S3 continuously displayed higher values for DO (monsoon), total solids (pre- and post-monsoon), and hardness across the three seasons, suggesting localized geogenic or human impacts. Elevated levels of organic markers (OD254 and chlorides) at Station S2 pointed to possible agricultural runoff or wastewater inputs. PCA was primarily carried out to improve the dimensionality of the data set to further analyse the most prominent parameter in the water quality (Fig.2).

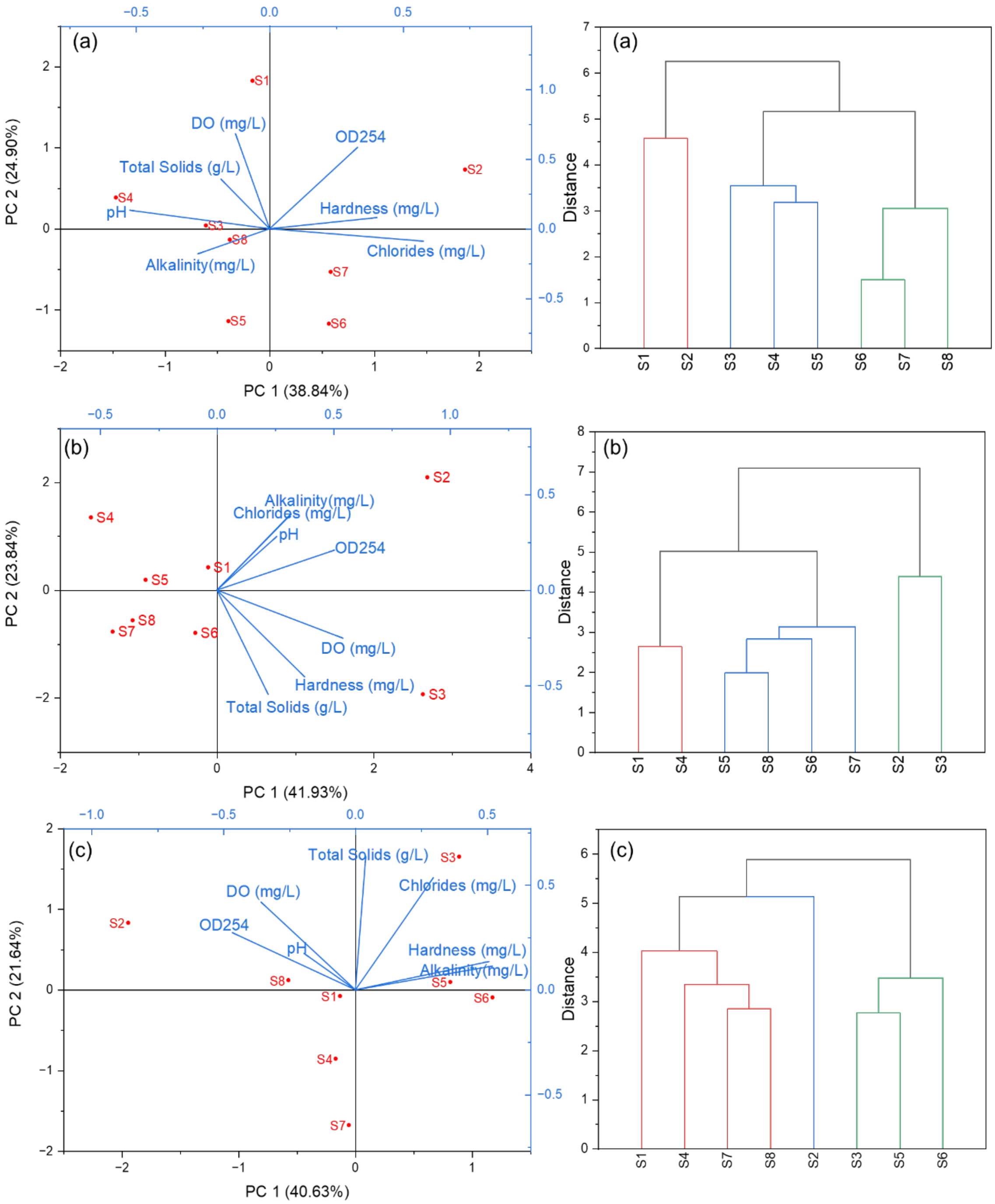

Fig. 2: PCA and HCA of seasonal variations of water quality parameters (a) pre-monsoon, (b) monsoon, and (b) post-monsoon

The multivariate analysis conducted using HCA and PCA demonstrates clear seasonal trends in the water quality at the sites of sampling. At pre-monsoon, the PCA biplot shows that water quality is highly determined by factors like DO, OD254 (organic matter), hardness, and chlorides. Particularly, the sampling location S2 is strongly differentiated from all the others and has a high association with hardness and OD254, indicating high organic and mineral content levels. Likewise, S1 with greater DO and OD254, and S3 and S4 represent alkaline environments. This is supported by HCA also splits the locations into three distinct major clusters, but isolates S2 because it uniquely has an exclusive water chemistry. The pre-monsoon dendrogram showed distinct clusters, forming groups of upstream and downstream sites, possibly due to anthropogenic activities and different sources of input. These findings align with previous studies that focus on the importance of organic pollution and mineral transport in river ecosystems during seasonal changes [27]–[29]. During the monsoon period, the pattern of sampling locations changes significantly, possibly due to enhanced runoff and dilution effects. The PCA indicates that alkalinity, total solids, and chlorides gain more prominence, and although S2 remains distinct, other locations such as S3 now cluster more with total solids and hardness, perhaps because of the influx of sediments and minerals. Sites S5, S6, S7, and S8 show a wider spread, reflecting the differential impacts of rainfall at different locations. The dendrogram using HCA shows a more even clustering with a significant grouping of S5, S6, S7, and S8, reflecting that these sites have similar monsoonal influences on water quality. Monsoon season revealed predominantly seasonal clustering patterns, highlighting the influence of surface runoff.

During the post-monsoon period, PCA shows a general merging of the sample locations around the centre of the biplot, which implies that there is a stabilization of water quality after the monsoon. S2 is still separated from the other points along the OD254, showing continued organic pollution. S3 is close to parameters such as total solids and chlorides, which indicate lingering effects of sedimentation due to the monsoon. Most other sites, including S1, S4, and S6, cluster closely together, reflecting more uniform water quality conditions. This pattern is replicated in the HCA, where most sites fall into one compact cluster, whereas S2 and S3 exist as separate clusters based on residual deviations in their chemical profiles. During the post-monsoon phase, the effects of accumulated pollutants were observed in the clustering patterns. The analysis shows that site S2 systematically differs from other sites, probably because of ongoing pollutant input, and that seasonal processes like rainfall and runoff have a major impact on water chemistry. Pre-monsoon condition depicts greater amounts of organics and minerals, monsoon imposes heterogeneity via inputs from the outside, and post-monsoon conditions reveal relative stability. These results are essential to distinguish pollution origins and design specialized water management tactics. HCA further corroborated these findings by grouping sites with similar water characteristics.

5. Conclusions

The seasonal assessment of water quality measurements across the Godavari River Basin reveals the temporal variations caused by hydrological conditions. High levels of total solids, alkalinity, and hardness during the pre-monsoon season suggest significant evaporation and reduced dilution, which was likely aggravated by low flow conditions. The monsoon season, on the other hand, exhibits a noticeable increase in measures like DO and decreased total solids, which are suggestive of improved aeration, dilution, and runoff-induced pollution flushing. Nonetheless, some organic indicators (OD254) increased in particular locations, suggesting that organic materials may have contributed to surface runoff. Although most measures showed a mild recovery in the post-monsoon season, alkalinity and hardness showed a revival at some locations, which may have been caused by delayed leaching or groundwater interaction. These findings demonstrate how riverine water quality is dynamic and responds to seasonal variations, highlighting the necessity of ongoing monitoring and catchment-specific management techniques to maintain sustainable water quality all year long.

References

[1] D. V. Dhawan, "Water and Agriculture in India," *South Asia Expert panel Dur. Glob. Forum Food Agric. 2017*, vol. 28, pp. 80–85, 2017, [Online]. Available: https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf

[2] S. Das, A. M. Kandekar, and S. J. Sangode, "Natural and anthropogenic effects on spatio-temporal variation in sediment load and yield in the Godavari basin, India," *Sci. Total Environ.*, vol. 845, p. 157213, Nov. 2022, doi: 10.1016/J.SCITOTENV.2022.157213.

[3] A. Rama, K. R. Penmetsa, S. Reddy Muppidi, R. Popuri, S. B. Golla, and R. Tenneti, "Impact of Aquaculture on Physico-Chemical Characteristics of Water and Soils in the Coastal Tracts of East and West Godavari Districts,

Andhra Pradesh, India," *Int. J. Eng. Trends Technol.*, vol. 6, no. 6, 2013, [Online]. Available: http://www.ijettjournal.org

[4] S. Navasakthi, A Pandey, R Dandautiya, M Hasan, A M Khan, P Kahkashan, A Shamshad,G Rajni, Q Obaid., "Assessment of Spatial and Temporal Variation in Water Quality for the Godavari River," *Water (Switzerland)*, vol. 15, no. 17, p. 3076, 2023, doi: 10.3390/w15173076.

[5] P. K. Jha, J. Tiwari, U. K. Singh, M. Kumar, and V. Subramanian, "Chemical weathering and associated CO2 consumption in the Godavari river basin, India," *Chem. Geol.*, vol. 264, no. 1–4, pp. 364–374, Jun. 2009, doi: 10.1016/J.CHEMGEO.2009.03.025.

[6] S. P. Gorde and M. V Jadhav, "Assessment of Water Quality Parameters : A Review," *Int. J. Eng. Res. Appl.*, vol. 3, no. 6, pp. 2029–2035, 2013.

[7] Mohd Khairul Amri Kamarudin, "Seasonal Variation on Dissolved Oxygen, BiochemicalOxygen Demand and Chemical Oxygen Demandin Terengganu River Basin, Malaysiadrinking water (Manda and Das 2011). Water has its own criteria for composition and purity for various uses, and each body of wat," *J. Environ. Sci. Manag.*, vol. 7, no. December, pp. 1–7, 2020.

[8] H. Pia, M. Aktar, S. Sarkar, and A. Rahman, "Assessment of Water quality varies between pre- monsoon and post-monsoon season of the typical contaminated ...," *Int. J. Agric. Environ. Bioresearch*, vol. 3, no. February 2022, pp. 129–141, 2018.

[9] M. Arienzo, T Marco, F Luciano, D Carlo, M Priyanka, M Ponniah, J Sarkar, S Kumar, T Maria., "Influence of monsoon season on heavy metal composition of Hooghly River estuary sediments, West Bengal, India," *J. Geochemical Explor.*, vol. 248, p. 107181, May 2023, doi: 10.1016/J.GEXPLO.2023.107181.

[10] P. V. Nageswara Rao, S. Appa Rao, and N. Subba Rao, "Suitability of groundwater quality for drinking, irrigation and industrial purposes in the Western Delta Region of the River Godavari, Andhra Pradesh," *J. Geol. Soc. India*, vol. 86, no. 2, pp. 181–190, 2015, doi: 10.1007/s12594-015-0297-1.

[11] S. M. Shravan Kumar, M. Pandey, and A. K. Shukla, "Spatio-temporal analysis of riverbank changes using remote sensing and geographic information system," *Phys. Chem. Earth, Parts A/B/C*, vol. 136, p. 103692, Dec. 2024, doi: 10.1016/J.PCE.2024.103692.

[12] S. Naik, R. K. Mishra, K. C. Sahu, A. A. Lotliker, U. S. Panda, and P. Mishra, "Monsoonal Influence and Variability of Water Quality, Phytoplankton Biomass in the Tropical Coastal Waters – A Multivariate Statistical Approach," *Front. Mar. Sci.*, vol. 7, no. August, pp. 1–14, 2020, doi: 10.3389/fmars.2020.00648.

[13] A. Solutions, A. Solutions, and I. Solutions, "A.Ph.A.," *J. Am. Pharm. Assoc. (Practical Pharm. ed.)*, vol. 15, no. 9, pp. 542–544, 1954, doi: 10.1016/s0095-9561(16)33485-5.

[14] A. C. Rencher, "A Review Of 'Methods of Multivariate Analysis, Second Edition,'" *IIE Trans.*, vol. 37, no. 11, pp. 1083–1085, Nov. 2005, doi: 10.1080/07408170500232784.

[15] S. Shrestha and F. Kazama, "Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan," *Environ. Model. Softw.*, vol. 22, no. 4, pp. 464–475, Apr. 2007, doi: 10.1016/J.ENVSOFT.2006.02.001.

[16] P. Tatavarthi, K. Katam, P. Sharma, and P. Singh, "Assessing Downstream Heavy Metal Contamination and Risks in the Godavari River Basin: Implications for Irrigation and Water Quality Management," *J. Irrig. Drain. Eng.*, vol. 151, no. 3, p. 04025007, Feb. 2025, doi: 10.1061/JIDEDH.IRENG-10484.

[17] L. M. Mosley, R. W. Fitzpatrick, D. Palmer, E. Leyden, and P. Shand, "Changes in acidity and metal geochemistry in soils, groundwater, drain and river water in the Lower Murray River after a severe drought," *Sci. Total Environ.*, vol. 485–486, no. 1, pp. 281–291, Jul. 2014, doi: 10.1016/J.SCITOTENV.2014.03.063.

[18] P. Padmavathi and R. Birudu, "Interlinking of Krishna and Godavari rivers: An ecological study Sustainable Aquaculture View project Malacofauna View project," *Int. J. Fish. Aquat. Stud.*, vol. 4, no. February, pp. 593–595, 2019, [Online]. Available: https://www.researchgate.net/publication/331023508

[19] J. Klassen and D. M. Allen, "Assessing the risk of saltwater intrusion in coastal aquifers," *J. Hydrol.*, vol. 551, pp. 730–745, Aug. 2017, doi: 10.1016/J.JHYDROL.2017.02.044.

[20] J. M. Tellier, N. I. Kalejs, B. S. Leonhardt, D. Cannon, T. O. Höök, and P. D. Collingsworth, "Widespread prevalence of hypoxia and the classification of hypoxic conditions in the Laurentian Great Lakes," *J. Great Lakes Res.*, vol. 48, no. 1, pp. 13–23, Feb. 2022, doi: 10.1016/j.jglr.2021.11.004.
[21] A. Luo, H. Chen, X. Gao, L. Carvalho, H. Zhang, and J. Yang, "The impact of rainfall events on dissolved oxygen concentrations in a subtropical urban reservoir," *Environ. Res.*, vol. 244, p. 117856, Mar. 2024, doi: 10.1016/J.ENVRES.2023.117856.
[22] K. K. Satpathy, A K Mohanty, G Sahu, S K Sarkar, N Usha, R Venkatesan, M. V.R Prasad. "Variations of physicochemical properties in Kalpakkam coastal waters, east coast of India, during southwest to northeast monsoon transition period," *Environ. Monit. Assess.*, vol. 171, no. 1–4, pp. 411–424, 2010, doi: 10.1007/s10661-009-1287-9.
[23] J. D. Ritchie and E. Michael Perdue, "Proton-binding study of standard and reference fulvic acids, humic acids, and natural organic matter," *Geochim. Cosmochim. Acta*, vol. 67, no. 1, pp. 85–96, Jan. 2003, doi: 10.1016/S0016-7037(02)01044-X.
[24] S. Wu, P. Kuschk, H. Brix, J. Vymazal, and R. Dong, "Development of constructed wetlands in performance intensifications for wastewater treatment: A nitrogen and organic matter targeted review," *Water Res.*, vol. 57, pp. 40–55, Jun. 2014, doi: 10.1016/J.WATRES.2014.03.020.
[25] V. S. Pitchaimani, R J J Joe, G Shyamala, G Manjula, B Hemalatha, M D Babu, S S Ezhil, R Gobinath *Multivariate statistical and hydrogeochemical analysis of seasonal groundwater quality variations in coastal villages of Trivandrum district, south India*, vol. 5, no. 1. Springer International Publishing, 2024. doi: 10.1007/s43621-024-00584-w.
[26] N. Arora, S. Tripathi, G. P. Philippidis, and S. Kumar, "Thriving in extremes: harnessing the potential of pH-resilient algal strains for enhanced productivity and stability," *Environ. Sci. Adv.*, 2025, doi: 10.1039/d4va00247d.
[27] S. Dey, S. Botta, R. Kallam, R. Angadala, and J. Andugala, "Seasonal variation in water quality parameters of Gudlavalleru Engineering College pond," *Curr. Res. Green Sustain. Chem.*, vol. 4, no. December 2020, p. 100058, 2021, doi: 10.1016/j.crgsc.2021.100058.
[28] R. Sharma, A. Kumar, N. Singh, and K. Sharma, "Impact of seasonal variation on water quality of Hindon River: physicochemical and biological analysis," *SN Appl. Sci.*, vol. 3, no. 1, pp. 1–11, Jan. 2021, doi: 10.1007/S42452-020-03986-3/TABLES/3.
[29] W. Ojok, J. Wasswa, and E. Ntambi, "Assessment of Seasonal Variation in Water Quality in River Rwizi Using Multivariate Statistical Techniques, Mbarara Municipality, Uganda," *J. Water Resour. Prot.*, vol. 09, no. 01, pp. 83–97, 2017, doi: 10.4236/jwarp.2017.91007.