DOI: https://doi.org/10.36094/sc.v91.2025.An_Indicator_of_the_Contemporary_Trophic_State.Das_Gupta.394

ARTICLE

Sci. and Cult. 91 (7–8) : 394-399 (2025)

AN INDICATOR OF THE CONTEMPORARY TROPHIC STATE: CHLOROPHYLL A CONTENT CONDITION IN RELATION WITH POLLUTION LOAD OF THE LOWER GANGA RIVER

SUBHADEEP DAS GUPTA, BASANTA KUMAR DAS, ARKA MONDAL, SURAJ KUMAR CHAUHAN AND TRUPTI RANI MOHANTY

The Ganga is one of India's most revered rivers, serving as a vital cultural, historical, and ecological asset. The river is threatened by pollution from rapid urbanization, industrialization, and agricultural practices, threatening human health and the ecosystem. The proliferation of algal blooms is a developing worry in the Ganga's water. The measurement of Chlorophyll a, a pigment present in algae, serves as an indicator for evaluating algal biomass and monitoring water quality. In river systems, elevated Chlorophyll a concentrations signify eutrophication, a condition characterized by an ecological imbalance resulting from nutrient overabundance. Over five years and eight sampling sites, twelve water quality metrics, including Chlorophyll a, demonstrated notable geographic variations in their principal component analysis. Increased quantities of Chlorophyll a are positively correlated with higher water temperature, greater turbidity, enhanced specific conductivity, rising pH levels, and increased total alkalinity, indicating correlations with warmer waters, higher turbidity, and increased alkaline conditions. In downstream and coastal regions, the significant association between elevated Chlorophyll a concentrations and increasing levels of nitrogen, phosphorus, turbidity, and conductivity at numerous sample locations indicate early indication of eutrophication as a critical concern. The results indicate a significant ecological shift in which the accumulation of nutrient load is enhancing algal production, potentially leading to long-term ecosystem degradation.

Introduction

The Ganga is one of India's most sacred rivers and serves as a vital cultural, historical, and ecological resource. The river runs through multiple states on its way to the Bay of Bengal from its source in the Himalayas. It is a biodiversity hotspot and a water source for millions of people's daily needs, including drinking, irrigation, and industry. Nevertheless, the river is facing a threat to polluted due to fast urbanization, industrialization, and agricultural activities, which endangers the health of humans and the environment.[1] Untreated sewage, industrial effluents, and agricultural runoff, which often include pesticides and fertilizers, are the main culprits behind this contamination. The growth of algal blooms is one emerging concern in the Ganga's water. Overabundances of nutrients, especially nitrogen and phosphorus, which encourage the rapid expansion of algae, are the usual culprits of algal blooms.[2] Depleting oxygen levels, diminishing biodiversity, and potentially releasing dangerous poisons are some ways these blooms impact aquatic ecosystems.[3-5] An indication for assessing algal biomass and monitoring water quality is the quantity of Chlorophyll a, a pigment found in algae.[6] In river systems, high Chlorophyll a levels indicate eutrophication, a state in which an imbalance in the ecosystem occurs due to an excess of nutrients. The subsequent criteria are employed to characterize water

ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata, West Bengal
* Corresponding author: basantakumard@gmail.com

conditions based on their Chlorophyll a concentration: Waters containing less than 2 µg/L of Chlorophyll a are classified as oligotrophic; those with 2-6 µg/L are termed mesotrophic; water with 6-20 µg/L are categorized as eutrophic; and waters exceeding 20 µg/L are designated hypertrophic.[7] Implementing effective strategies for managing water quality, such as pollution reduction and monitoring algal blooms, is essential for preserving the health of the Ganga River. This river is critical for the environment and the millions of individuals who rely on it. Chlorophyll a concentration in water is commonly utilized as an indication of phytoplankton biomass, including algae. Consequently, quantifying Chlorophyll a concentrations helps elucidate the extent and intensity of algal blooms. To evaluate the overall water quality of the lower stretch of river Ganga, it is crucial to monitor a range of water quality parameters, such as dissolved oxygen (DO), pH, total solids (TS), and turbidity, etc.[8] The parameters offer significant insights into the ecological condition of the river and the possible threats to aquatic organisms and human populations. In a previous study on the river Ganga[9] it was depicted that different environmental parameters (Temperature, salinity, pH, etc.) are influencing the Chlorophyll a concentration in the river water. The study aimed to analyse the current levels of Chlorophyll a concentration in the lower segment of the Ganga River, along with its correlation with other water quality metrics, to determine the pollution load in the river.

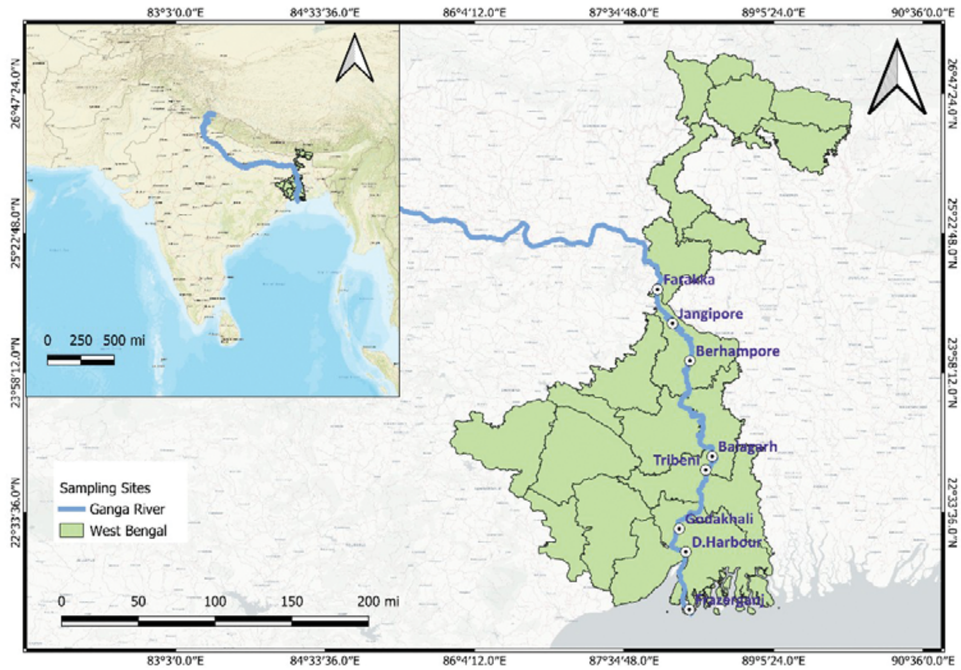

Fig. 1. Study area map depicting eight sampling sites throughout lower stretch of river Ganga

Materials and Methods

Study Area: The study area encompasses eight distinct sampling locations, i.e. Farakka, Jangipur, Berhampore, Balagarh, Tribeni, Godakhali, and Fraserganj, along the lower section of the River Ganga in West Bengal. Quarterly sampling was used to collect samples from the year 2020 to 2024. The study covered both tidal and non-tidal zones of the river. The research was carried out over the four principal seasons *viz*. winter, summer, pre-monsoon, and monsoon.

Sampling and Analysis of Water Samples: Water samples were collected from the sub-surface region of the river Ganga in 1liter High Density Polyethylene (HDPE) amber colour bottle for Chlorophyll a and in a 1Litre HDPE white bottle for other water parameters. All the samples were kept in a cool condition (4ºC) in an ice-box and transported to laboratory. Triplicate sampling was done (Both banks and middle of the river). A total of twelve physico-chemical parameters, *viz*. water temperature (°C), dissolved oxygen (DO), pH, electrical conductivity (EC), total solids (TS), total alkalinity (TA), salinity, Secchi-disc transparency, nitrate and phosphate, were analysed following Standard Methods.[10] Chlorophyll a (Chl-a) samples were collected individually and analysed according to APHA (2005) guidelines. Samples from every single replicate were vacuum-filtered using membrane filters with a Millipore membrane filter (pore size of 0.45 µm). The residues were encased in aluminium foil and sent to the laboratory in cool conditions, and thereafter frozen at -20 °C immediately upon arrival. A digital laboratory tissue homogenizer (RQT-127AD) (Remi, India) was used for extracting the Chl-a pigment with acetone. A UV-VIS spectrophotometer was used to measure how much the extracts absorbed light at 664 nm, 647 nm, and 630 nm. The following equation was used to figure out the concentration of Chl-a in water: With Chl-a = 11.85 (OD 664) -1.54 (OD 647) -0.08 (OD 630), Chl-a is the amount of Chl-a in µgL^{-1}, which is also written as ppb (parts per billion).

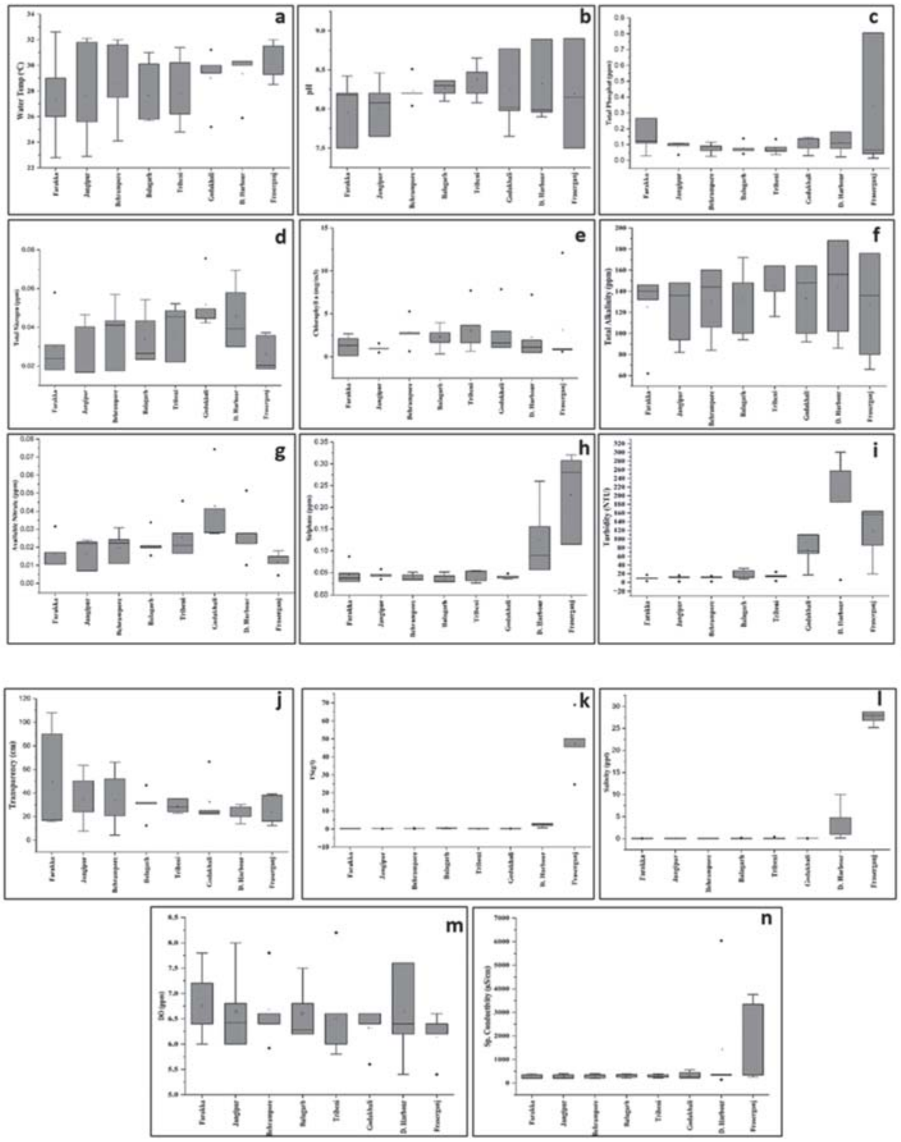

Fig. 2 (a-n) Sampling station-wise different water quality parameters. (a) Water Temperature, (b) pH, (c) Total phosphate, (d) Total nitrogen, (e) Chlorophyll a, (f) Total Alkalinity, (g) Available nitrate, (h) Sulphate, (i) Turbidity, (j) Transparency, (k) Total Solid, (l) Salinity, (m) Dissolved oxygen and (n) Specific conductivity.

Statistical Analysis: Origin Pro 2024 was employed for calculating several water quality metrics and the total Chlorophyll a concentration at multiple locations along the lower Ganga River. Principal Component Analysis (PCA) was conducted using Origin Pro software to evaluate the correlations between Chlorophyll a concentrations and water quality measures at eight separate sampling sites. A heatmap analysis was performed to examine the link between water quality indicators and Chlorophyll a content, utilizing Python programming.

Results

Analysis of Limnological Parameters: From upstream freshwater areas like Farakka and Jangipur to estuaries and coastal zones like Fraserganj and Diamond Harbour, a five-year assessment of water quality across eight stations reveals clear spatial variations and changing trends reflecting both natural processes and anthropogenic pressures. Fraserganj and Tribeni (3.05 µg/L) showed the highest average concentrations of Chlorophyll a, (Fig. 2e) an indicator of algal biomass and a factor for nutrient enrichment, followed closely by Behrampore and Godakhali, suggesting that these areas are probably experiencing high levels of primary production, most likely driven by nutrient loading. Particularly at Diamond Harbour and Godakhali, these same stations also reported greater levels of total nitrogen, accessible nitrate, and phosphate, indicating likely growing pollution, probably from agricultural runoff, urban discharge, or tidal nutrient influx. Increased suspended solids in the water, generally linked with organic pollution and sediment resuspension, elevated turbidity readings at Diamond Harbour (186.64 NTU) and Fraserganj (118.08 NTU) support this (Fig. 2i). Transparency was much lower at these places (as low as 22.4 cm), therefore lowering light penetration and implying possible shade from algal blooms or suspended solids (Fig. 2j).

Specific conductivity stayed optimum at upstream sites, including Farakka (191.2 µS/cm) and Jangipur (178.86 µS/cm), but it increased significantly in coastal areas, particularly at Fraserganj, where it reached a startling 21,779.22 µS/cm (Fig. 2n) probably the result of saline water mixing or industrial runoff. Though somewhat similar across all stations, dissolved oxygen (DO) levels revealed somewhat lower averages at Fraserganj (6.16 mg/L) and Godakhali (6.27 mg/L) (Fig.2m), presumably reflecting increased biological oxygen demand due to organic matter breakdown or phytoplankton respiration. Fascinatingly, even places with modest nutrient levels, such as Tribeni and Balagarh recorded high Chlorophyll a, suggesting localised circumstances like slower flow, point-source discharges, or nutrient recycling that can sustain algal development irrespective of more general nutrient patterns.

All of which are early indicators of eutrophication, taken together the five-year dataset shows a clear ecological gradient: while upstream stations have maintained rather stable water quality, the midstream to coastal sites are increasingly showing signs of nutrient-driven pollution, higher turbidity, reduced water clarity, and algal proliferation. These developments highlight the need for comprehensive water quality control and ongoing long-term observation, particularly in vulnerable transitional areas where human activity and natural dynamics interact more closely.

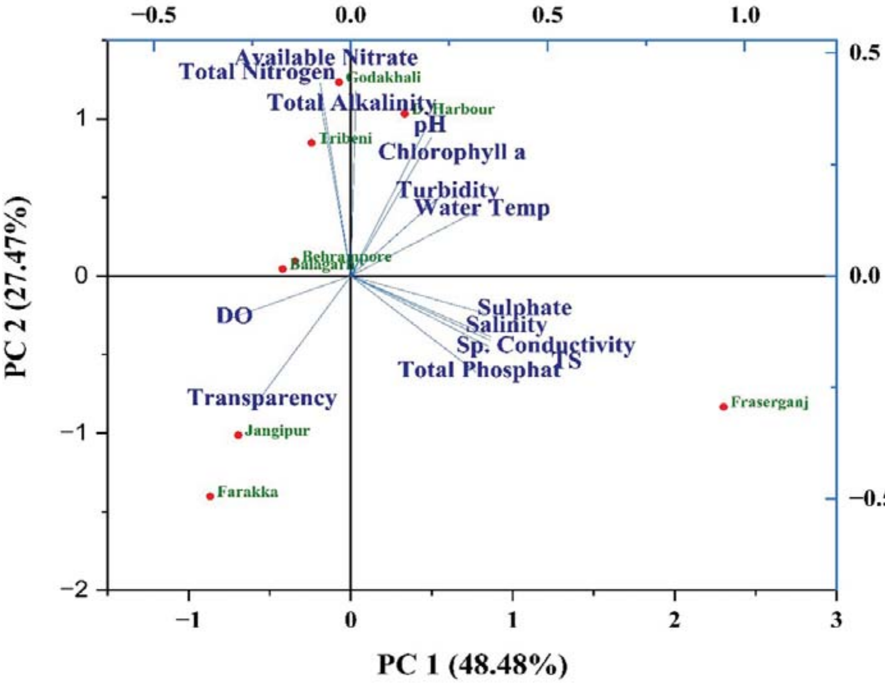

Fig. 4. PCA bi-plot of different water quality parameters

Heat Map Analysis: The heat map analysis of Chlorophyll a correlations with water quality parameters reveals clear patterns reflecting eutrophication dynamics in the aquatic system. A strong positive correlation with pH (0.92298) suggests that alkaline conditions significantly promote phytoplankton growth. Similarly, positive associations with water temperature (0.60444), total alkalinity (0.55023), specific conductivity (0.36129), salinity (0.35935), and total nitrogen (0.30522) highlight that warmer, nutrient-rich, and more ionized waters support increased algal biomass. Turbidity also shows a modest positive link (0.27791), indicating productive but potentially degraded water conditions. Conversely, Chlorophyll a is negatively correlated with transparency (-0.59378) and dissolved oxygen (-0.65657), suggesting that algal blooms are more prevalent in turbid, oxygen-depleted waters. These interactions highlight how both nutrient enrichment and physicochemical stresses affect phytoplankton growth together, therefore providing an understanding of the complicated interactions forming eutrophic trends in the river system.

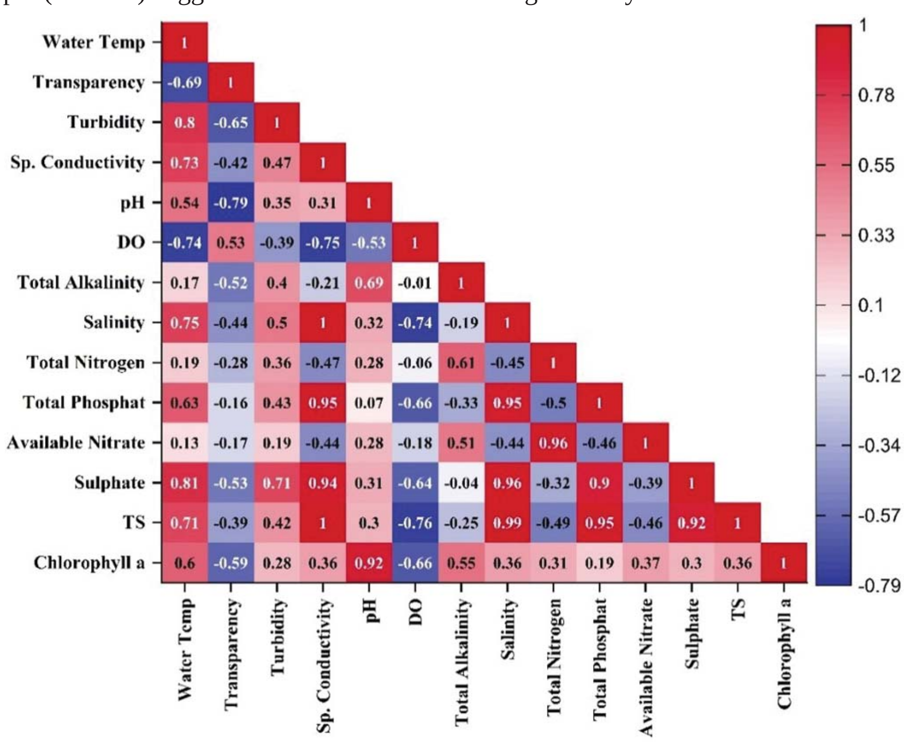

Fig. 3 Heat map analysis between water quality indicators and Chlorophyll a

***Principal Component Analysis* (PCA):** Over five years and eight sampling sites, the principal component analysis (PCA) of twelve water quality parameters, including Chlorophyll a, revealed significant geographic variations and highlighted strong environmental gradients across the river system. PC1 (48.48% variance) predominantly reflects pollution and nutrient enrichment, with downstream sites like Fraserganj and Diamond Harbour showing high salinity, total solids (TS), sulphate, and Chlorophyll a concentrations, indicating a strong link between phytoplankton biomass and ionic concentrations, as well as marine influences. On the other hand, PC2 (27.47% variance) correlates with nutrient-driven factors such as total nitrogen and available nitrate, which are more prominent at upstream sites like Farakka and Jangipur. Key indicator of eutrophication potential, chlorophyll a is found in both components and emphasises the significance of both natural and anthropogenic factors on the trophic conditions and water quality. The PCA bi-plot highlights these dynamic interactions, hence underlining the influence of environmental gradients on the ecological status of the river.

Discussion

These findings are in line with other research showing that phytoplankton development in freshwater and estuaries can be much influenced by nutrient enrichment, especially nitrogen and phosphrous.[11,12] Reduced transparency and high turbidity along with the raised Chlorophyll a levels seen in nutrient-rich zones, fit early eutrophication recorded in similar riverine-coastal transition zones worldwide.[13] The significant rise in conductivity at coastal stations particularly Fraserganj may indicate both anthropogenic effects, including urban wastewater inputs or industrial effluents, and saline intrusion.[14] Particularly in biologically active or nutrient-loaded areas, a slight decline in DO highlights the issue of increasing biological oxygen demand, which, if allowed unbridled, may cause hypoxic conditions.[15]

From rather constant upstream conditions to declining downstream and estuarine areas, the regional gradient in water quality points to the combined influence of land use, hydrological changes, and human population density. These results highlight how urgently integrated watershed management strategies addressing nutrient inputs at their source, supporting wastewater treatment, and enabling ecological monitoring must be implemented. Understanding long-term environmental changes and guiding policy frameworks for river and estuary preservation depend on regular assessments like this one as well.[16]

With downstream sites like Fraserganj and Diamond Harbour closely linked with salinity, sulphate, total solids, and Chlorophyll a, the PCA indicated different spatial patterns in water quality, demonstrating estuarine effect and nutrient enrichment.[17,18] Higher loadings for total nitrogen and nitrate indicated agricultural runoff in upstream areas like Farakka and Jangipur. Consistent with trends seen in other tropical rivers, the incorporation of Chlorophyll a revealed places with high primary productivity and possible eutrophication hazards.[19]

Conclusion

This five-year study of the lower Ganga River and its estuarine stretches aimed to evaluate water quality and trophic status using ecological indicators such as Chlorophyll a. Findings reveal a clear link between elevated Chlorophyll a levels and rising concentrations of nitrogen, phosphorus, turbidity, and conductivity, particularly in downstream and coastal zones, indicating eutrophication driven by nutrient enrichment and human activities. These patterns suggest a major ecological change characterised by rising algal production and possible long-term damage to water quality. These results demand quick legislative changes and sustainable watershed management, considering the cultural, ecological, and economic value of the river. Prioritising pollution control, upgrading wastewater treatment, and promoting community-based monitoring are critical to preserving the river's integrity for future generations.

Acknowledgment

The authors express their sincere gratitude to the National Mission for Clean Ganga, Ministry of Jal Shakti, Government of India, for generously funding the experiments conducted in this study. They also extend their thanks to the ICAR-Central Inland Fisheries Research Institute for offering comprehensive research support and facilities. ❐

References

1. R. Singh, T. Choudhury, N. Sharma, *Environmental Pollution*, **245,** 612–620 (2019). https://doi.org/10.1016/j.envpol.2018.11.073
2. H.W. Paerl, R.S. Fulton, J.J. Pinckney, *Hydrobiologia*, **62**6(1), 1-9 (2011). https://doi.org/10.1007/s10750-009-9962-9
3. J.H.W. Lee, I.J. Hodgkiss, K.T.M. Wong, I.H.Y. Lam, *Coastal and Shelf Science*, **65**(1–2), 172–190 (2005). https://doi.org/10.1016/j.ecss.2005.06.005
4. R. Devi, E. Tesfahune, W. Legesse, B. Deboch, A. Beyene, *Bioresource Technology*, **99**(5), 975–979 (2008). https://doi.org/10.1016/j.biortech.2007.03.013
5. M.M. Steffen, E.M. Boss, W. Mohr, *Science of the Total Environment*, **575**, 56-67 (2017). https://doi.org/10.1016/j.scitotenv.2016.09.102

6. Y. Liu, J. Deng, H. Li, *Environmental Monitoring and Assessment*, **185**(9), 7417–7426 (2013).. https://doi.org/10.1007/s10661-013-3143-2
7. S.E. Purnamaningtyas, In IOP Conference Series: Earth and Environmental Science (IOP Publishing, 2021, October) Vol. 860, No. 1, p. 012082.
8. A.V. Rao, S.M. Rao, S. Tiwari, *Environmental Monitoring and Assessment*, **188**(5), 292 (2016). https://doi.org/10.1007/s10661-016-5389-3
9. S.D. Sarkar, U.K. Sarkar, M. Naskar, K. Roy, A.K. Bose, S.K. Nag, B.K. Das, *Revista de Biología Tropical*, **69**(1), 60-76 (2021).
10. A.P.H.A. (2005) Standard Methods for the Examination of Water and Wastewater. 21st Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.
11. V.H. Smith, G.D. Tilman, J.C. Nekola, *Environmental Pollution*, **100**(1-3), 179-196 (1999). https://doi.org/10.1016/S0269-7491(99)00091-3
12. P.M. Glibert, R. Maranger, D.J. Sobota, L. Bouwman, *Environmental Research Letters*, **9**(10), 105001 (2014). https://doi.org/10.1088/1748-9326/9/10/105001
13. H.W. Paerl, R.L. Dennis, D.R. Whitall, *Estuaries and Coasts*, **25**(4), 677-693(2006). https://doi.org/10.1007/BF02841382
14. H. Gupta, S. Paul, *Environmental Earth Sciences*, **63**(5), 1007-1016 (2011).. https://doi.org/10.1007/s12665-010-0771-4
15. R.J. Diaz, R. Rosenberg, *Science*, **321**(5891), 926-929 (2008). https://doi.org/10.1126/science.1156401
16. UNESCO. (2020). UNESCO Water Quality Report. https://unesdoc.unesco.org/ark:/48223/pf0000372985
17. R. Bhateria, D. Jain, *Applied Water Science*, **6**(4), 107–119 (2016). https://doi.org/10.1007/s13201-016-0476-1
18. H.W. Paerl, J.T. Scott, M.J. McCarthy, S.E. Newell, W.S. Gardner, K.E. Havens, W.A. Wurtsbaugh, *Science of the Total Environment*, **579**, 810–821(2016). https://doi.org/10.1016/j.scitotenv.2016.05.001
19. S. Singh, M. Rani, A. Malik, S.P. Shukla, *Chemosphere*, **223**, 583–594 (2019). https://doi.org/10.1016/j.chemosphere.2019.01.024