

Seasonal Water Quality Trends at Diamond Harbour West Bengal: A Pilot Study

Divya Ghildyal^{1*}, Manisha Chaudhary², Nidhi Yaduvanshi³

^{1*,2,3}Department of Physics, JSS Academy of Technical Education, Noida, India-201301

Abstract

Diamond Harbour is located on the Hugli river, which is a tributary of Ganges, tidal bore occurs here wherein the ocean water rushes into the river's mouth, raising the water level and making the harbour accessible. Twenty Six water quality parameters were analysed over a period of one year (2024). The analysis was done on the basis of the four major seasons of the year Winter, Summer, Monsoon and Autumn. Major variations in water quality parameters were observed for Summer season. Temperature was highest in summer compared to other seasons, also Turbidity, Total Hardness, TDS, Sulphate, Sodium, Potassium, Magnesium, Chloride, Calcium and Conductivity were found to be very high in Summer season compared to other seasons. While Fecal coliforms, E. Coli were found in less concentration in summer compared to other seasons. The following parameters did not show much change in all four seasons BOD, Nitrate, pH, COD, Fluoride, Nitrite-N, Phosphate and Total Alkalinity. Diamond Harbour is basically a navigation point, high values of hardness of water, TDS etc. much above permissible limits as prescribed by CPCB being observed here in Summer season could be due to river's concentration becoming high due to evaporation, resulting in the deterioration of its quality or mixing of sea water at Diamond Harbour. The correlation matrix for different seasons, showed a strong correlation between Winter and Autumn season, followed with Winter and Monsoon season concluding that similar treatment can be used on water in Winter and Autumn season and also to some extent in Monsoon season. Our study found that compared to other seasons, in summer season highest concentration of Magnesium, Sodium and sulphate ions was observed. A further analysis with decision tree model found that sulphate is the most important parameter, followed by COD for splitting the data set. Implementation of any water treatment technology is not useful unless the correct source is identified. Our study helped in identifying that high concentrations of Sulphate ions are responsible for hardness of water at Diamond Harbour in summer season. Special monitoring of water hardness in summer season is required at Diamond Harbour, before the water can be used for any purpose. Future scope of work lies in enhancing the water treatment plants with ion-exchange technology which is very efficient in removing magnesium ions from water and reverse osmosis for removing sulphate and sodium ions from water, so that the water is safe to some extent for usage.

Keywords: Seasonal Variations, TDS, Water quality, Magnesium, Sulphate

INTRODUCTION

To assess the general quality of water bodies, it is essential to measure various WQPs, including pH, temperature, total dissolved solids (TDS), alkalinity, the concentration of different ions, dissolved oxygen (DO), carbonates, hardness, and others. Each of these provides vital information about the water quality in a particular region. For example, pH indicates the level of acidity or basicity in the water, and by analyzing the responsible ions for acidity or basicity, it is feasible to pinpoint the origins of water pollution and take necessary actions to mitigate it. Monitoring these parameters can help in identifying potential water quality issues and implementing appropriate measures to maintain or improve water quality.[1][2][3]

In present times due to major variations in temperatures throughout the year, monitoring water quality parameters as per seasons is a must. Seasonal monitoring of water quality parameters will not only help in effective management strategies but also help policy makers decide updates for water treatment plants to adjust with seasonal variations.

The present study has determined water quality assessment on the basis of physico-chemical analysis for the following Twenty Six parameters Biological Oxygen Demand (BOD), Conductivity, Dissolved Oxygen (DO), E-Coli, Fecal Coliform, Fecal Streptococci, Nitrate-N, pH, Temperature (Water), Total Coliforms, Calcium, Chloride, Chemical Oxygen Demand (COD), Fluoride, Magnesium, Nitrite N, Phosphate - P, Potassium, Sodium, Sulphate, Total Alkalinity, Total Dissolved Solids (TDS), Total Fixed Solids (TFS), Total Hardness as CaCO₃, Total Suspended Solids (TSS), Turbidity for four major seasons of the year. Winter, Summer, Monsoon and Autumn.

At Diamond Harbour in West Bengal, the Ganga river experiences significant seasonal variations in water quality,

with the most noticeable change occurring during summer and autumn season while in monsoon season heavy rainfall drastically increases water volume, diluting pollutants and causing a drop in contaminant concentrations, while the water level is lower and pollution levels may rise during winter and summer months; this is mainly due to reduced dilution from rainfall and increased wastewater discharge from human activities.

Literature survey [4][5][6][7] have shown that a strong correlation exists among different parameters and a combined effect of their inter-relatedness indicates the water quality in different seasons. In the present study, an attempt is made to analyse quantitatively a step-by-step study of correlation and of the water quality parameters helps to assess the overall water quality. It also helps to quantify relative concentration of various pollutants in water and provides necessary cure for the implementation of rapid water quality management programmes. By this study, an attempt has been made to assess and improve the quality of surface water in the study area and thereby to analyse correlation and their variations as per different seasons of the year.

It also helps to quantify relative concentration of various pollutants in water and provides necessary cue for the implementation of rapid water quality management programmes. By this study, an attempt has been made to assess and improve the quality of surface water in the study area and thereby to analyse correlation of various physico-chemical parameters.

To address water related environmental problems, it is a must to have accurate information and to know precisely what the problem is, where it is occurring and how serious it is, and what is causing it is used for regression techniques for prediction to assess the quality of water in the specific area.[8][9][10][11].

As the routine chemical analysis requires a lengthy and time-consuming process, it would be a better and cost-effective solution to establish relationships between other different parameters with a common and easily determinable parameter. correlation coefficients can be successfully used to estimate the concentration of other constituents. Through this cost effective solution of decision tree model, the most influential parameter for Water Quality Index for this data set was sulphate followed with COD, Potassium, Fecal Coliforms.

2. Study Area

Diamond Harbour in West Bengal is a coastal town in the South 24 Parganas district, (22.19°N 88.19°E) known for its historical significance as an ancient port and its proximity to the Sundarbans mangrove forest. At Diamond Harbour, the water from the a distributary of the Ganges, mixes with the Bay of Bengal in a large estuarine system. This area is considered a coastal and estuarine zone where freshwater from the river gradually merges with the saltwater of the ocean, creating a unique mixing zone with fluctuating salinity levels.



Figure 1: Study Area (Diamond Harbour, West Bengal)

MATERIALS AND METHODS

The West Bengal Pollution Control Board (WBPCB) is responsible for water quality monitoring of the stretch of River Ganga in the eastern Region of India, in the State of West Bengal. The physio-chemical data of monitoring during 2024 was obtained from the database of WBPCB. The raw data analysed in this study is in the form of monthly data in reference to surface water samples collected every month at Diamond harbour. These data sets were grouped as per the major four seasons of the year, Winter (December to February), Summer (March to May), Monsoon (June to September) and Autumn (October to November). Total 26 parameters were taken for study as presented in Table 1. Out of the 26 parameters analysed variations for all four seasons were observed in their concentrations for all four seasons considered. The correlation coefficient (r) measures the degree of association that exists between two variables, one taken as dependent variable. Data was also analysed under

decision tree model, to detect the most important parameter for splitting the dataset. This helps to identify the most influential pollution parameter.

RESULTS AND DISCUSSION

Table 1:

Water Quality of Ganga at Diamond Harbour West Bengal (2024)					
S.No.	Parameter	Winter	Summer	Monsoon	Autumn
1	BOD	2.3925	2.655	2.715	2.73
2	Conductivity	2286.75	6283	4819.5	452
3	Dissolved Oxygen	7.215	6.16	5.79	5.475
4	E-Coli	885	695	865	865
5	Fecal Coliform	1775	1010	2850	1200
6	Fecal Streptococci	257.5	94.5	124	335
7	Nitrate-N	1.285	1.605	0.89	2.27
8	pH	7.34	7.54	7.765	7.135
9	Temperature(Water)	25.25	30	30	29
10	Total Coliforms	7450	2150	6300	5100
11	Calcium	106.4	190	74	41.6
12	Chloride	655.6625	1324	764	73
13	COD	14.7325	16.2	14.805	12.72
14	Fluoride	0.2975	0.41	0.43	0.36
15	Magnesium	22.115	114.17	44.955	9.24
16	Nitrite N	0.02	0.02	0.015	0.01
17	Phosphate-P	0.04	0.03	0.065	0.065
18	Potassium	13.65	42	26.9	6.6
19	Sodium	333.5	1275	429.5	64.25
20	Sulphate	108.225	450	182.5	59.395
21	Total Alkalinity	146.5	167.5	160	129
22	Total Dissolved Solids (TDS)	1580	5032	2664	303
23	Total Fixed Solids(TFS)	1937.5	4817	2278	289
24	Total Hardness as CaCO ₃	357	945	370	142
25	Total Suspended Solids(TSS)	513	727	269	192
26	Turbidity	286	462.5	249.5	167

These values were used to calculate the Mean, Standard Deviation (SD), Standard Error (SE) and Coefficient of Variation (CV) the statistical summary. These values are summarized in Table No.3. In the West Bengal stretch of the River Ganga, seasonal variations significantly impact water quality parameters, with the monsoon season generally leading to dilution of pollutants due to heavy rainfall, resulting in lower concentrations of contaminants like dissolved solids and higher water volume, while the dry season sees increased pollution levels due to less dilution and higher concentration of pollutants; key factors include changes in dissolved oxygen (DO), pH, electrical conductivity (EC), and bacterial populations, with the lowest DO often observed during the summer months due to higher temperatures and increased biological activity.

Temperature is one of the most significant characteristic that influence nearly all the physical, chemical and biological characteristics of water and thus the water chemistry. It never remains steady in rivers due to varying environmental conditions. During the study the maximum temperature range (30°C) was recorded in summer in comparison with monsoon and winter season .Turbidity of water is an important parameter, which influences the light penetration inside water and thus affects the aquatic life. During the study maximum value of turbidity (462.5 NTU) was observed in summer in comparison with other seasons .High value of turbidity was due to increasing quantity of waste, eroded material submerged in water, influx of rain water from catchment area and sand in monsoon season. Finally, velocity has an impact on the DO levels in a river or stream. Fast moving sections of a river tend to have higher levels of DO than comparatively slower parts of a river because they are

better aerated. The water level and its velocity started increasing from winter season to incorporate pollutants; larger, swiftly moving streams and rivers can receive pollutants with a diminished negative effect. The existence of Total Salts is due to silt and organic matter. Total Salts refer to matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity. In the study maximum range of TS (727) was recorded in summer season.

In the study maximum range of DO was recorded during the winter season as compared with monsoon and summer months. During the study the overall highest mean value of DO was observed 7.215. It may be due to higher temperature, oxygen demanding wastes, inorganic reluctant and seasonal variation. A high level of BOD deteriorates river water quality by rapid decomposition of biodegradable organic matter and the subsequent depletion of DO, while COD traditionally represents the total organic matter. During the study the maximum range of BOD 2.73 was recorded in autumn season as compared with monsoon and winter season with the Ganga water. This was due to increased chemical and biological activities in summer and monsoon season. The hardness of water is not a pollution indicator parameter but indicates water quality mainly in terms of Ca^{2+} and Mg^{2+} , bicarbonate, sulphates, chloride and nitrates. In the study maximum value of Total Hardness (°) was recorded in summer months than in monsoon and winter (Table 1). Higher concentration of Total Hardness (°) was This due to result from poor dilution owing to low precipitation rate. The seasonal behaviour's of TH were more or less similar at all the sites. It was lowest (90 ppm) in summer season and highest (200 ppm). During the study maximum range of Cl, SO_4 , nitrogen and P were recorded to be 5.11 summer as compared with monsoon and winter season. Higher concentration of Cl (5.78 mg), SO_4 (21.40 mg), and P (0.14 mg) were recorded. This is due to increased human, animal, agricultural and industrial activities that released large volume of wastewater which is main sources of pollution. This finding is in agreement with other works of many researchers.[12][13][14]. For the evaluation of seasonal variation in physio-chemical parameters of the Ganga River water, correlation matrix was considered and given in Table 2.

Values of all the 26 parameters are summarized in Table 1 for all four seasons. These values were used to calculate the Mean, Standard Deviation (SD), Standard Error (SE) and Coefficient of Variation (CV). These values are summarized in Table No.3.

The temperature of the water is in the range 25-30° C. The important physico-chemical characteristics of analyzed water samples viz., Mean and Standard Deviation (SD) have been presented in Table-2 and the values are compared with standard parameters in Table-3. It shows that variation among the measured values of these parameters at different locations is not too high and variation range is very narrow.

The study emphasized the significance of multivariate statistical techniques [15][16] in discerning the variability patterns of parameters, as well as in formulating management strategies to enhance river water quality by pinpointing the most impactful parameters contributing to water quality degradation.

Winter Season

Out of the 26 parameters studied for winter Season, the parameters which were found highest in winter season compared to summer, autumn, and monsoon were Dissolved Oxygen (DO) which showed a value of 7.215, slightly higher than other seasons, also higher than standard limit prescribed by CPCB, indicating good health of water. (Table 1) E-Coli was found around 23 percent higher compared to Monsoon and Autumn season and 27 percent increase compared to Summer season. Total Coliforms were found highest in Winter season (7450 MPN/100ml).

DO generally higher in winter due to increased oxygen solubility at lower temperatures, and lower during summer and monsoon due to increased biological activity and turbidity.

The parameters which showed a decline in winter season compared to others were BOD (2.39) approximately 14% less compared to summer, monsoon and autumn. Fluoride concentration was lowest in winter (0.29mg/l). DO found higher in winter season could be due to increased oxygen solubility at lower temperatures. E-Coli levels being high in Winter season could be due to untreated sewage waste getting dumped in river system. High amount of Total Coliforms in Winter season is a matter of concern.

Summer Season

Summer season which covers the months of March, April and May also known as the pre monsoon season is characterized by warm winds and rising temperatures. Highest temperature of 30°C out of all four seasons was observed for summer season. Out of all four seasons under study maximum variations in parameters were observed for summer season.

Electrical conductivity higher in dry season with increased dissolved solids. TDS higher in dry season. Biological

load may be higher during dry seasons due to less dilution and potential for stagnant water. Minimum dissolved oxygen was observed during summer season ranging from

Rising temperature causes low solubility of oxygen resulting in the decrease of DO content during summer season.

Summer season is characterized with higher pollution concentration, with less water flow, pollutants become more concentrated, increased water temperature can further decrease DO solubility. Potential for algal blooms, lower flow can lead to increased algal growth due to nutrient accumulation. Maximum variations in parameters were observed in summer season. Temperature showed a rise in summers by 5°C compared to Winter and approximately 1°C more compared to Autumn, while Monsoon season the temperature was approximately as that of summers. Highest value of conductivity was observed for summers (6283 microsiemens per centimeter) which is approximately 92% higher compared to Autumn,

Chemical Oxygen Demand (COD) in river water is typically highest during the summer months (16.2 mg/l) because higher temperatures accelerate the decomposition of organic matter, leading to a greater demand for oxygen in the water, thus resulting in a higher COD level. Magnesium ion concentration which leads to hardness of water was found highest in summer season (114.17 mg/l), 91% higher compared to Autumn season, 61% higher compared to Monsoon, and approximately 80% higher compared to winter season. Similar trend was observed for sulphate ions with highest value being observed in summer (450 mg/l) compared to other seasons. Because of the high presence of these salts total alkalinity was found highest (167.5 mg/l). Total Dissolved Solids (TDS), Total Fixed Solids (TFS), Total Hardness as CaCO₃, Total Suspended Solids (TSS) and Turbidity were all observed highest for summer season compared to other seasons as presented in Table 1.

Reason could be in summers with higher temperatures evaporation occurs which leads to higher concentration of salts, leading to high conductivity whereas Autumn season leads to Water quality is often considered better in autumn because the cooler temperatures slow down the growth of algae and other aquatic plants, leading to less organic matter decomposing in the water, resulting in higher dissolved oxygen levels and generally clearer water with less turbidity, hence lower conductivity.

Chloride ion also found highest in summers (1324 mg/l) almost double of winters (655 mg/l) and 94% higher compared to Autumn and 54% higher compared to Monsoon season. Reason for lower concentration of chloride in monsoon season compared to summer could be that in monsoon river experiences running water hence lesser concentrations

Higher concentrations of Magnesium, Potassium, Sodium, Sulphate, TDS, TFS, Total hardness as CaCO₃, TSS could be attributed to the fact that in summers due to high temperatures (30°C), evaporation occurs which leads to higher concentration of salts and high conductivity. Turbidity was also found highest for summer season because of high TDS content.

Parameters which were found showing a decline in summer season compared to other seasons were E-Coli, Total Coliforms, Fecal Streptococci this could be due to less discharge of sewage waste in the river system in summers or water treatment plants functioning well in summers.

Monsoon Season

All 26 parameters in monsoon season showed values between Summer and Autumn season, not even one parameter reached its maximum value or minimum, reason could be monsoon season observes rainfall which results in running water hence none of the parameters obtain their maxima or minima. Monsoon season is characterized by dilution effect, increased turbidity, and lower DO levels. Heavy rainfall brings large volumes of water, diluting pollutants and lowering their concentration in the river. High sediment load from run off can increase turbidity, reducing light penetration and affecting aquatic life. Higher bacterial activity due to increased organic matter can lead to lower dissolved oxygen levels.

Electrical conductivity usually lower during monsoon due to dilution. Seasonal variations are mainly by the changes in water volume during monsoon the river receives silts and debris from the drainage area during monsoon which increases turbidity, chemical oxygen demand, suspended solid while the large volume of runoff water dilutes the ionic components of the river.

Rain water is rich in DO content.

Autumn Season

Autumn season or the post monsoon marked from October to November the following parameters showed minimum value even much below the standards prescribed by CPCB. Conductivity, Dissolved Oxygen (DO), magnesium, Potassium, Nitrite N, Sodium, Total Alkalinity, Total Dissolved Salts (TDS), Total Fixed

Solids(TSS), Total Hardness as CaCO₃, Total Suspended Solids (TSS), Turbidity as presented in Table 1.

Autumn season leads to Water quality is often considered better in autumn because the cooler temperatures slow down the growth of algae and other aquatic plants, leading to less organic matter decomposing in the water, resulting in higher dissolved oxygen levels and generally clearer water with less turbidity, hence lower conductivity.

In general the organic pollution indicators BOD and COD indicated some seasonal variability but no immediate bench marks. The Total coliforms for all seasons far exceeded the <500MPN/100mL limit for safe bathing hitting a high of 7,450(Winter) and a low of 2,150 (Summer).Conductivity, TDS , Chloride, Sodium, Magnesium, Calcium , Sulphate , Total Hardness all show marked increase in summer then taper off in monsoon and dramatically drop in Autumn likely driven by tidal intrusion and evaporation factors.

Autumn shows sharp decline in sodium. Phosphate is higher during monsoon and autumn indicating nutrient loading from surface run off or sewage.

DISCUSSION

Table 2 :Correlation Matrix for Different Seasons

<i>Seasons</i>	<i>Winter</i>	<i>Summer</i>	<i>Monsoon</i>	<i>Autumn</i>
Winter	1			
Summer	0.512757	1		
Monsoon	0.923035	0.742185	1	
Autumn	0.947903	0.224927	0.785018	1

The correlation matrix compounded form the various water quality parameters studied for the four seasons of the year as shown in Table 2. The table shows that water quality parameters for winter season have a strong correlation with Autumn season, while weaker correlation with summer season this could be due to temperature difference in winter and summer seasons, also excess sunlight in summer causes evaporation of water leading to high value of TDS , also summer season experiences less flow of running water

While summer season bears a very poor or almost nil correlation with Autumn season. Autumn season marks the transition from summer to winter , water quality as per the correlation matrix is worse in summers compared to Autumn primarily because of higher temperature , increased algal growth and lower water levels in summer , leading to higher concentration of pollutants from run off and wastewater discharge, while Autumn experiences improved water quality with cooler temperatures and potentially higher water levels, resulting in better dilution of pollutants.

Higher summer temperatures promote faster decomposition of organic matter and increased algal growth which can deplete dissolved oxygen levels, negatively impacting water quality.

Summer often experiences less rainfall, leading to lower river flow and higher concentration of pollutants from sources like sewage and industrial waste. In contrast autumn may see more rain , which can dilute pollutants. Higher water levels in autumn can help settle sediments that may be suspended during summer , improving water clarity. Monsoon and Autumn season bear a strong correlation , this could be due to the fact that both these seasons experience heavy rainfall , this rainfall acts like a natural flushing mechanism , diluting pollutants and replenishing water sources, showing a strong correlation with improved water quality parameters.

Table 3 : Statistical Analysis of Different Seasons

Winter		Summer		Monsoon		Autumn	
Mean	722.01	Mean	993.97	Mean	866.7	Mean	364.917
Standard Error	299.97	Standard Error	336.83	Standard Error	317.9	Standard Error	197.466
Median	127.36	Median	178.75	Median	142	Median	61.8225
Standard Deviation	1529.55	Standard Deviation	1717.49	Standard Deviation	1620.728	Standard Deviation	1006.88
Sample Variance	2339517.3	Sample Variance	2949776.64	Sample Variance	2626760	Sample Variance	1013812
Kurtosis	15.77	Kurtosis	4.06	Kurtosis	5.103	Kurtosis	21.5217

Skewness	3.72	Skewness	2.21	Skewness	2.336	Skewness	4.50894
Range	7449.98	Range	6282.98	Range	6299.985	Range	5099.99
Minimum	0.02	Minimum	0.02	Minimum	0.015	Minimum	0.01
Maximum	7450	Maximum	6283	Maximum	6300	Maximum	5100
Sum	18772.375	Sum	25843.29	Sum	22533.33	Sum	9487.85
Count	26	Count	26	Count	26	Count	26

The statistical analysis of different seasons as represented in Table shows the mean value highest for summer season 993.37, followed by Monsoon, Winter and least value for Autumn season. The standard error which is a statistical measure that quantifies the dispersion from the actual mean, was found highest for summer season followed with monsoon, winter and lowest for autumn season. Large standard error means high uncertainty. The median value which is very useful for identifying the typical value when data is skewed, was found highest for summer followed by monsoon, winter and lowest for Autumn. The standard deviation, which measures how spread out the data is from the mean and a larger standard deviation indicates greater variability was observed for summer season followed by monsoon, winter and lowest for autumn season. Sample variance which is used to calculate the variability in a given sample was highest for summer followed with monsoon and winter, observed lowest for autumn season. High positive Kurtosis values for all four seasons shows the data is more peaked, Kurtosis was found highest for Autumn, followed with winter and monsoon season and lowest for summer season. Skewness which refers to asymmetrical data distribution was found highest for Autumn, followed by winter, monsoon and lowest for summer season.

CONCLUSION

Out of the four seasons under study, winter season has the best overall water quality reason could be cooler temperatures, higher DO and lower microbial counts. Summer –Monsoon-Autumn were categorized in medium category driven down by DO, high turbidity and high fecal coliforms. Summer season comes under worst category with high temperature leading to high salinity, TDS. Rain in monsoon does dilute the salinity but microbial and nutrient levels remain elevated. Autumn appears the least mineral laden season but still exhibits persistent contamination and DO.

The correlation matrix between various seasons shows a strong correlation between winter and autumn season followed with winter and monsoon season. The worst correlation was found between summer and autumn. Main parameter in split of decision tree model was sulphate. Future scope of work lies in enhancing water treatment plants with removal of sulphate ions at Diamond harbor and special treatment of water in summer season before it can be used for any purpose for safety of mankind.

REFERENCES

- Adesakin, T. A., Oyewale, A. T., Bayero, U., Mohammed, A. N., Aduwo, I. A., Ahmed, P. Z., et al. (2020). Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samaru community, Zaria. *Northwest Nigeria. Heliyon*, 6(8), e04773. <https://doi.org/10.1016/j.heliyon.2020.e04773>
- Ali, S. Y., Sunar, S., Saha, P., Mukherjee, P., Saha, S., & Dutta, S. (2021). Drinking water quality assessment of river Ganga in West Bengal, India through integrated statistical and GIS techniques. *Water Science and Technology*, 84(10–11), 2997–3017. <https://doi.org/10.2166/wst.2021.293>
- Bhakar, P., & Singh, A. P. (2019). Groundwater quality assessment in a hyper-arid region of Rajasthan. *India. Natural Resources Research*, 28(2), 505–522.
- Bhat, S. A., Meraj, G., Yaseen, S., & Pandit, A. K. (2014). Statistical assessment of water quality parameters for pollution source identification in Sukhnag stream: An inflow stream of lake Wular (Ramsar Site), Kashmir Himalaya. *Journal of Ecosystems*, 2014(1), 898054.
- Bon, A. F., Aoudou Doua, S., Banakeng, L. A., Narke, C., Chouto, S., & Mboumbouo Ndam, A. (2020). Contribution of a geostatistical model of electrical conductivity in the assessment of the water pollution index of the Quaternary aquifer of the Lake Chad basin (Kousseri-Cameroon). *Arabian Journal of Geosciences*, 13(4), 170
- Brown, R. M., McClelland, N. I., Deininger, R. A., & O'Connor, M. F. (1972). A water quality index—crashing the psychological barrier. In W. A. Thomas (Ed.), *Indicators of environmental quality* (vol 1). Environmental Science Research. Springer. https://doi.org/10.1007/978-1-4684-2856-8_15
- Chattopadhyay, S., Rani, L. A., & Sangeetha, P. V. (2005). Water quality variations as linked to landuse pattern: A case study in Chalakudy river basin, Kerala. *Current Science*, 89(12), 2163–2169. <http://www.jstor.org/stable/24111081>
- Dimri, D., Daverey, A., Kumar, A., & Sharma, A. (2021). Monitoring water quality of River Ganga using multivariate techniques and WQI (Water Quality Index) in Western Himalayan region of Uttarakhand, India. *Environmental Nanotechnology, Monitoring & Management*, 15, 100375. <https://doi.org/10.1016/j.enmm.2020.100375>

9. Franklin, P. (2014). Dissolved oxygen criteria for freshwater fish in New Zealand: A revised approach. *New Zealand Journal of Marine and Freshwater Research*, 48(1), 112–126
<https://doi.org/10.1080/00288330.2013.827123>
10. Gani, A., Pathak, S., Hussain, A., Ahmed, S., Singh, R., Khevariya, A., et al. (2023). Water Quality Index Assessment of River Ganga at Haridwar Stretch Using Multivariate Statistical Technique. *Molecular Biotechnology*. <https://doi.org/10.1007/s12033-023-00864-2>
11. Gurjar, S. K., & Tare, V. (2019). Spatial-temporal assessment of water quality and assimilative capacity of river Ramganga, a tributary of Ganga using multivariate analysis and QUEL2K. *Journal of Cleaner Production*, 222, 550–564. <https://doi.org/10.1016/j.jclepro.2019.03.064>
12. Kamboj, N., & Kamboj, V. (2019). Water quality assessment using overall index of pollution in riverbed-mining area of Ganga-River Haridwar. *India. Water Science*, 33(1), 65–74
<https://doi.org/10.1080/11104929.2019.1626631>
13. Seasonal dynamicity of environmental variables and water quality index in the lower stretch of the River Ganga. Chakresh Kumar, Anwasha Ghosh, Yash, Manojit Debnath and PunyaslokeBhadury 2021 .**Environmental Research Communications, Volume 3, Number 7 Chakresh Kumar et al 2021 Environ. Res. Commun. 3 075008DOI 10.1088/2515-7620/ac10fd**
14. Seasonal variation of surface water quality and streamflow in Rispana: A tributary of Ganges river, India Environmental Quality Management Manish Pant, Jabrinder Singh 2024. <https://doi.org/10.1002/tqem.22199>
15. Annals of Agrarian Science Volume 15, Issue 2, June 2017, Pages 278-286 Research on heavy metal pollution of river Ganga: A review Environmental Nanotechnology, Monitoring & Management. Volume 15, May 2021, 100375
<https://doi.org/10.1016/j.aasci.2017.04.001>
16. Monitoring water quality of River Ganga using multivariate techniques and WQI (Water Quality Index) in Western Himalayan region of Uttarakhand, India Deepika Dimri, Achlesh Daverey , Ambika Kumar , Archana Sharma <https://doi.org/10.1016/j.enmm.2020.100375>