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Prometteur evaluation of surface water quality to respect of seasons from the holy Ganges River, India

Kavita Singh[1], Mariyam Khan[1], Abhijeet Sharma[2], Shanthy Sundaram[2], Adi Nath[1]*

[1]Department of Botany, Nehru Gram Bharati deemed to University, Prayagraj-221505, India
[2]Centre of Biotechnology, University of Allahabad, Prayagraj-211006, India
*Corresponding author: adinathupadhyay@gmail.com

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Abstract:

With an emphasis on the seasonal variations in the sacred Ganga River, this research highlights the intricate relationship between human activity and environmental conditions. The study looks at the physicochemical characteristics of water and offers scientific evidence of its effects on the river environment in the year 2023-2024. The thermodynamics of the self-purifying response was discovered to be maintained by year-round learning from nature. The month of May had the lowest dissolved oxygen levels, indicating an optimization nature. During the wet season, August had the highest concentration of chloride. As the summer draws to a close, the amount of total sulphate falls in May. The variation in levels of magnesium from November to March indicates the influence of anthropogenic activities during the winter season. The amount of alkalinity was increased in the May month surpass acceptable standards, emphasizing pollution concerns. Total Dissolved solids values, higher during non-Mela periods, suggest controlled sewage discharge during Mela events. The coliform bacteria found low in dry season and higher in wet season by MPN count. The Microalgae dominant in biofilm having effective patch size. PCA score indicates that the seasonal variation maintained the water quality. The findings underscore the need for sustainable water management practices, pollution control measures, and continued efforts, such as the Ganga Samagra, Namami Gange initiative, to preserve and enhance the ecological health of the river. The observed self-regulatory mechanisms, including biofilm formation, offer promising avenues for future research and environmental conservation.

Introduction:

Anthropogenic nutrient loading in aquatic systems is a global concern. India's most significant river, the Ganga, is currently facing serious threats to its biodiversity and long-term environmental sustainability due to pollution. To assess the nutrient load, eutrophication risk, and river trophic status, the Ganga and Yamuna rivers in Uttar Pradesh were subjected to nutrient concentration analysis (Akoto et al. 2020, Batabyal, 2023, Bowes et al. 2020). After over-exploitation, the ecology of rivers is now under risk. Parameters like DO, BOD and the hardness is high and over the acceptable threshold. In order to evaluate and safeguard the environment from harmful effects caused by different organic contaminants that arise from industrial emissions and those released during harvesting, environmental water quality evaluation is necessary (Dong et al. 2020, Dutta et al. 2020). Using seven water quality criteria, this study examined the Ganga River's water quality in Prayagraj at nine different locations where sampling was conducted upstream, downstream, and middle stream between January 2023 and December 2024 (Chatanga et al. 2019).

Over the years, the Ganga River has been the primary source of drinking water for humans. Millions of relict species, including fish, planktons, benthic organisms, and other aquatic creatures, occupy this ecological niche (Dwivedi et al. 2020, Gupta et al. 2023). Every year from January to March, India celebrates the Magh Mela (also known as the Kumbh Mela), a religious Hindu event that includes ceremonial mass bathing at the confluence of the Ganga, Yamuna, and Saraswati rivers in Prayagraj, Uttar Pradesh (Aggrawal et al. 2020, Purohit et al. 2020, Quadri & Padala, 2021). For the Ganga River Basin to have sustainable water availability, an efficient water management plan is necessary due to the groundwater's rapid depletion and determination. For the four main rivers that flow through Uttar Pradesh, India—the Ganga, Yamuna, and Hindon—the changes in the concentrations of chloride, sulphate, magnesium, alkalinity, total dissolved solids, and dissolved oxygen (DO) were examined in surface river water samples during the pre-monsoon, monsoon, and autumn seasons, January to December 2023 and 2024 (Kannaujiya & Tiwari, 2023, Kishor et al. 2021, Kumar et al. 2020 and 2021, Misra, 2011, Rad et al. 2022, Raman et al. 2023, Rao et al. 2022). Although physicochemical characterization is the primary method used to measure water quality, eutrophication and climate change support the presence of hazardous Microcystins (MCs)-producing cyanobacteria as a new bio-indicator. In order to strengthen comprehensive and sustainable plans for future urbanization and city sustainability, local authorities and decision-makers rely on the mapping and spatial monitoring of land cover variation. Around the world, floods are a devastating natural calamity that poses a serious threat to ecosystems and human life.

In Indian areas, flooding is a common occurrence during the monsoon season (Su et al. 2023, Tariq & Mushtaq, 2023, Subba Rao et al. 2020, Subba Rao, 2021, Varikoden & Revadekar, 2020). Water is essential to humans' basic needs for survival. As in other parts of the world, it is not surprising that the majority of civilizations have developed around riverbanks or in river valleys. In this sense, India is fortunate to have a large number of rivers. The experimental findings of several researchers who have monitored Ganga River water from mass bathing locations to Sitamari (Sant Ravidas Nagar) over the last two years are presented in this research report. Understanding the Gangajal's slow deterioration and current pollution level in connection to different uses has been attempted. Since aquatic biodiversity in India's great rivers is seriously threatened, flagship initiatives aimed at conserving freshwater biodiversity are being carried out utilizing a variety of techniques and approaches. Because of its great sociocultural, economic, and ecological significance, the Ganga River is India's national river. It supports about 500 million people and forms India's largest river basin. Since ancient times, it has served as the birthplace of Indian culture. The Ganga River is experiencing deteriorating water quality, ecological status, and health effects as a result of growing environmental pressures brought on by the world's population growth, urbanization, industrialization, and intensification of agriculture (Zhang et al. 2022, & 2019, Wang et al. 2022, Mariya et al. 2019, Munnawar et al. 2022, Jaiswal & Pandey, 2019, Chen et al. 202, Reddy et al. 2023, Rice et al. 2012, Shukla et al. 2023). Due to the regular cultural and religious activities that include hundreds of people bathing in the Ganga waters and performing rituals, the river also occasionally suffers health and pollution issues. India's water consumption has grown and changed in recent years, causing more water scarcity and deteriorating river and aquifer water quality, endangering the sustainability of the environment as a whole(https://nmcg.nic.in/NamamiGanga.aspx, https://cpcb.nic.in/water-quality-criteria/).

A major health concern is water pollution brought on by faecal contamination. Even yet, it is challenging to identify the various pathogens found in each sample that is taken. Rather, the indirect technique of detecting the presence of pathogens involves examining indicator organisms like coliform bacteria. Gram-negative, rod-shaped, spore-forming, motile or non-motile coliform bacteria are capable of fermenting lactose and producing gas and acid. There are several ways to determine whether coliform bacteria are present. The Most Probable Number (MPN) is one of them. It is used to test the water's purity (Jani et al. 2018). The physical and chemical characteristics of water affected the abundance species composition, stability and productivity of the indigenous population of aquatic organisms (chromeextension://efaidnbmnnnibpcajpcglclefindmkaj/https://cpcb.nic.in/wqm/BIS_Drinking_Water_Specification.pdf 468).

Materials and Methods

Experimental designs:

The experiment was performed in triplicates, a Complete Randomized Design (CRD) was used to elucidate the effects of abiotic and biotic perturbances on structure and function of river ganga in the seasonal variation consisting Z1- Gangoli Shivala Jhunsi, Z2- Chhatnaag ghat, Jhunsi, Z3- Durwasha ashram, Kakra, Prayagra, Z4- Kandala, Mavaiya, Z5- Babarpur, Z6- Saidabad, Z7- Bankar Tari, Baripur, Z8- Chak colepur khurd, Z9- Sitamarhi, Bhadohi (Fig. 1). The samples were collected in the August to July of 2023–2024. For the study of several physicochemical parameters, including, chloride, sulphate, Magnesium alkalinity, Total dissolve solid, Dissolve oxygen and bacterial coliform. Each sample from several sampling sites was delivered to the lab in an inbox. These samples were gathered in a double-capped, carefully cleaned polythene container that held two litters and was completely filled, leaving no room for air. Samples were collected in 100ml polythene containers rinsed multiple times with (1+1) nitric acid, then with distilled water, and then to these 5ml

Figure 1. Google location of the sampling sites

Concentration Chloride:

The presence of chloride in natural waters was estimated according to the Jadhav & Purohit, 2008.

***Sulphate**:*

The concentration of Sulphates was determined nephalometrically by using the coefficients provided by Jadhav & Purohit, 2008. Nephelometer, attractive, stirrer, nessler's cylinders. 147.9mg of AR grade sodium sulphate was disintegrated in refined water and made up to 100ml to give 1ml= 100mg sulphate. 100ml of the example is sifted in to a Nesselr's cylinder containing 5ml of molding 5ml of reagent. About 0.2gm of barium chloride gems is included with kept blending. A working standard is set up by taking 1ml of the standard, 5ml of molding reagent and made up to 100ml, to give 100NTU. The turbidity created by the example and the standard are estimated utilizing a nephelometer and the outcome are organized. The amount of sulphate was calculated by formulae: Sulphate (as mg/L) = (Nephelometric reading) (0.4) (dilution factor)

Magnesium Hardness:

The Magnesium concentration in upstream as well as in downstream were determined as per method of Jadhav & Purohit, 2008. Magnesium hardness can be calculated from the determined total hardness and calcium hardness.

Magnesium (as mg/l) = (T – C) × 0.243. Where T = Total hardness mg/l (as $CaCO_3$), C = Calcium hardness mg/l (as $CaCO_3$)

Alkalinity:

The alkalinity levels were measured according to Jadhav & Purohit, 2008. 50ml of waterway water test was taken in carafe and added 2-3 drop of phenolphthalein indicator. Phenolphthalein alkalinity was confirmed due to the appearance of pink colour and it was due to the hydroxide/ carbonate. Sulphuric acid (0.02N) used as titrant, we added in to the solution till solution become colourless and noted volume used (p). Now 2-3 drops of methyl orange indicator were added in the same flask and continued used to titrate against sulphuric acid. Yellow colour of solution turned in to orange end point (+) and calculated with the help of following equation.

Phenolphthalein Alkalinity (as $CaCO_3$mg/L) $= \dfrac{P \times 1000}{5}$

Total alkalinity (as $CaCO_3$ mg/L) = $\dfrac{t \times 1000}{5}$

Where P is volume of the titrated used against phenolphthalein indicator (ml). S Volume of the sample in ml, T= Total volume of titrant used for the two titrant ions (ml).

Total Dissolved Solids (TDS):

Total Dissolved Solids were estimated using the method of Jadhav

& Purohit, 2008. Take an evaporating dish of suitable size and weight it. Evaporate 250-500ml filtered sample in the evaporating dish on a water bath.

The amount of TDS was calculated by the formulae:

$$\text{TDS g/L} = \frac{(A-B)\times 1000}{V}$$

Where A= final weight of dish in gm, B= initial weight of the dish in gm, V= volume of test taken in ml.

Dissolved Oxygen:

50ml of river sample was taken in stoppered BOD bottle and added 1ml magneous sulphate. 1ml alkaline potassium iodide. In solution precipitate appeared and in this 2ml of sulphuric corrosive was added and shake altogether to break down the hasten 20ml of test was taken from entire substance in a funnel shaped cup and added of few drops starch indicator. Titrated against sodium thiosulphate solution. (A) Blue green color changed in to colorless end point (Jadhav & Purohit, 2008). Whilst the dissolved oxygen was quantified to the formulae:

If whole content is used for titration

$$\text{D.O mg/L} = \frac{V_1 \times N \times 8 \times 100}{V_2 - V_3}$$

If a fraction of the contents is used for titration.

$$\text{D.O. mg/L} = \frac{V_1 \times N \times 8 \times 100}{V_2(V_3 - V_4)}$$

Where, DO=Dissolved oxygen, V_1= "volume of titrant (ml)", N = "Normality of titrant", V_2= "Volume of sampling bottle after placing the stoppers

(ml)"", V_3= "Volume of magneous sulphate + potassium iodide

solution added(ml)", V_4= Volume of fraction of the contents for titration.

Isolation of Microorganisms and MPN (Most Probable Number) Count:

To separate the microorganisms in the water sample, the Spread Plate Technique was used to keep everything sterile and prevent the growth of contaminants, laminar air flow was used throughout. The nutrient agar plate was filled with 100 microliters of the sample, and a glass spreader was used to disperse the water sample. To give the bacteria the ideal temperature (370 C) for growth, the culture was incubated for 24 hours. The most likely number is used frequently to test the water's quality. Fecal coliform bacteria are a kind of bacteria that are frequently used as a marker for fecal contamination of water. The likelihood of water can be determined based on the quantity of bacteria present. A little number of coliform bacteria suggests that there are no harmful bacteria in the water. On the other hand, an increase in coliform bacterial counts indicates the presence of disease-causing organisms in the water. Lactose broth is used to inoculate a serially diluted water sample. If coliform is found in a water sample, it will use the lactose in the medium to create gas and acid. Colour changes indicate the presence of acid, and gas bubbles gathered in the medium's inverted Durham's tube indicate the presence of acid. By counting the number of test tubes that yield a positive result and comparing it to the usual statistical table, one can determine the number of coliform bacteria.

Table 1. MPN values per 100 ml of sample and 95% confidence limits for various combinations of positive and negative results (when five 10-ml, five 1ml and five 0.1 ml test portions are used):

No. of tubes giving a positive reaction			**MPN (per 100 ml)**	**95%confidence limits**	
5 of 10 ml	**5 of 1 ml**	**5 of 0.1 ml**		**Lower**	**Upper**
0	0	0	≤2	≤1	7
0	1	0	2	≤1	7
0	2	0	4	≤1	11
1	0	0	2	≤1	7
1	0	1	4	≤1	11
1	1	0	4	≤1	11
1	1	1	6	≤1	15
2	0	0	5	≤1	13
2	0	1	7	1	17
2	1	0	7	1	17
2	1	1	9	2	21
2	2	0	9	2	21
2	3	0	12	3	28
3	0	0	8	1	19
3	0	1	11	2	25
3	1	0	11	2	25
3	1	1	14	4	34
3	2	0	14	4	34
3	2	1	17	5	46

Both single and double strength lactose media were made. Double strength indicates that a certain amount of distilled water has twice as much of the substance used in the medium.

Media Composition:

Ingredients	**Conc. (gm/L)**
Peptic digest of animal tissue	5 gm
Beef extract	3 gm
Lactose	3 gm
Final pH **(at 25^{0}C)**	**6.9±0.2**

The test is performed in three steps:

1. **Presumptive test:** Using a measuring cylinder, five double-strength and ten single-strength media tubes were taken and measured. Put a cotton plug in the test tube and autoclave the media for 15 minutes at 1210C and 15 atmosphere pressures to sanitize it. Using a sterile pipette, 10 ml of water was added to five tubes that contain 10 ml of double strength medium after sterilization. In a similar manner, five tubes holding 10 ml of single strength medium were filled with 1 ml of water sample. All of the tubes were incubated for 24 hours at 370 C. Following incubation, the test tubes were examined for the formation of gas and acid, and the number of tubes exhibiting a positive reaction was compared to a standard chart and record.

2. **Confirmed Test:**

   In addition to coliforms, some additional microbes digest lactose to create gas and acid. A confirmatory test is performed to verify the presence of coliform. One loopful of medium were transferred from each fermentation tube that produced good findings to (i) three milliliters of lactose-broth or brilliant green lactose fermentation tube, (ii) an agar slant, and (iii) three milliliters of tryptone water. After 24±2 hours, the gas production was checked in the lactose-broth fermentation tubes that have been incubated at 370C. The gram-stained preparation generated from the agar slants were inspected under a microscope after being incubated at 370C for 24±2 hours. A member of the coliform group is present in the sample under investigation if gas is formed in the lactose broth and gram-negative, non-spore-forming bacilli are visible in the matching agar. A test is considered negative if there is no gas generation in the lactose broth or if the accompanying agar slant does not show Gram-negative, non-spore-forming bacilli (lack of coliforms in the tested sample).

Tryptone water Test:

For 18 to 24 hours, incubate the tryptone water at 44.5±0.20C. After incubation, 0.1 ml of Kovacs reagent was carefully mixed. When indole is present, the Kovacs reagent turns red and forms a film over the medium's aqueous phase. The presence of thermotolerant E. coli is demonstrated by confirmatory tests that are positive for indole, growth, and gas generation. In the absence of indole, growth and gas production validate thermotolerant coliforms.

3. Completed Test:

It is preferable to do entire testing because some of the confirmatory test's positive results could be erroneous. A plate of Endo agar or EMB is streaked with the inoculum from each confirmatory test tube that tested positive. This procedure involves streaking a loopful of sample from each positive BGLB tube onto a selective medium, such as Endo's medium or Eosin Methylene Blue Agar. Each plate was incubated for 24 hours at 370°C and 44.5°C by 0.20 degrees Celsius. All plates were checked for the existence of typical colonies after incubation. Colonies produced by coliforms have a greenish metallic shine that sets them apart from colonies produced by non-coliforms. The existence of thermotolerant E. coli is shown by the presence of typical colonies at high temperatures (44.5±0.2) (Kumar et al. 2013).

Microscopy:

Microalgae cultures were collected when cultures reached to their carrying capacity and washed twice with phosphate buffer (pH, 7.8), rinsed with sterile water and diluted in fresh sterile BG11 media to yielded 1×108 cells mL-1, 20 µL of each culture was flooded on clean slide, covered with cover glasses and seen under either 40X or 100X (with oil immersion) objectives. The micrographs were recorded at 20 µm bar scale. The compound light microscopy was performed using Olumpus microscope. For Microscopic identification a colony of plankton is done as a single count (Desikachary,1959)

Statistical Analysis:

For every experiment, three duplicates were conducted. For the statistical analysis, Graph Prism (version 5.0) was utilized. Mean values and standard deviations have been computed. One-way analysis of variance (ANOVA) was used to confirm that the results were significant (p 0.05). Principle component analysis was performed using PAST software, Version 2.17 (Maji & Chaudhary, 2019).

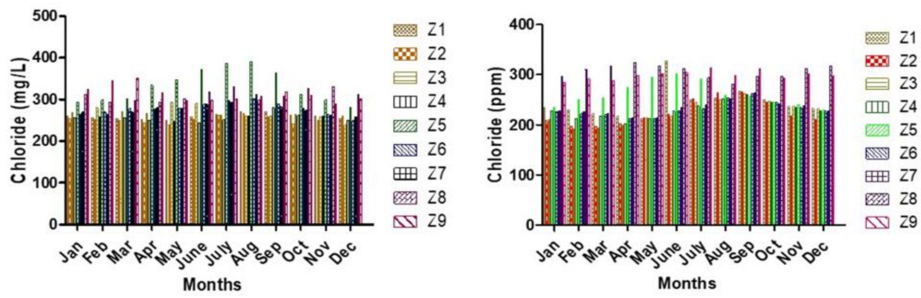
Results and Discussion

Ganga river zones: As the holy river Ganga undergoes seasonal fluctuations, the planned study places a particular focus on the total quantity of abiotic components. A sample was taken for the study and it was discovered that the upstream location of Ganga-Gangoli Shivala Jhunnsi was the meeting point of the subsidiary river Yamuna, Chhatnaag Ghat Yamuna, with a range of 5–10 kilometers. The entire river distance between Gangoli Shivala and Sitamdi, where the Bhadohi distance begins, is 54 km. The holy river Ganga's elemental changes in 2023–2024 are measured for health evaluation.

Chloride:

Z5 Site, August had the highest concentration at 391 mg/l, followed closely by July with 387 mg/l. That suggests that the Z5 site elevated chloride levels during mid to late summerZ8 Site, exceptionally high levels were observed in 2024 (324 mg/l in April and 317 mg/l in March), suggesting a potential early- to mid-spring seasonal peak. Chloride levels were consistently lowest at the Z4 site. April 2024 had the lowest, at 202 mg/l, followed by February 2024 at 212 mg/l and June 2023 at 244 mg/l. This pattern implies that the Z4 site might include elements that lead to lower chloride concentrations, such as less pollution inflow and a more efficient natural cleansing mechanism. The lowest figure ever recorded at the Z2 location was 197 mg/l in February 2024, indicating a substantial decrease in chloride levels during this period. There is a noticeable seasonal change in the statistics. For instance, at most locations, chloride levels often reach their highest in the summer and early spring, while the lowest levels are typically found in the winter and early spring. Variations in temperature, patterns of precipitation, and human activity (such as the wintertime application of road salt) could all have an impact on this. The same months in different years can differ from one another. For example, the concentration was much lower at Z4 in June 2023 (244 mg/l) than it was at Z1 in June 2024 (234 mg/l). This implies that variations in human activity and yearly climate or environmental changes may have an impact on chloride levels.

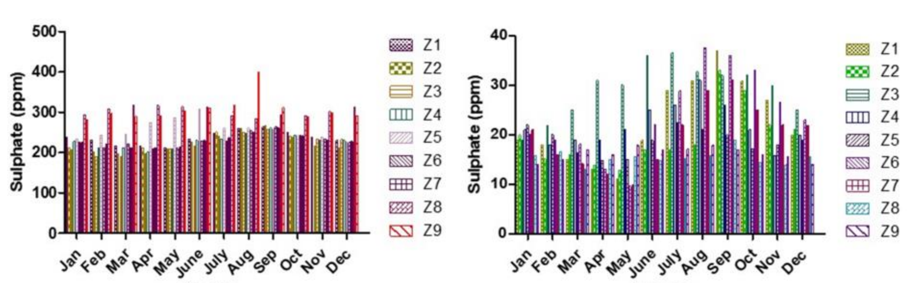
Figure 2: Month wise variation in chloride (mg/L) at different sampling zones of holy River Ganga at Prayagraj and Associated Bhadohi district: (a) 2023 (b) 2024



Sulphate:

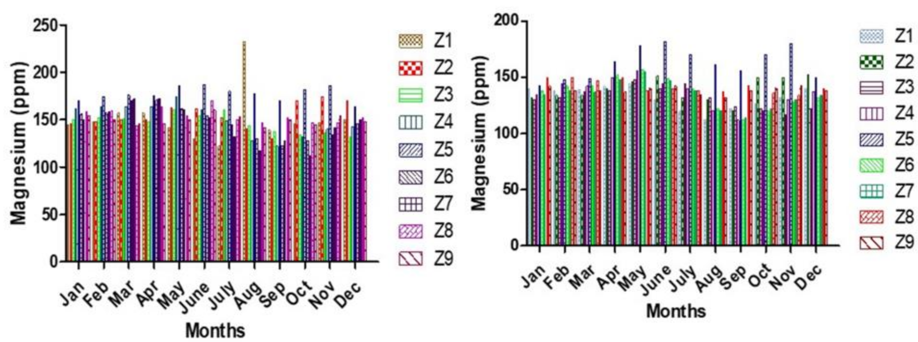
Z9 Site, the highest sulphate concentration was recorded in August (398.0), followed by Aril (314.0 ppm). This suggests that the Z9 site experiences peak sulphate levels during late spring and summer. In July 2023, the Z6 site displayed a noticeably elevated value (228.0 ppm). The lowest quantity, 9.6 ppm, was found at the Z6 Site in May 2024. Low levels were also recorded at this location in July 2024 (228.0 ppm) and August 2024 (37.6 ppm). Low sulphate levels were observed at the Z7 Site in April 2024 (12.1 ppm) and May 2024 (9.9 ppm). In April 2023 (197.0 ppm), February 2023 (191.0 ppm), and July 2024 (36.5 ppm), Z3 Site displayed low quantities. Sulphate concentrations at Z1 Site were 37.0 ppm in September 2024. The spring and summer (April to August) seasons appear to have the highest concentrations, whereas the spring (April to May) and summer (July to September) seasons of 2024 had the lowest concentrations.

Figure 3: Month wise variation in sulphate (ppm) at different sampling zones of holy River Ganga at Prayagraj and Associated Bhadohi district: (a) 2023 (b) 2024



Annual variability is suggested by observable variations between years, such the sharp site. High sulphate levels are regularly recorded at the Z9 Site, suggesting that some factors, such as industrial activities or natural sulphate sources, may have an impact. The Z6 site has a broad range of sulphate levels, ranging from extremely high (228.0 ppm) to extremely low (9.0 ppm), which may indicate that remediation activities or changing environmental conditions are to blame. Generally speaking, the Z3 and Z7 Sites have lower sulphate levels, especially in the spring and summer. This could be because of efficient natural filtration or fewer sources of pollutants.

Figure 4: Month wise variation in Magnesium (ppm) at different sampling zones of holy River Ganga at Prayagraj and Associated Bhadohi district: (a) 2023 (b) 2024



Magnesium:

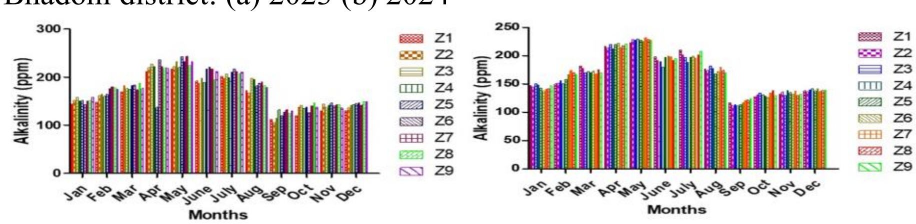
*Z1 Si*te, the highest concentration was recorded in August (232.0 ppm), followed by 130.0 ppm in July and the same 232.0 ppm in June. This indicates that magnesium levels peaked at the Z1 site during the summer Z5 Site, in 2023, significant amounts were also recorded in May (186.0) and June (187.0 ppm). June had the greatest concentration (182.0 ppm), followed by November (180.0 ppm) and May (178.0 ppm) at the Z5 Site. According to this, there will be two peaks in 2024: one in late autumn and another in late spring and early summer. August saw the lowest levels (122.0 ppm) at the Z7 Site. In 2023, 112.0 ppm in June and 130.0 ppm in July came next. In September, the Z6 Site's lowest value was 112.0 ppm. In 2024, the Z1 site reported the same low concentration in August, and Z6 reported the same low concentration in September.

Particularly at the Z1 site, the data shows elevated magnesium levels in 2023 over the summer months of June through August. High amounts were detected at the Z5 location in late spring and early summer (May to June) and late fall (November) of 2024. Late summer and early fall saw the lowest concentrations, with a potential decline following the summer high. Z1 Site: Showed elevated quantities in both 2024, suggesting a reliable magnesium source or favourable environmental circumstances. Significant concentrations were seen at the Z5 Site in both years, especially in the late spring and early summer, with a further peak in the late autumn of 2024. Lower quantities were typically found at the Z6 and Z7 sites, suggesting either less exposure to magnesium-containing environmental sources or more efficient natural cleansing mechanisms.

***Alkalinity*:**

Z7 Site, in May, the alkalinity was at its greatest (243.0 ppm). With 242.0 ppm in May, Z5 Site: Not for the faint of heart. Z6 Site: 236.0 ppm was recorded in April, suggesting high levels in the spring of 2023. Z7 Site: High alkalinity (232.0 ppm) was once more observed in May. Z4 Site: Consistent values, with a May reading of 230.0 ppm. A trend across several sites in May 2024 was highlighted by the Z8 Site, which also recorded 229.0 ppm in May. Z2 Site: September had the lowest alkalinity (106.0 ppm). Z5 Site: In April, 137.0 ppm was recorded. Z6 Site: In September 2023, there were 127.0 ppm. Z2 Site: In September, the alkalinity was once more measured at 112.0 ppm. Z5 Site: September registration of 114.0 ppm. Z6 Site: In September 2024, 117.0 ppm was recorded. Across several sites, the maximum alkalinity concentrations are often found in the spring (May), especially in 2023 and 2024. Late summer to early autumn (September) regularly has the lowest amounts, indicating a seasonal drop in alkalinity during these times. Z7 Site: Consistently exhibits high alkalinity in May, suggesting that some anthropogenic or environmental causes may have an impact on it during this time. Z5 Site: Shows notable amounts of alkalinity during the summer and spring, indicating enduring sources of alkalinity or circumstances that support greater concentrations. Z2 Site: For both years, September has the lowest alkalinity, suggesting that there are fewer polluting sources or efficient natural filtering at this time.

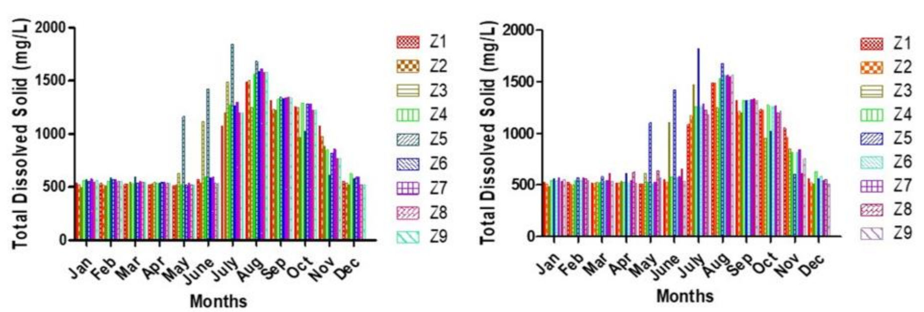
Figure 5: Month wise variation in Alkalinity (ppm) at different sampling zones of holy River Ganga at Prayagraj and Associated Bhadohi district: (a) 2023 (b) 2024



Total Dissolved Solid:

Z5 Site; In July and August, the maximum TDS concentrations were 1843.0 mg/l and 1683.0 mg/l, respectively. Z7 Site: In August 2023, 1611.0 mg/l was recorded. High amounts were once more seen at the Z5 Site, with 1823.0 mg/l in September and 1677.0 mg/l in August. Z8 Site: In August 2024, 1547.0 mg/l was recorded. Z3 Site: In January, the lowest TDS was 497.0 mg/l. Z1 Site: 514.0 mg/l was recorded in May. 526.0 mg/l at the Z2 Site in June 2023. The Z5 location experienced high TDS levels in mid-summer (July and August), while the Z3 and Z1 sites experienced the lowest levels in winter (January) and spring (May) of 2023.

Figure 6: Month wise variation in Total Dissolved Solid (mg/L) at different sampling zones of holy River Ganga at Prayagraj and Associated Bhadohi district: (a) 2023 (b) 2024

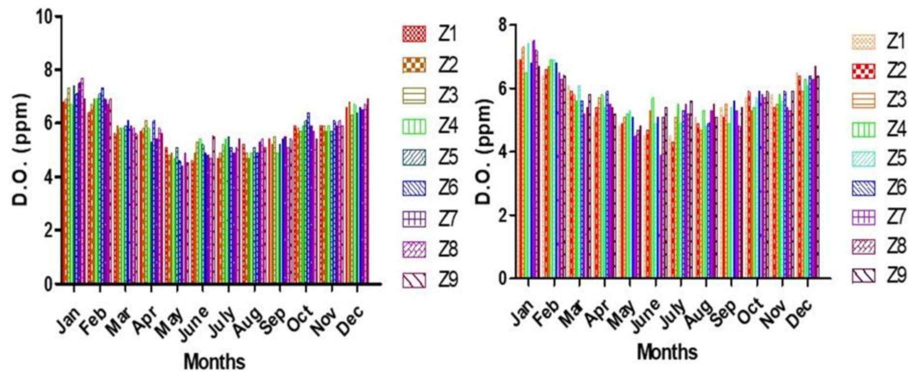


The Z5 and Z8 sites consistently had high concentrations in late summer (August), whereas the Z1 sites once more had the lowest levels in spring (May) and early summer (June) of 2024. Z5 Site: Showed continuously elevated TDS levels in both years, especially in the middle to late summer, suggesting that there may be enduring sources of dissolved solids or environmental elements that raise concentrations. The Z6 and Z1 sites consistently displayed low TDS levels, which suggests better environmental controls, fewer sources of pollution, or efficient natural filtration. TDS levels were also lower in the Z3 and Z4 sites, especially throughout the winter and early spring.

Dissolved Oxygen (D.O.):

Z7 Site; In January, the highest D. O. level was recorded at 7.5 ppm once more. Z5 Site: In January, 7.4 ppm was recorded. Z3 Site: January 2024 had 7.3 ppm. Z9 Site: In May, the D.O. level was at its lowest, 4.5 ppm. Z7 Site: In May, it had 4.4 ppm. Z2 Site: In June 2023, registered at 4.9 ppm. Z7 Site: In June, D.O. concentrations were at their lowest, at 3.9 ppm. In July, Z2 Site had 4.3 ppm. Z1 Site: In July 2024, 4.5 ppm was recorded.

Figure 7: Month wise variation in D.O. (ppm) at different sampling zones of holy River Ganga at Prayagraj and Associated Bhadohi district: (a) 2023 (b) 2024



***MPN (Most Probable Number) Assessment**:*

The years 2023 and 2024 are included in the study. The amount of organic matter in the water increases throughout the rainy season, which runs from August to December. As a result, the MPN values increase from August to December. The nutrients from the organic materials help the coliform bacteria proliferate. The MPN values are lower during the dry season, which runs from January to July. Because the lower MPN denotes lower levels of contamination, these months are considered the best times to take a bath. The downstream site Z9 is the subject of the study.

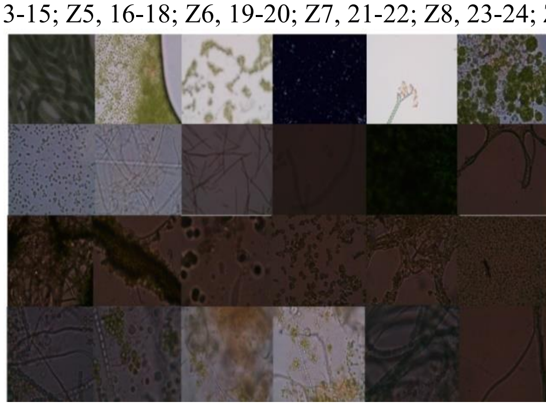
Because pollutants build up from upstream sources, downstream areas are frequently more vulnerable to contamination. The MPN technique measures coliform bacteria, which are not always dangerous in and of themselves but act as a proxy for other toxic bacteria. A higher MPN indicates a greater chance of contamination and possible health risks for people who use the water for bathing and other activities. The safest time to take a bath is from January to July, according to the MPN values. For the purpose of controlling water quality and guaranteeing the security of those who use the water body, MPN levels must be continuously monitored. Seasonality affects the MPN values, which are lower in the dry season and greater during the wet season because of an increase in organic matter. Because they collect contaminants from upstream, downstream sites like site Z9 are essential for monitoring. The study offers practical public health insights, indicating that reduced levels of pollution make bathing safer during the dry season.

Table 2. MPN Number of the different sites at the month-wise variation 2023-24:

Month/Year	Sites	Test tubes giving positive result	MPN per 100 ml
January/2023	Z9	5-3-2	43
February/2023	Z9	4-3-2	56
March/2023	Z9	5-2-1	58
April/2023	Z9	5-4-0	52
May/2023	Z9	5-3-0	79
June/2023	Z9	5-1-0	39
July/2023	Z9	5-3-3	70
August/2023	Z9	5-1-0	140
September/2023	Z9	5-4-1	130
October/2023	Z9	5-5-1	170
November/2023	Z9	5-5-2	170
December/2023	Z9	5-4-2	350
January/2024	Z9	5-5-4	48
February/2024	Z9	5-1-0	54
March/2024	Z9	5-3-1	54
April/2024	Z9	5-3-2	79
May/2024	Z9	5-3-2	79
June/2024	Z9	5-4-0	78
July/2024	Z9	5-2-1	86
August/2024	Z9	5-4-1	180
September/2024	Z9	5-5-2	180
October/2024	Z9	5-4-2	230
November/2024	Z9	5-1-0	250
December/2024	Z9	5-3-2	300

***Microalgae Examination**:*

Figure 8. Microscopic Examination of Phytoplankton from Biofilm (1-3; Z1, 4-6; Z2, 7-9; Z3, 10-12; Z4, 13-15; Z5, 16-18; Z6, 19-20; Z7, 21-22; Z8, 23-24; Z9).



It was clearly found that most of the biofilm of photosynthetic phytoplankton having the species richness genera more or less in most of the zones; *Synechococcus* sp., *Synechocystis* sp., *Oscillatoria* sp., *Lyngbya* sp., *Nostoc* sp., *Anabaena* sp., *Chlorella* sp. *Scenedesmus* sp., *Chlamydomonas sp*., *Microcystis* species. Thus, we can say that in most of the biofilm having members of the Cynophyceae and Chlorophyceae dominant over the Niche area of the standing water.

Table 3: Enumeration of the Phytoplankton from biofilm estimated different sites:

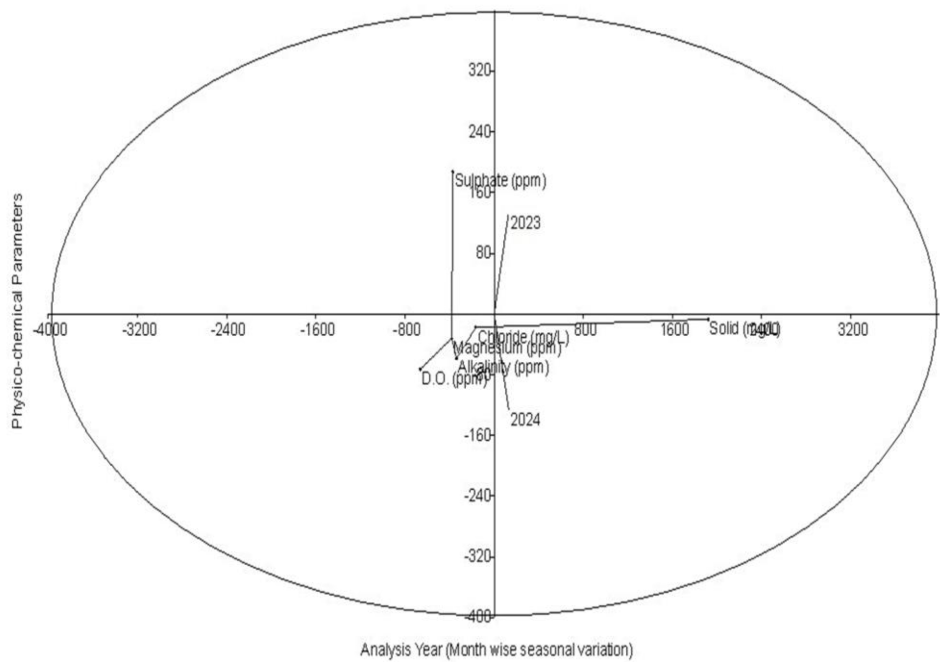
Dominant Phytoplankton Species Richness	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**
Anabaena sp., *Nostoc* sp. *Oscillatoria* sp., *Synechocystis* sp., *Synechococcus* sp., *Chlorella* sp., *Scenedesmus* sp.	+								
Chlamydomonas sp., *Nostoc* Sp., *Anabaena* sp., *Chlorella* sp. *Scenedesmus* sp., *Synechocystis* sp., *Synechococcus* sp.		+							
Synechocystis sp., *Synechococcus* sp., *Lyngby* sp., *Anabaena* sp., *Nostoc* sp., *Oscillatoria* sp.			+						
Lyngby sp., *Spirulina* sp., *Chlorella* sp., *Scenedesmus* sp.				+					
Nostoc sp., *Anabaena* sp., *Chlorella* sp., *Scenedesmus* sp. *Microcystis* sp.					+				
Synechocystis sp., *Synechococcus* sp., *Anabaena* sp., *Nostoc* sp., *Scenedesmus* sp.						+			
Anabaena sp., *Nostoc* sp., *Scenedesmus* sp., *Chlamydomonas* sp., *Chlorella* sp., *Spirulina* sp., *Synechocystis* sp., *Synechococcus* sp.							+		
Synechocystis sp., *Synechococcus* sp., *Anabaena* sp., *Nostoc* sp., *Scenedesmus* sp., *Chlorella* sp., *Scenedesmus* sp.								+	
Nostoc sp., *Anabaena* sp., *Lyngby* sp., *Scenedesmus* sp., *Chlorella* sp.									+

Principal Component Analysis (PCA):

To comprehend how the water quality metrics in the various Ganga River zones change seasonally. Zone 9 (Z9) had the greatest sulfate concentration in 2023. The lowest concentrations of alkalinity, magnesium, chloride, dissolved oxygen, and total dissolved solids (TDS) were found in a number of zones in May. According to PCA, seasonal variations have a major impact on the water quality, with certain metrics rising or falling at different periods of the year. These realizations are essential for maintaining the health of the river ecology and controlling water quality. At the Z9 site, the highest recorded concentration of sulphate reached an impressive 398.0 ppm in August, establishing it as the site with peak sulphate levels during the vibrant late spring and summer months. Closely following was the Arail site, which recorded a substantial concentration of 314.0 ppm, highlighting a notable regional difference in sulphate presence. In July 2023, the Z6 site also showcased a remarkably high sulphate concentration of 228.0 ppm. However, this site exhibited significant variability, as evidenced by a stark low of just 9.6 ppm in May 2024. Additionally, Z6 continued to present low sulphate readings in both July and August 2024, measuring 228.0 ppm and 37.6 ppm, respectively, further underscoring its fluctuating levels. The Z7 site consistently registered low sulphate levels, particularly in May 2024 with a reading of 9.9 ppm and in April 2024 at 12.1 ppm, suggesting effective natural processes that mitigate sulphate presence. Similarly, the Z3 site reflected this trend with lower concentrations observed during April 2023 (197.0 ppm), February 2023 (191.0 ppm), and July 2024 (36.5 ppm). In September 2024, the Z1 site recorded a sulphate level of 37.0 ppm, indicating its comparatively lower status in the context of the other sites. Overall, the data reveals that the highest sulphate concentrations tend to manifest during the warmer spring and summer months, specifically from April to August, while the lowest concentrations are noted during both the early spring (April to May) and late summer (July to September) of 2024.

The significant year-to-year variations, particularly at specific sites, clearly illustrate notable annual fluctuations in sulphate levels. The Z9 site stands out with its consistent high sulphate readings, potentially influenced by factors such as industrial activities or natural sources of sulphate. In contrast, the Z6 site demonstrates a dramatic fluctuation in sulphate levels, ranging from very high (228.0 ppm) to strikingly low (9.0 ppm). This variability could indicate its susceptibility to changing environmental conditions or the impact of remediation efforts. Meanwhile, the Z3 and Z7 sites generally maintain lower sulphate levels, particularly during the spring and summer, possibly due to effective natural filtration processes or a reduction in pollutant sources. In 2023, the highest concentration of magnesium was recorded at the Z1 Site during the warm, sun-filled days of August, reaching an impressive 232.0 ppm. This was closely followed by notable levels of 130.0 ppm in July and an equal peak of 232.0 ppm in June, indicating that magnesium levels experienced a significant surge during the summer months at this location. Additional significant concentrations were also observed in June at the Z5 Site, where magnesium levels measured 187.0 ppm, along with a near-equivalent reading of 186.0 ppm in May, further highlighting the vibrancy of magnesium presence in the warmer months.

Figure 9. Principal Component Score of the Ganga River at seasonal variation.



Looking ahead to 2024, the magnesium trend continued, with the highest concentration recorded at 182.0 ppm in June, signalling robust levels during the late spring and early summer. Subsequently, levels moderated slightly to 180.0 ppm in November, followed by 178.0 ppm in May at the Z5 Site, suggesting a notable peak in magnesium availability not only during the vibrant late spring and early summer but also extending into a remarkable late autumn. Conversely, the lowest magnesium concentration recorded in 2023 fell to 122.0 ppm in the heat of August at the Z7 Site, followed by 112.0 ppm in the cooler month of June and 130.0 ppm in July. The pattern continued into 2024, where the month of September registered the lowest concentration at 112.0 ppm at the Z6

Site. Interestingly, this same low level was also noted again in August at the Z1 Site and in September at the Z6 Site, reinforcing the trend of reduced magnesium presence during these particular months. Overall, the data underscores a pronounced elevation in magnesium levels during the summer months, specifically from June to August 2023, with the Z1 Site demonstrating particularly high concentrations. In 2024, significant magnesium levels were notably detected in late spring and early summer (May to June), and an intriguing peak appeared in late autumn (November) at the Z5 Site, further enriching our understanding of seasonal trends. In contrast, lower concentrations were generally recorded in late summer and early autumn, painting a picture of a decline following the exuberance of summer peaks. The Z1 Site consistently showcased elevated magnesium concentrations across both years, suggesting either a continual source of magnesium or favorable environmental conditions that sustain higher levels. Meanwhile, the Z5 Site also exhibited significant magnesium concentrations during both years, especially during late spring and early summer, with an additional late autumn peak in 2024. In contrast, the Z6 and Z7 Sites typically reported lower levels, pointing to either diminished exposure to magnesium sources or more effective natural processes that cleanse the environment of excess magnesium, thereby maintaining the ecological balance.

The Z7 Site achieved a remarkable peak in alkalinity during May 2023, registering an impressive measurement of 243.0 ppm. Trailing closely behind was the Z5 Site, which also showcased elevated alkalinity levels at 242.0 ppm in the same month. Additionally, in the preceding month of April, the Z6 Site marked a noteworthy figure of 236.0 ppm, indicating a significant rise in alkalinity levels. Fast forward to May 2024, and the Z7 Site continued to demonstrate its trend of high alkalinity, this time recording 232.0 ppm. The Z4 Site revealed a measurement of 230.0 ppm during this month, underscoring a sense of consistency in alkalinity levels for this year. Furthermore, the Z8 Site reflected this overarching trend by achieving 229.0 ppm, showcasing a pattern of elevated alkalinity across several locations in May. In stark contrast, the Z2 Site experienced the lowest recorded alkalinity levels in September 2023, plummeting to just 106.0 ppm. Similarly, the Z5 Site recorded a relatively low 137.0 ppm in April, while the Z6 Site faced a decline to 127.0 ppm in September. The following year, 2024, saw the Z2 Site again grappling with low alkalinity, measuring 112.0 ppm in September. During this same month, the Z5 Site and Z6 Site mirrored this trend, recording 114.0 ppm and 117.0 ppm, respectively.

Overall, a seasonal pattern emerges, showcasing that the highest concentrations of alkalinity are typically captured in the spring month of May across various sites in both 2023 and 2024. In contrast, the lowest concentrations are consistently observed during the transition from late summer to early autumn in September. This seasonal fluctuation indicates a notable decline in alkalinity during these months, likely influenced by various environmental factors. The Z7 Site, with its consistently high alkalinity levels in May, may be under the influence of specific environmental or anthropogenic factors that boost alkalinity during this time. Meanwhile, the Z5 Site’s ability to sustain significant alkalinity levels across both spring and summer suggests persistent sources contributing to high concentrations or environmental conditions that favor such outcomes. The Z2 Site stands out for its notably low alkalinity in September over both years, hinting at effective natural filtration processes or reduced pollution from surrounding sources during this particular period. In 2023, the Z5 Site experienced a significant spike in total dissolved solids (TDS), recording the highest concentration of 1843.0 mg/l in the sweltering month of July, which was closely followed by another elevated level of 1683.0 mg/l in August. The Z7 Site also reported a substantial measure of 1611.0 mg/l during August, indicating a trend of increasing dissolved solids in that region. Moving into 2024, the Z5 Site continued this pattern of elevated TDS levels, peaking at 1823.0 mg/l in September and reaching 1677.0 mg/l in August. Not to be overlooked, the Z8 Site reported a noteworthy concentration of 1547.0 mg/l in August, contributing to a broader understanding of the area's water quality dynamics.

In sharp contrast, the Z3 Site recorded the lowest TDS level in January 2023, with a mere 497.0 mg/l. This was closely followed by the Z1 Site, which logged 514.0 mg/l in May, and the Z2 Site at 526.0 mg/l in June, all indicative of more pristine water conditions during those colder months. Notably, the peak TDS levels at Z5 during the mid-summer months of July and August starkly contrasted with the lowest levels observed in the winter (January) and spring (May) at Z3 and Z1, respectively, illustrating a clear seasonal variation. As 2024 unfolded, the trend of consistently elevated TDS concentrations persisted, prominently in late summer (August) at both the Z5 and Z8 Sites. Meanwhile, the Z1 Site remained a benchmark for lower TDS during spring (May) and early summer (June), maintaining a consistent pattern of purity. The persistent high TDS levels at the Z5 Site throughout both years, especially during the warmer months, raises concerns about potential continuous sources of dissolved solids or environmental factors that might be exacerbating these concentrations. Conversely, the Z6 and Z1 Sites exhibited consistently low TDS levels, suggesting effective natural filtration processes, fewer pollution sources, or robust environmental management strategies in place. Similarly, the Z3 and Z4 Sites also maintained lower TDS readings, particularly during the winter and early spring months, which may reflect the impact of seasonal influences on water quality.

In January 2023, the Z8 Site distinguished itself by recording the highest dissolved oxygen (D.O.) level, a remarkable 7.7 ppm. This was closely followed by the Z7 Site, which boasted a D.O. level of 7.5 ppm during the same month, showcasing the healthy oxygen levels in these waters. The Z6 Site, not far behind, registered a D.O. level of 7.3 ppm in February, indicating favorable conditions for aquatic life. As we transitioned into 2024, the Z7 Site again claimed the top spot, reaching a D.O. level of 7.5 ppm in January. The Z5 Site demonstrated strong results as well, recording a D.O. level of 7.4 ppm, while the Z3 Site reported a level of 7.3 ppm, contributing to the overall positive water quality at the start of the year. However, the scenario shifted dramatically when we examined the sites with the lowest D.O. levels. In May 2023, the Z9 Site faced a concerning low of 4.5 ppm, marking it as the site with the most diminished oxygen levels, while the Z7 Site followed closely with a D.O. concentration of 4.4 ppm. In June, conditions remained challenging for the Z2 Site, which recorded a slightly higher yet still low level of 4.9 ppm. Fast forward to June 2024, and the Z7 Site faced a troubling decline, reaching its lowest D.O. level of just 3.9 ppm, raising red flags about the water quality. The Z2 Site showed some improvement with a measurement of 4.3 ppm in July, but challenges continued, as the Z1 Site also recorded a concerning D.O. level of 4.5 ppm that same month. This downward trend highlights the ongoing struggles of these aquatic ecosystems and underscores the importance of monitoring and addressing water quality issues. The readjustment of DO levels after each MM event highlights the self-healing attributes of the River Ganges. Ongoing efforts, such as the Namami Gange initiative and the Clean Ganga project, contribute to increased DO levels in the river, showcasing the positive impact of government and public endeavors in healing and improving river ecosystems (Kumar et al., 2020). This underscores that elevated Total Microbial Count (TMC) values are primarily due to anthropogenic activities in the river.

The consistently high TMC levels throughout the sampling timeline signify the discharge of a substantial amount of untreated sewage water into the river (Dwivedi et al., 2020). Effective infrastructure management is imperative to address this issue, regulating TMC levels, and preserving the composition of the river ecosystem. These findings underscore that the Ganges River water, through the promotion of specific remediation-capable microbes, has a self-regulatory mechanism for controlling contaminants. The presence of cyanobacteria enhances dissolved oxygen levels, while other microbial species aid in removing sulphur and methane gases, controlling the growth of harmful microbes (Reddy et al., 2019). The identified microbial biofilm self-assembly in Ganges River water emerges as a unique mechanism contributing to the river's relatively low pollution levels despite significant anthropogenic activities along its banks. This biofilm, acting as a natural purification agent, holds promise for rejuvenating the river ecosystem and mitigating water pollution. The study's implications extend to the management of river pollution and the preservation of river ecosystems, providing valuable insights for environmental conservation efforts.

Conclusion:

The analysis of water quality parameters in the Ganges River for the years 2023 and 2024, conducted monthly, reveals the complex dynamics of seasonal variation and the river's self-purification mechanisms. The observed fluctuations in D.O., chloride, sulphate, total dissolved solids, magnesium, alkalinity, and principal component score reveal the direct influence of seasonal fluctuations, indicates the self-water quality improving capability in the riverine. Leveraging and understanding these natural purification processes could pave the way for innovative water treatment approaches. However, challenges persist, notably concerning industrial effluents and untreated sewage discharge. Developing focused actions to lower pollution inputs, improve monitoring systems, and adopt sustainable habits during large gatherings should be the main emphasis of future approaches. Furthermore, to guarantee the Ganges River's long-term viability and health, current projects like Namami Gange and the Clean Ganga project require continual funding and improvement. It will be essential to embrace these chances and challenges in order to protect this essential water resource and maintain its ecological integrity for coming generations.

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