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Spatio seasonal discrepancies in the physico-chemical parameters along the surface water of Gahirmatha Estuary, east coast of India in the Bay of Bengal

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ABSTRACT

Water is a key factor in our lives, yet this valuable asset is progressively under threat. From the total share of the Earth's water, only 2% is fresh water, which is available for various life forms, including humans. Monitoring the quality of water is very important to check the physical, chemical, and biological characteristics, and the subsequent control of its wholesomeness. Particularly, the estuarine water bodies that are rich in diversity confront more threats for contamination in the entire riverine framework. This study was carried out to evaluate the current status of various physico-chemical properties of four different estuarine locations of the Gahirmatha coast, in the Indian state of Odisha in the eastern part of the Bay of Bengal: water temperature, pH, conductivity, TDS, TSS, turbidity, salinity, DO, BOD, total alkalinity, fluoride, Nitrite-N, Ammonia-N, Nitrate-N, phosphate, silicate, total chlorophyll. The study was carried out during the pre-monsoon (March to April) and post-monsoon (November to December) seasons in 2019. The surface water samples were collected from designated stations both during low tide and high tide to observe tidal influence. The data were subjected to statistical analysis regarding correlation coefficient, principal component analysis (PCA), and cluster analysis (CA) for interpretation. The Pearson correlation showed that the results were significantly correlated both at the 0.05 and 0.01 level of significance. When PCA was interpolated for the pre-monsoon and post-monsoon data, three broad groups were categorized. The highest eigen value was about 10.87 during the pre-monsoon and 9.07 during the post-monsoon season, and the cluster analysis showed there were two major groups of parameters with respect to the Euclidean distance. The observed variations in the concentration of these physico-chemical parameters in the estuarine waters of the Gahirmatha may be attributed to the riverine inputs from the catchment of rivers like the Brahmani, Baitarani, and Dhamra, which are associated with anthropogenic local activities.

1. Introduction

Water is the key ingredient of life on our planet, yet it progressively loses its pristine nature day by day and is under threat. The surface of the earth is comprised of 70% water that includes rivers, lakes, streams, oceans as well as groundwater, which are all significant in the life cycle of the respective form [1]. Around 780 million people do not have access to clean and safe water, and nearly 2.5 billion people do not have suitable sanitation [2]. Less than 3% of freshwater is accessible, and its inconsistent dispersion makes water pollution a matter of extraordinary concern. The toxins present in natural environments experience numerous reactions and forms and can threaten our lives. Nowadays, nearly 70% of India's fresh water is polluted, which can affect biodiversity and pose a threat to ecosystems. As the world relies upon water, a hydrological study is very important to comprehend the connection between trophic levels and food webs. The morpho-ecological conditions such as topography, stratification,

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water movement, temperature, salinity, oxygen content, and nutrients profile additionally decide the arrangement of its biota. Generally, different influential factors play vital roles in water bodies close to the shore and estuaries to determine their overall condition: tidal incursions, different biotic and abiotic processes, fresh water influx, nutrient cycle, etc. [6]. Variations in water temperature mainly due to seasonal changes and rainfall [7] are also influential as both the atmospheric and water temperatures often fluctuate with reference to the topography of the location and from season to season [8]. Generally, estuaries are significant nutrient providers to coastal regions, breeding grounds for marine life, a nursery for different species, and support the potential diversity in the environment. Nowadays, the water quality of numerous estuary areas around the world has become polluted due to anthropogenic activity and the introduction of excessive nutrients, heavy metals, herbicides, polyaromatic hydrocarbons, and pesticides [9-11]. The water quality of an estuary is either affected naturally [12,13] through normal processes such as weather, tidal cycle, soil erosion, and rainfall or anthropologically through industrial and agricultural activities, discharging of untreated sewage, and human manipulation of its pristine nature [14]. The rivers receive pollutants from their catchment areas, which ultimately enter into the marine ecosystem through estuaries and seriously disturbs its quality [15,16]. Estuaries are the prime passage for nutrients and other pollutants that originate from the mainland, affecting the marine ecosystem [17]. The river provides significant levels of nutrients, which make the estuary increasingly beneficial for a natural environment [18]. Despite the fact that the nutrients are a basic requirement for marine biota, still, its higher concentration in estuarine and coastal water may bring ecological changes. An abnormal supply of nutrients to the coastal body may affect the ecological equilibrium [14]. So, both quantitative and subjective coastal monitoring with its proper valuation is crucial [19] for its sustenance. Monitoring the water quality of estuaries around the world has been carried out in the last three decades. The Gahirmatha stretch is close to Bhitarakanika, the second largest mangrove ecosystem [21] of India and the largest breeding ground for Olive Ridley sea turtles [20,21]. Gahirmatha is positioned at the conjunction of the Brahmani and Baitarani stream deltas in the district of Kendrapara, Odissa. The Gahirmatha Marine Sanctuary is encompassed by the river Dhamara in the north and the river Bramhani (Hansua) in the south, a stretch in the Bay of Bengal [22]. The Bhitarkanika Sanctuary is home to estuarine crocodiles with a population of more than 1,650. The significant mangrove patches in this area protect from destructive cyclones and other disasters and have a long-term role in the life of the people residing nearby [23-25]. The National park is essentially comprised of a network of creeks and canals which are inundated from rivers, including the Brahmani, Baitarani, Dhamra, and Patasala, forming an extraordinary environment. Though significant consideration has been paid in recent years to study the physico-chemical parameters of the coastal waters around India to ascertain the water quality and estuarine productivity, various information on the Gahirmatha estuary is inaccessible. The current study was dedicated to acquiring the status of estuarine water with respect to the physico-chemical parameters and their relationship in the four different estuarine locations of the Gahirmatha coast, Odisha. The study was carried out during the pre-monsoon (March to April) and post-monsoon (November to December) seasons in 2019. The surface water samples were collected from designated stations both during low tide and high tide to observe tidal influence.

2. Materials and methods

The Gahirmatha estuary is located in the east coast of the Bay of Bengal, Odisha. Four strategic sampling locations were selected considering topography, riverine influx, and other environmental conditions. All four sampling sites are situated within 0.5 to 2.5 km from the seashore towards the sea (Table 1 and Figure 1). Surface water samples were collected at a depth of 0.5-1.5 meters of seawater with the help of a water sampler (Niskin type, Make- K.C. Denmark), and then transferred to the pre-cleaned sampling bottles (1 litter) from each site during both the low and high tide. The physico-chemical parameters of pH, water temperature, total dissolved solid (TDS), conductivity, dissolved oxygen (DO), and salinity were analyzed with the help of an YSI (556MPS) portable analyzer kit. For the other physico-chemical parameters, the water samples were taken to the laboratory with proper preservation, and the analysis was carried out within 72 hours. The turbidity was analyzed by a nephelometer (Systonics, Model-135), and the total suspended solids (TSS) were analyzed gravimetrically. For the analysis of the biochemical oxygen demand (BOD), the samples were incubated in a BOD incubator (SANCO, SAN 134) for three days using the Winkler's method and then titrated against sodium thiosulphate ($Na_2S_2O_3$); the total alkalinity was analyzed titrimetrically. The fluoride was analyzed by a specific ion meter (Thermo Scientific, Ion Star Benchtop A214), and the total chlorophyll was analyzed spectrophotometrically (Agilent, Cary Eclipse), whereas the nitrate, nitrite, ammonia, phosphate, and silicate were analyzed using an auto-analyzer (Skalar, Analytical B.V, SAN^{++}).

Table 1. Geographical locations of the sample collecting points.

Sampling Point	Name of Sampling Point	Coordinates	Distance from shore in km
G1	Hansua Mouth Up	20^{0}32’10.41’’N / 86^{0}47’30.95’’E	0.5
G2	Hansua Mouth	20^{0}29’53.08’’N / 86^{0}46’49.88’’E	2.0 from mouth
G3	Jambu Up	20^{0}27’43.14’’N / 86^{0}41’38.68’’E	2.2 from mouth
G4	Jambu	20^{0}25’29.60’’N / 86^{0}45’31.72’’E	2.5

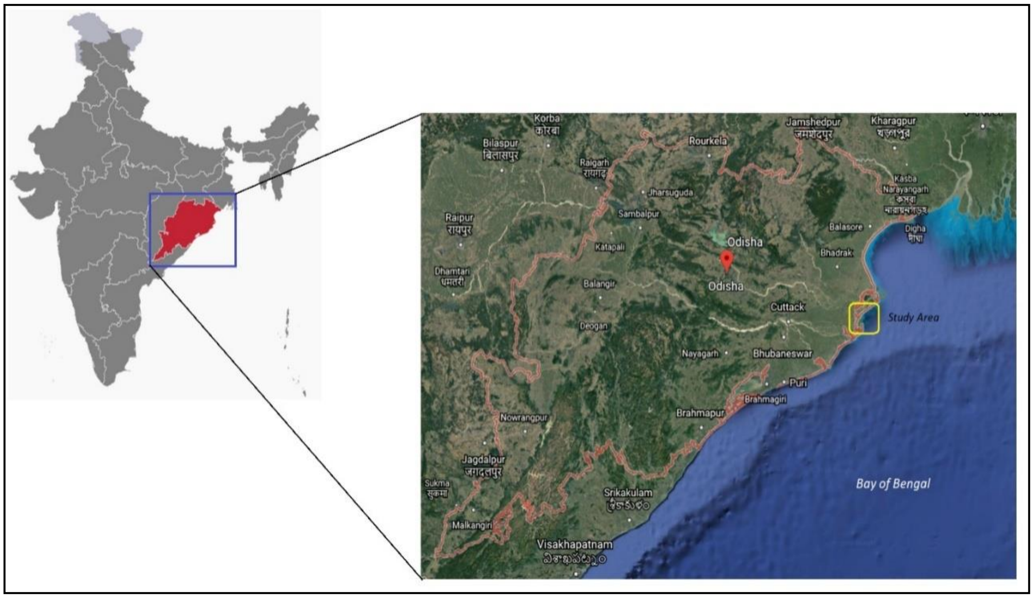

Fig.1. Map of Study area along the coast of Bay of Bengal.

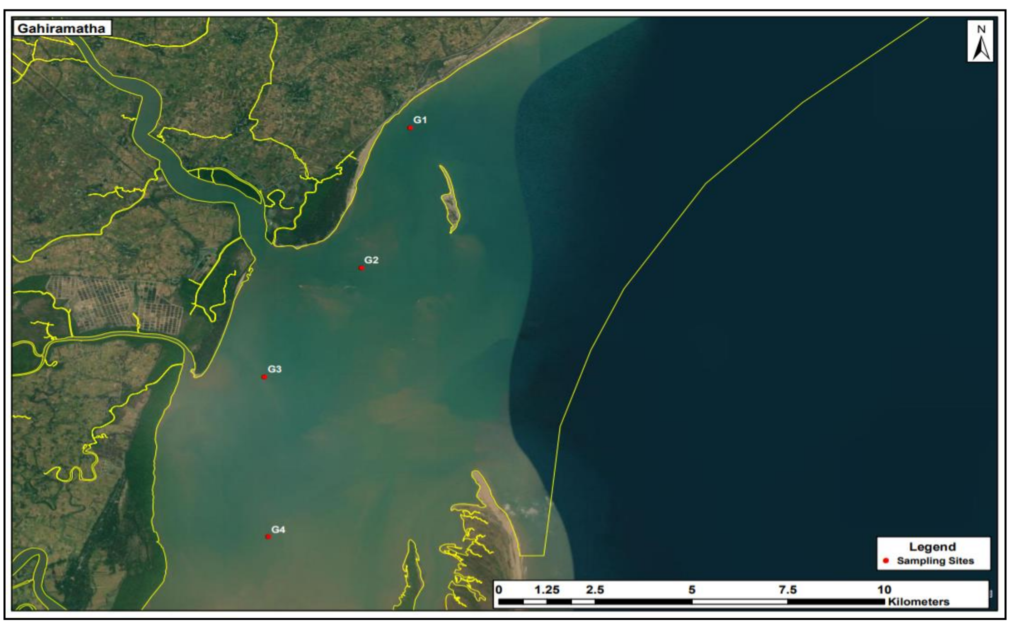

Fig.2. Map of study area showing sampling points in Gahirmatha estuary region.

3. Results and discussion

Physico-chemical parameters are considered as one of the most significant highlights that are equipped for impacting the marine condition and have demonstrated wide temporal and spatial differences. All the physico-chemical parameters indicated clear seasonal patterns, which are very typical to the marine environment of the Gahirmatha estuary. The water temperature (WT) of the estuary was recorded at four unique stations and ranged from 27.835 to 29.61ºC during the pre-monsoon season and from 27.025 to 28.58 ºC during the post-monsoon. The minimum pH value was detected during March and April 2019; the maximum was recorded during November as well as December 2019 at point G2 (Figure. 2, Table 2, and Table 3). The conductivity values in the post-monsoon were higher than those in the pre-monsoon, whereas the total dissolved solids (TDS) values varied seasonally (Table 2 and Table 3). On the contrary, the minimum observed total suspended solids at station G1 during the pre-monsoon as compared to the post-monsoon season show the TSS value is maximum during the pre-monsoon (77.64±5.26mg/L) and the minimum during the post-monsoon (56.72±4.76 mg/L). The salinity and turbidity values ranged between 4.835±1.95 to 21.515±5.32 PSU and 28.55±1.63 to 42.175±1.01 NTU, respectively. From observation, it was found that the turbidity and salinity were directly related to the study area. The dissolved oxygen (DO) concentration varied between 5.075 to 6.963 mg/L, registering a maximum at G3 and a minimum at G1 during the pre-monsoon, whereas it varied between 4.6 to 7.2 mg/L, with the maximum at G4 and minimum at G3 during the post-monsoon. The BOD concentration was maximum at point G2 during the post-monsoon (2.35±0.063mg/L) and minimum during the pre-monsoon (0.7±0.01mg/L) at the same point. The total chlorophyll values ranged between 2.66±0.04 mg/L and 5.9±1.26 mg/L, registering a maximum at point G3 and a minimum at point G4 during the pre-monsoon season. Whereas, the value of the total chlorophyll range was between 3.024±0.067 and 8.896±0.069 mg/L, with the maximum at G1 and minimum at G4 during the post-monsoon. The total alkalinity ranged from 79±3.69 mg/L to 139±7.02 mg/L with the maximum at station G3 during the post-monsoon and minimum at station G2 during the pre-monsoon. The observed fluoride concentration was found to be the lowest (0.335±0.024 mg/L) in the pre-monsoon at station-G2 and recorded the highest (0.682±0.078 mg/L) in the post-monsoon at station-G1 (Table 2 and Table 3). Similarly, the concentration of nitrite was the lowest (0.26±0.01 mg/L) at G1 during the pre-monsoon, and the highest was recorded (1.19±0.16 mg/L) at G2 in the post-monsoon; the value for nitrate was the lowest (1.225±0.68) at G4 in the pre-monsoon and the highest (6.346±1.12 mg/L) at G1 in the pre-monsoon. The maximum ammonia (NH4) concentration was found during the post-monsoon and the minimum during the pre-monsoon (Table 2 and Table 3). The minimum phosphate concentration was recorded (0.579±0.37 mg/L) during the pre-monsoon and the maximum concentration (5.896±0.92) at G4. The reactive silicate concentration ranged from 12.54±6.13 mg/L to 52.84±18.65 mg/L, with the higher value during the pre-monsoon at station G2 and the lowest during the post-monsoon at station G3.

Table 2. Concentration of physico-chemical parameters during pre-monsoon (Average of LT and HT) of all four stations.

Sl No.	Parameters	G1	G2	G3	G4
1	Water Temp (C°)	29.61±0.86	29.28±0.54	28.62±0.42	27.835±0.65
2	pH	8.135±0.023	7.24±0.031	7.835±0.015	8.21±0.037
3	Conductivity (mS/cm)	21.66±4.21	9.59±3.96	12.69±4.14	33.285±4.59
4	TDS (mg/L)	13082.25±65.86	6233.5±54.23	8248.5±68.71	21635.25±74.35
5	TSS (mg/L)	77.64±5.26	64.8±3.63	70.4±2.68	75.2±4.21
6	Turbidity (NTU)	28.55±1.63	31.4±0.46	33.75±1.51	32.51±0.82
7	Salinity (PSU)	12.495±2.64	4.835±1.95	6.625±3.18	9.525±2.32
8	DO (mg/L)	5.075±0.36	6.605±0.25	6.965±0.41	5.255±0.28
9	BOD (mg/L)	1.3±0.026	0.7±0.01	1.5±0.039	1.35±0.032
10	Total Alkalinity (mg/L)	117±5.45	79±3.69	97±3.65	124±6.12
11	Fluoride (mg/L)	0.666±0.065	0.335±0.024	0.415±0.036	0.6±0.019
12	Nitrite-N (µmol/L)	0.26±0.01	0.47±0.01	0.9±0.012	0.92±0.014
13	Ammonia-N (µmol/L)	0.3±0.053	0.58±0.036	0.175±0.01	0.156±0.048
14	Nitrate-N (µmol/L)	6.346±1.12	1.95±0.72	2.144±0.84	1.225±0.68
15	Phosphate (µmol/L)	4.422±0.56	1.263±0.24	0.895±0.26	0.579±0.37
16	Silicate (µmol/L)	16.77±6.94	52.84±18.65	40.018±14.52	19.92±5.37
17	Total Chl.(mg/m3)	3.55±0.03	4.43±0.09	5.9±1.26	2.66±0.04

Table 3. Concentration of physico-chemical parameters during post-monsoon (Average of LT and HT) of all four stations.

Sl No.	Parameters	G1	G2	G3	G4
1	Water Temp (C°)	28.58±0.94	28.345±1.2	27.025±0.86	27.037±1.1
2	pH	8.28±0.01	8.36±0.024	8.19±0.012	8.165±0.022
3	Conductivity (mS/cm)	36.62±4.12	35.34±2.99	36.5±3.97	26.0125±4.82
4	TDS (mg/L)	23803±82.65	22971±76.52	23725±72.64	16908±68.43
5	TSS (mg/L)	56.72±4.76	109.2±2.13	86.6±3.92	83.925±5.15
6	Turbidity (NTU)	32.9±0.4	35.7±0.25	41.95±0.76	42.175±1.01
7	Salinity (PSU)	21.515±5.32	20.64±4.21	18.075±3.69	17.435±2.86
8	DO (mg/L)	4.955±0.13	4.735±0.1	4.6±0.1	7.24±0.28
9	BOD (mg/L)	1.15±0.024	2.35±0.063	1.3±0.098	0.8±0.017
10	Total Alkalinity (mg/L)	115±6.35	138±7.62	139±7.02	105±4.31
11	Fluoride (mg/L)	0.682±0.078	0.635±0.092	0.64±0.042	0.609±0.049
12	Nitrite-N (µmol/L)	0.32±0.023	1.19±0.16	0.85±0.062	1.113±0.23
13	Ammonia-N (µmol/L)	0.619±0.069	0.220±.02	0.215±012	0.383±0.054
14	Nitrate-N (µmol/L)	2.015±0.64	1.354±0.76	1.628±0.82	6.048±1.34
15	Phosphate (µmol/L)	3.053±0.65	1.316±0.41	1.84±0.22	5.896±0.92
16	Silicate (µmol/L)	19.873±4.31	13.574±3.76	12.54±6.13	26.037±8.84
17	Total Chl.(mg/m3)	8.896±0.069	3.537±0.072	5.66±0.039	3.024±0.067

The information in this brief time frame series may permit us to understand the impact of short time disparities in the physico-chemical parameters of surface water in the estuary region of Gahirmatha. The Bay of Bengal is viewed as quite less productive when compared to the matching western part of the Arabian Sea [26-29]. The primary nutrient production of the coastal waters of the Bay of Bengal is produced by the participation of the river surplus [30-32]. The temperature stimulates some other parameters and can change the properties (physical and chemical) of the water. In such a manner, the water temperature (WT) should be represented when deciding the production of metabolic rates and photosynthesis, compound toxicity, dissolved oxygen and other liquefied gas concentrations, conductivity and salinity, oxidation-reduction potential (ORP), pH, and the density of the water. The pH of the water regulates the solubility and biological accessibility (amount that can be exploited by aquatic life) of chemical compounds like nutrients (phosphorus, carbon and nitrogen) and heavy metals (cadmium, lead, copper, etc.). When the conductivity exceeds their standard range, it can be unfavorable to the aquatic life. Estuarine life can endure quickly changing salinity levels better than both their freshwater and marine counterparts. But even these bitter water species can endure if the salinity or conductivity changes become excessively extraordinary [34]. Turbidity and TSS are the most visible indicators of water quality. These suspended particles can come from soil erosion, runoff, discharges, stirred bottom sediments, or algal blooms. While it is possible for certain streams to have normally significant levels of suspended solids, clear water is generally viewed as an indicator of healthy water. An unexpected increase in turbidity in a formerly away from of water is a reason for concern. Unnecessary suspended sediment can harm water quality for aquatic and human life, obstruct the route, and increase the risks in flooding. Turbidity can also inhibit photosynthesis by blocking sunlight. Diminished photosynthesis implies a decline in plant endurance and a reduction in the dissolved oxygen output [33]. The higher the turbidity levels, the less light that can influence the lower levels of water. This condenses plant productivity at the bottom of an ocean, lake, or river. Without the required sunlight, bay grasses and seaweed below the surface of the water will not be able to continue the process of photosynthesis and may die. The dissolved solids are important for aquatic life by keeping cell density balanced. These changes can affect an organism's ability to move in a water column, causing it to float or sink beyond its normal range. BOD is a significant water quality parameter as it affords an index to assess the effect that discharged wastewater will have on the receiving environment. The higher the BOD value, the greater the amount of organic matter or “food” available for oxygen-consuming bacteria. The data of BOD have been applied for two different resolutions: to foresee the total oxygen demand of wastewater and the frequency of de-oxygenation [36]. Silicon has been studied extensively because it is utilized by diatoms and other silica-secreting organisms. Generally, surface samples are low, attributable to the improvement of silica-emitting organisms, but a dynamic increment in silicate takes place with depth, which is attributed to the dissolving of soluble silicates. In the open ocean, as on land, the fixed nitrogen is one of the essential growth-limiting nutrients for primary producers such as algae and marine bacteria. It can also serve as an energy source or an oxidant for marine bacteria and archaea [34].

Ammonia is the preferred nitrogen-containing nutrient for plant growth. Ammonia can be changed to nitrite (NO_2) and nitrate (NO_3) by bacteria, and afterward utilized by plants. Nitrate and ammonia are the widely recognized types of nitrogen in aquatic frameworks. Nitrate predominates in unpolluted waters. Nitrogen can be a significant factor in controlling algal development when different nutrients, e.g., phosphate, are plentiful. The impartial, unionized form (NH_3) is exceptionally toxic to fish and other aquatic life [35]. However, such restrictive nutrient factors diverge for closed water bodies and water bodies, which are predisposed by the external emancipations.

3.1. Analysis of physico-chemical parameters by multivariate Statistics

The multivariate statistical instruments are highly popular today for explaining a large number of data set. Different statistical methods like cluster analysis (CA), principal component analysis (PCA), and factor analysis (FA) are utilized for this sort of study. These statistical tools are proficient in evaluating temporal and spatial scale differences in coastal water quality, identifying potential sources of water contamination, and drawing a meaningful conclusion [29,37-39]. Season-wise (pre-monsoon and post-monsoon) multivariate statistical analysis of the Gahirmatha estuarine was done through CA, PCA, and person correlation matrix by advanced software (IBM SPSS 20 and Minitab 17). The cluster analysis is cast-off to know similarity between different parameters during the pre- and post-monsoon seasons [40]. The estuarine data set were standardization through Z-score transformation to avoid misclassification due to wide variability in the data dimensionality [41]. The statistical correlation matrix analysis was carried out for 17 environmental physico-chemical parameters.

3.1.1. Correlation coefficient (r) matrix Study

All of the 17 parameters were correlated with each other by the help of Pearson correlation in SPSS software. The correlations were studied by both the 0.01 and 0.05 level of significance. During pre-monsoon season, various parameters correlated with each other either positively or negatively: salinity, conductivity, dissolved oxygen, total dissolved solids, total suspended solids, alkalinity, ammonia, chlorophyll, pH, fluoride, nitrate, phosphate, nitrite, and silicates. With respect to 0.05 levels of significance, fluoride was positively correlated with TSS. Salinity and silicate were negatively correlated with pH, TSS, and alkalinity. TDS and alkalinity were positively correlated with pH. Chlorophyll was positively correlated with dissolved oxygen. Concerning the 0.01 level of significance, TDS and conductivity were positively correlated. Silicate was negatively correlated with fluoride. Phosphate and nitrate were positively correlated with each other. During the post-monsoon season, parameters like salinity, temperature, dissolved oxygen, total dissolved solids, conductivity, pH, nitrate, turbidity, fluoride, nitrite, chlorophyll, alkalinity, and silicate correlated with each other at the 0.01 and 0.05 level of significances. With respect to the 0.05 levels of significance, fluoride and chlorophyll were positively correlated with pH. Dissolved oxygen and nitrate were negatively correlated with both chlorophyll and TDS. Salinity was positively correlated with temperature. Silicate was positively correlated with phosphate and negatively correlated with alkalinity. Considering the 0.01 levels of significance, turbidity was negatively correlated with temperature and salinity. Dissolved oxygen was positively correlated with nitrate, whereas total dissolved solids were positively correlated with conductivity.

Table 4. Pearson correlation matrix of different physico-chemical during pre-monsoon season.

Parameters	**Temperature**	**pH**	**Conductivity**	**TDS**	**TSS**	**Turbidity**	**Salinity**	**DO**	**BOD**	**Alkalinity**	**Fluoride**	**Nitrite**	**Ammonia**	**Nitrate**	**Phosphate**	**Silicate**	**Chlorophyll**
Temperature	1																
pH	-.393	1															
Conductivity	-.602	.834	1														
TDS	-.655	.810	.997**	1													
TSS	-.127	.957*	.766	.724	1												
Turbidity	.542	-.623	-.947	-.949	-.584	1											
Salinity	.107	.849	.669	.615	.966*	-.534	1										
DO	.040	-.728	-.821	-.781	-.836	.817	-.888	1									
BOD	-.434	.822	.464	.455	.695	-.155	.515	-.215	1								
Alkalinity	-.408	.975*	.923	.900	.949	-.773	.864	-.841	.683	1							
Fluoride	-.073	.904	.801	.756	.979*	-.676	.981*	-.928	.540	.939	1						
Nitrite	-.629	.229	.726	.756	.142	-.885	.088	-.500	-.174	.409	.258	1					
Ammonia	.641	-.853	-.625	-	-.684	.354	-.476	.280	-	-.754	-.550	-.078	1				
Nitrate	.748	.316	-.015	-	.560	.102	.725	-.490	.139	.285	.580	-.476	.050	1			
Phosphate	.768	.276	.005	-	.536	.045	.719	-.536	.041	.271	.580	-.396	.132	.992**	1		
Silicate	.195	-.95*	-.844	-.807	-.989*	.697	-.954*	.893	-.630	-.975*	-.99**	-.284	.655	-.489	-.479	1	
Chlorophyll	.035	-.516	-.764	-.735	-.632	.859	-.713	.953*	.063	-.682	-.772	-.661	.044	-.345	-.423	.722	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5. Pearson correlation matrix of different physico-chemical parameters during post-monsoon season

Parameters	Temperature	pH	Conductivity	TDS	TSS	Turbidity	Salinity	DO	BOD	Alkalinity	Fluoride	Nitrite	Ammonia	Nitrate	Phosphate	Silicate	Chlorophyll
Temperature	1																
pH	.670	1															
Conductivity	.537	.558	1														
TDS	.537	.558	1.000**	1													
TSS	-.177	-.811	-.092	-.092	1												
Turbidity	-.991**	-.765	-.560	-.560	.305	1											
Salinity	.988*	.738	.651	.651	-.234	-.991**	1										
DO	-.481	-.404	-.984*	-.984*	-.085	.482	-.587	1									
BOD	.515	-.164	.505	.505	.710	-.412	.498	-.619	1								
Alkalinity	.083	-.185	.712	.712	.584	-.028	.157	-.824	.750	1							
Fluoride	.716	.963*	.761	.761	-.654	-.795	.803	-.637	.053	.087	1						
Nitrite	-.433	-.959*	-.500	-.500	.906	.551	-.524	.337	.377	.224	-.905	1					
Ammonia	.467	.820	-.017	-.017	-.896	-.561	.466	.189	-.517	-.712	.636	-.798	1				
Nitrate	-.540	-.394	-.974*	-.974*	-.129	.532	-.635	.995**	-.681	-.823	-.628	.301	.191	1			
Phosphate	-.427	-.164	-.897	-.897	-.357	.391	-.508	.960*	-.790	-.927	-.424	.067	.413	.971*	1		
Silicate	-.182	.012	-.823	-.823	-.440	.145	-.273	.908	-.715	-.984*	-.258	-.051	.582	.903	.967*	1	
Chlorophyll	.495	.962*	.639	.639	-.822	-.603	.597	-.492	-.233	-.062	.953*	-.986*	.708	-.458	-.235	-.114	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.1.2. Cluster Analysis

Cluster analysis is a class of techniques used to categorize various objects and individuals of cases into comparative groups known as clusters. This tool analyzed the different physicochemical parameters for understanding the association within all the stations and seasons. Agglomerative hierarchical clustering (AHC) was performed for the different parameters for the year 2019 (Figs. 3 and 4) using MINITAB-17 software. The pre-monsoon season formed two foremost clustering and groups, in which temperature, nitrate, phosphate, turbidity, silicate, DO, and ammonia account for one group. The second group consisted of pH, alkalinity, TSS, fluoride, conductivity, salinity, TDS, BOD, and nitrite.

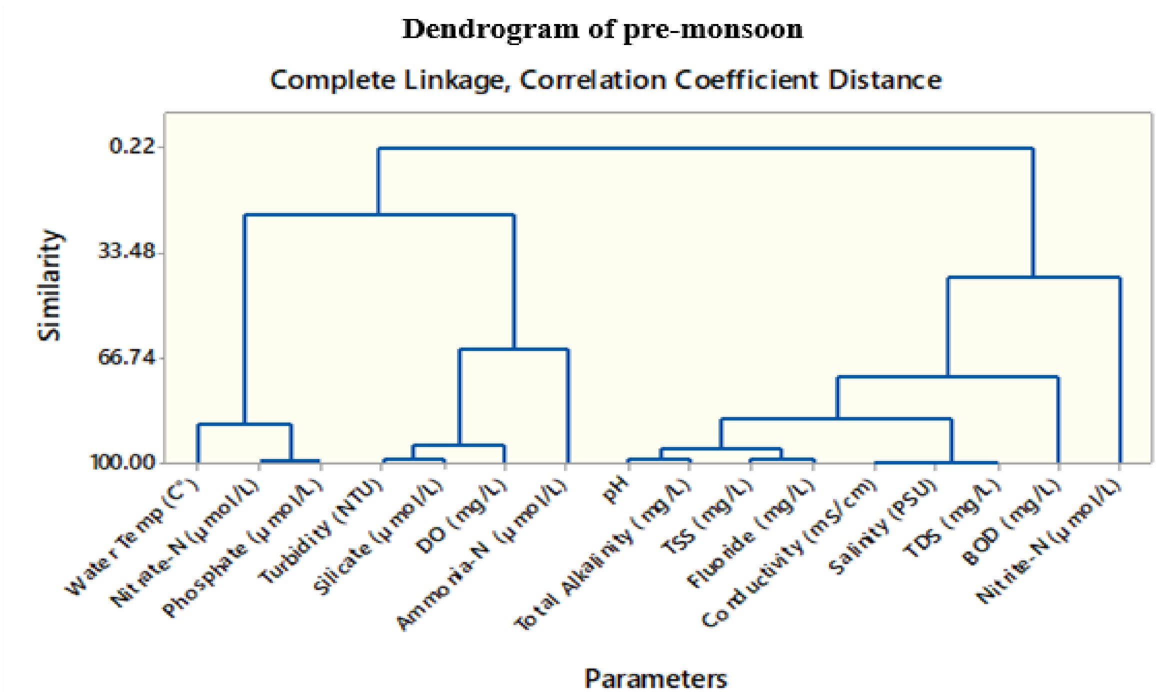

Fig.3. Agglomerative Hierarchical clustering dendrogram showing relationship between physico-chemical parameters during pre-monsoon season.

Post Monsoon seasons showing 2 major groups and cluster. In first cluster again two grouping are formed, within 1st group Temperature, pH, Fluoride and Ammonia are present but within 2nd group Conductivity, TDS, Salinity, BOD and Total Alkalinity are present. In second cluster, 1st group containing TSS, Nitrate and Turbidity but within 2nd group DO, Nitrate, Phosphate and silicate are present.

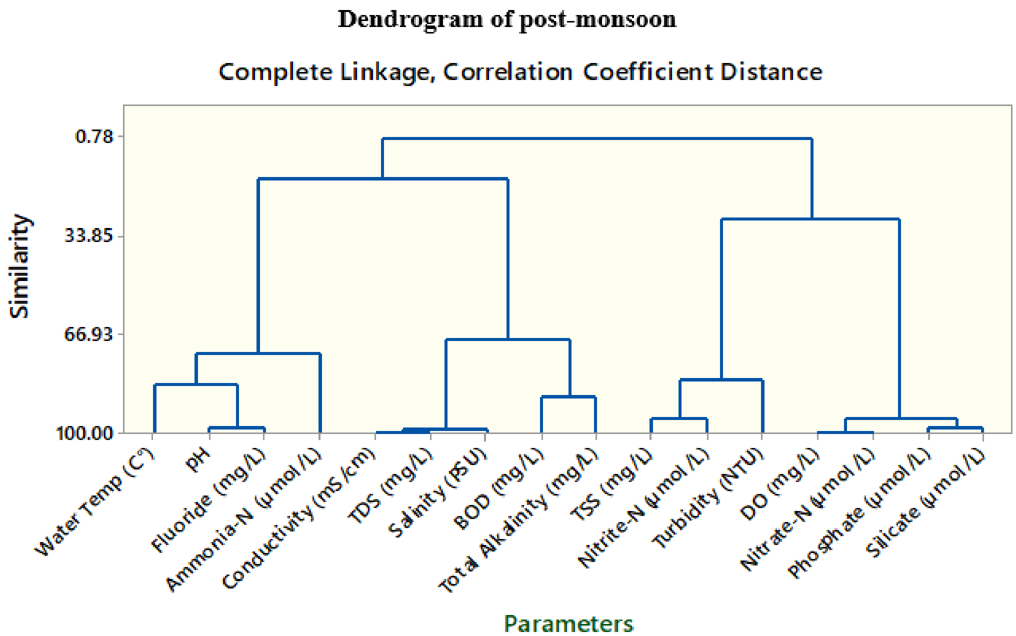

Fig.4. Agglomerative Hierarchical clustering dendrogram showing relationship between physico-chemical parameters during post-monsoon season.

3.1.3. Principal component analysis (PCA)

A principal component analysis was conducted for both the pre-monsoon and post-monsoon seasons with the help of MINITAB-17. During The pre-monsoon season, the PCA uprooted about 3 factors from PC-1 to PC-3, which had an eigen value of more than 1 and accounted for 63.93% of total variance. Both of the seasonal eigen values are shown in Table 6 and Figure 5. In the principal component analysis of the pre-monsoon season, the first principal (PC-1) was considered to be about 63.933% of the total variance and had more positive values of pH, TDS, salinity, fluoride, TSS, and total alkalinity, while having a negative loading of turbidity and dissolved oxygen. These values may be due to the ecotone region of both the seawater and estuarine region. The PC-2 group was showing 22.51%, with a positive loading of water temperature, nitrate, and phosphate. PC-3 accounted for about 13.56%, with a positive load towards BOD and total chlorophyll.

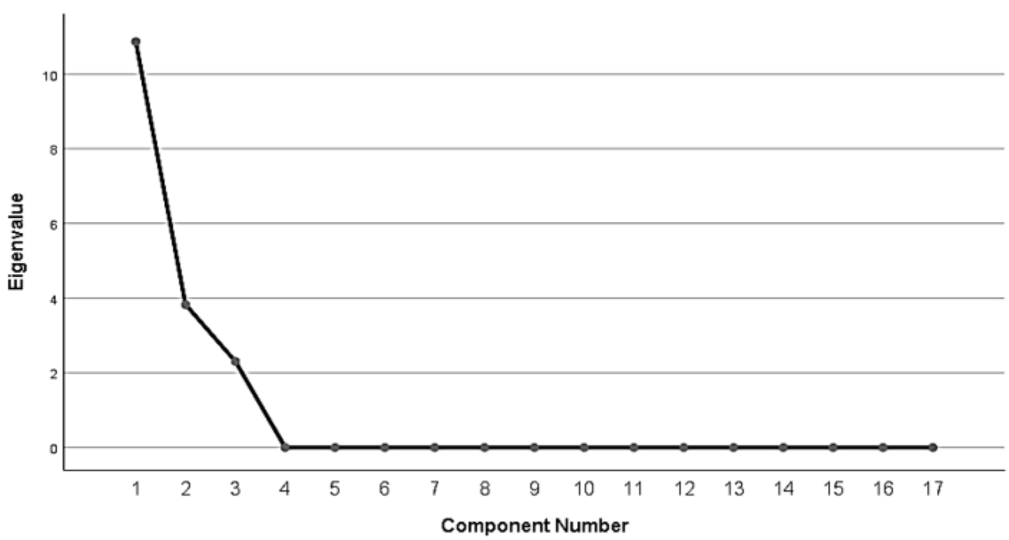

Fig.5. Eigen curve extracted from PCA during pre-monsoon.

Table 6. Seasonal rotated component matrix (RCM) of physico-chemical parameters (Principal component Analysis, PCA).

Seasonal rotated components matrix						
	Pre-Monsoon			Post-Monsoon		
Parameters	**PC-1**	**PC-2**	**PC-3**	**PC-1**	**PC-2**	**PC-3**
Water Temp (C°)	-0.351	0.926	-0.136	0.59	0.197	0.783
pH	0.947	-0.018	0.321	0.61	0.766	0.204
Conductivity (mS/cm)	0.932	-0.321	-0.169	0.997	-0.051	-0.052
TDS (mg/L)	0.906	-0.388	-0.17	0.997	-0.051	-0.052
TSS (mg/L)	0.946	0.252	0.205	-0.137	-0.983	0.124
Turbidity (NTU)	-0.955	-0.282	0.088	-0.252	-0.539	0.803
Salinity (PSU)	0.936	-0.305	-0.177	0.97	-0.015	-0.242
DO (mg/L)	-0.898	-0.244	0.366	-0.971	0.229	0.06
BOD (mg/L)	0.597	-0.126	0.792	0.493	-0.732	0.47
Total Alkalinity (mg/L)	0.993	-0.048	0.106	0.666	-0.714	-0.216
Fluoride (mg/L)	0.958	0.286	0.005	0.801	0.575	0.166
Nitrite-N (µmol/L)	0.453	-0.603	-0.656	-0.541	-0.838	0.065
Ammonia-N (µmol/L)	-0.672	0.341	-0.658	0.049	0.946	0.322
Nitrate-N (µmol/L)	0.324	0.943	0.081	-0.965	0.262	-0.029
Phosphate (µmol/L)	0.324	0.945	-0.042	-0.875	0.484	-0.008
Silicate (µmol/L)	-0.981	-0.174	-0.083	-0.784	0.583	0.211
Total Chl.(mg/m3)	-0.761	-0.159	0.628	0.676	0.735	-0.062
Eigen Value	10.869	3.825	2.306	9.068	6.096	1.836
% of Variance	63.933	22.503	13.565	53.341	35.861	10.798
Cumulative %	63.933	86.435	100	53.341	89.202	100

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

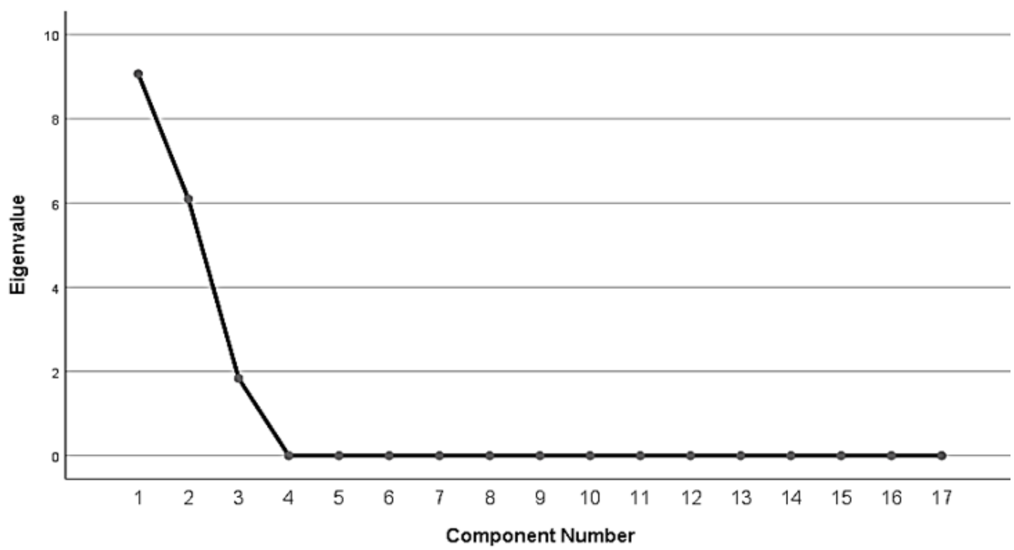

Fig.6. Eigen curve extracted from PCA during post-monsoon.

During the post-monsoon season, the PCA categorized about three groups, namely PC-1, PC-2, and PC-3, which contained Eigen values >1 and accounted for about 53.34% of the total variance. Both of the seasonal Eigen values are plotted in Table 6 and Fig.6. The PC-1 shows about 53.34% of the total variance with huge positive values for conductivity, TDS, and fluoride; it also shows huge negative values for nitrate and dissolved oxygen. The PC-2 accounts for about 35.86% of the total variance and has positive loading of ammonia, pH, and total chlorophyll; it also shows a huge negative for TSS. PC-3 accounts for about 10.79% of the total variances with a more positive load towards turbidity and water temperature but also showing negative for salinity and total alkalinity.

5. Conclusions

The present study attempted to determine the concentration of different physico-chemical parameters by the use of various prescribed methods. The Pearson correlation between all the seventeen physico-chemical parameters concluded that during the pre-monsoon season, silicate was highly correlated with various parameters like pH, total dissolved solids, salinity, and alkalinity with respect to a 0.05 level of significance, but in the case of post-monsoon season, both the dissolved oxygen and nitrate were negatively correlated with the conductivity and total dissolved solids. The principal component analysis concluded that both the pre-monsoon and post-monsoon season accounted for three categories. The highest Eigen value was about 10.87 during the pre-monsoon and 9.07 during the post-monsoon season. The agglomerative hierarchical clustering grouped all the physico-chemical parameters into two major groups with respect to their similarities. The observed variations in the concentration of these physico-chemical parameters in the surface waters of the Gahirmatha estuary may only be due to the riverine water inputs from the large catchment of rivers like the Brahmani, Baitarani, and Dhamra. Other factors that influence the water quality, i.e., the anthropogenic liberation through local activities, may be responsible for the changes and need to be investigated.

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