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Analytical Hierarchical Process-based Water Quality Index Evaluation for Overall Knowledge on Spatial and Seasonal Changes of Water Quality of the Lower Stretch of River Ganga

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Abstract: ***Water quality of a surface water body refers to the status of its water whether it can be used as potable water sources. Basic knowledge of water quality and associated methods regarding its analysis are of notable importance as ecological advantage and human wellbeing are also associated with it. But defining water quality condition of a surface water body for a single particular aspect will lead to misinterpretation of the condition status as it is open to any sort of pollution possibilities. There are many conventional techniques allied to water quality assessment for different pollution scenarios with defined water quality parameters. Despite of the availability those methods, the present study adhered to the quality index calculation with all sorts of water quality issues in an integrated way. The current study chose an important watershed to analysis water quality characteristics under the aegis of multi criteria decision making (MCDM). Locations for water sample collection along the stretch of the river were selected on the basis of population density and practices of cloth washing, bathing, utensil cleaning in the river, agricultural practices and industrial activities such as discharging effluent from industries to the adjacent portion of the river. Suitable water quality parameters were considered to define Water Quality Index (WQI). The study after all the sampling, laboratory experiments, values of different parameters and finally water quality indexing could come to a conclusion that according to the water quality scale range the river water is unsuitable for drinking without any proper treatment. Though the condition of water usually gets better in monsoon and autumn compared to winter and summer seasons but that too can't ensure good health of the river water.***

Keywords: MCDM, AHP, Ganga river, Water quality, Spatial seasonal variation

1. Introduction

Water quality plays a vital part in ecosystem and human wellbeing (Gorenflo and Warner 2016, Wu 2018). Surface water quality gets affected by different environmental processes and anthropogenic activities (Zeinalzadeh and Razaei 2017). Different contaminants like microbes, radioactive compounds and contaminants present in very low concentration but can accumulate to the water for a very long time can be harmful to the health of the water body. Chemical analysis of those contaminants is not sufficient to predict and decipher the quality condition of a surface water body as it is opened to several pollutants mixture and also it shows uncertainties during evaluation of WQI (Benedini 2013). Consequently, river water quality analysis needs variety of indicators for an overall quality assessment which is essential in water resources management (Rosińska 2022). In India, the concern for river pollution gained interest since 1980s after the approval of Water Act 1974. National River Conservation Plan (NRCP) was commenced for observation of quality condition of some important river systems of India (Singh 2004). Different strategies such as water quality modeling (Paredes-Arquiola 2010, Tsakiris 2012), statistical approaches (PCA/FA, DA, ANOVA etc.), neural network-based approaches, fuzzy logic and artificial intelligence etc. separately or in combination (Othman 2012, Ma 2013, Wu 2018, Dutta 2018, Gurjar 2019, Matta 2020, Baghapour 2020, Varol 2020, Das 2021, Bagla 2021, Vijay-Kamaraj 2021) were used for better understanding of the water quality conditions.

Ganga being a sacred river in India from the ancient times has various use of its water in recent days also. Ganges river basin is the most fertile plan in India enriching the agricultural activities as well as amalgamation of people from different community and workplace to get settled on the bank of the river which anyway gives rise to the population density. With time multiple industries were situated on the vicinity of the Ganga river to use its water in production as well as to dump industrial effluent in the river water. Beside that there are other activities like cloth washing, cattle bathing, cleaning of utensils and different rituals as well which are affecting the quality of the river water. Government of India through National Mission for Clean Ganga project under Central Pollution Control Board (CPCB) categorized the river water in Class A, Class B and Class C for suitability in drinking and bathing based on different water quality parameters. A lot many studies associated to the water quality assessment of Ganga river (Sharma 2011, Parmar 2015, Singh 2018, Elkiran 2019, Duttagupta 2020) are there which indicate that the river

water is getting polluted with days despite of several attempts taken by the government for its cleanliness.

The lower part of the river is still facing so many challenges to maintain its water quality as there are multiple utilization of its water (Das 2021). So far, several studies were conducted on water pollution aspects of the river but not many are there focusing the lower stretch. Ghose (2009), Chakraborti (2016), Khuman (2019), Duttagupta (2020) and Khuman (2020) studied the nature of pollution caused by agricultural discharge into the river, Ghosh (2019) focused on river water pollution due to urban waste disposal, Paul (2013 and 2017) emphasized on heavy metals pollution scenarios. Mishra (2025) assessed overall water quality of the Ganga river emphasizing on hydro-chemical parameters using multivariate statistical approach. Characterization of different pollution sources such as industrial waste disposal, agricultural and municipal run-off which are affecting the lower stretch were studied by Sarkar (2024). A real time water quality monitoring were conducted to check the water quality standard of lower stretch of Ganga river along with some municipal drains which directly discharging into the river water by Sahoo (2024). The emerging contaminants like pharmaceutical products, personal caring products, perfluoro compounds were also detected in the range of 10-30 ng/L by Shamra (2016 and 2019) in lower stretch of Ganga.

MCDMs stand out enough to be noticed in water quality analysis due to the possible reduction in the subjectivity in criteria selection and vast application fields (Walkar 2015, Salehi 2018, Pourmand 2020, Gupta 2022, Rashidi 2022). Analytical hierarchical process (AHP) is a very popular MCDM tool used worldwide for its user friendliness and error lessness in multiple application fields. Previously in water quality studies it was used for determination of water quality indices (Sarkar 2020, Gorantla 2020, Castro-Pardo 2021, Akhtar 2021). AHP was also applied to make strategies for emergency situations in drinking water supply system (Pagano 2021). It helps practitioners to make decisions out of complex issues with the help of connections between the objective of the work, priority outcomes, criteria and the alternatives. So, the current study opted for AHP based water quality analysis for the lower stretch of river Ganga. A qualitative and quantitative assessment was carried out AHP was utilized for weights of individual water quality parameters as well as for the determination of water quality indices. Authors are hopeful that the study will be beneficial to understand the overall quality conditions of the lower stretch of Ganga river in different seasons and will be helpful in pollution assessment to make sustainable approaches in rejuvenation planning.

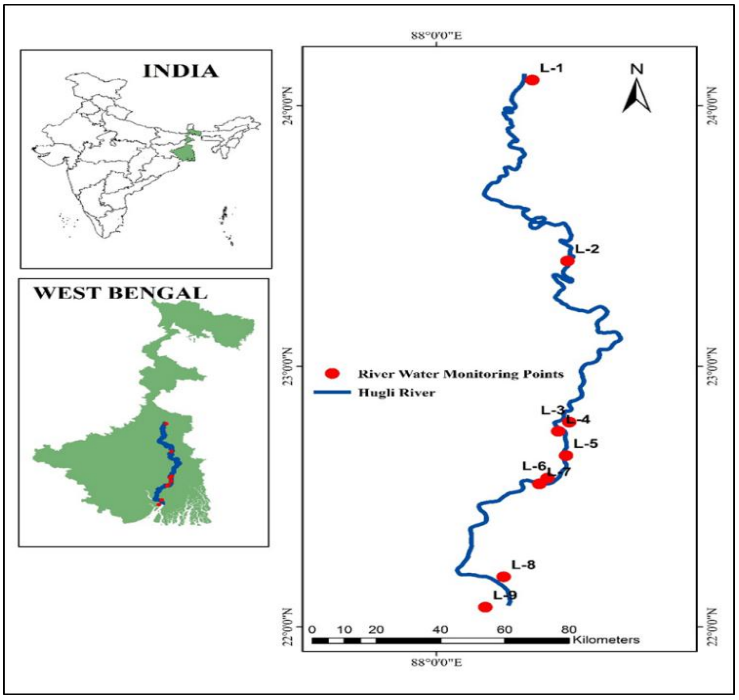


Figure 1: Study area map showing Hugli River and the river water monitoring locations along the length of the river

2. Methodology

2.1 Description of study area

In West Bengal, lower stretch of Ganga, covers eight districts where it is popularly known as Bhagirathi-Hugli. Besides being an important source of fresh water, the river is also the center for rural and urban development and industrial-economical growths. For few years now, the huge pollution loads in the river mainly anthropogenic are affecting the river habitat, social and economic situation of the areas which directly or indirectly depend on river water. The level of pollution is so high that some water quality parameters sometimes show irrelevant values which are beyond any standards. CPCB in their annual river water quality report 2020 documented (CPCB, 2020) highest electric conductivity 11980 µS/cm and DO vary between 3.7-12.5 mg/L near East Midnapore region. Based on previous researches, water use and government reports, location that were chosen to conduct the current study are shown in the Fig-1 and with details are depicted in Table-1. As this stretch is flowing through the districts consisting of agricultural land as well as industries and high density population, pollution loads are mainly the effect of effluents from industries, untreated municipal

wastewater, and agricultural runoff (Panigrahi 2021). People in Kolkata and the adjacent districts depend on the river as an important drinking water source. Such effluents in river water make water purification a challenge to the water treatment plants pressurizing the treatment process to maintain the drinking water guidelines as well as increasing the cost.

Table 1: Locations along the districts and specifications

Stations	Places	Districts	Remarks
L-1	Baharampur	Mushirdabad	Rich in agriculture, small scale industries
L-2	Nabadwip	Nadia	Rich in agriculture
L-3	Palta	North 24 Parganas	Urban area
L-4	Serampore	Hooghly	Medium and small industries
L-5	Dakkhineswar	Kolkata	Urban area
L-6	Shibpur	Howrah	Medium and small industries
L-7	Garden Reach	Kolkata	Urban area with high population volume
L-8	Diamond Harbour	South 24 Parganas	Urban area, higher population volume due to shipping, port activity, tourist spots
L-9	Durgachak	East Midnapore	Rich in agriculture

The present study considered the data archives of West Bengal Pollution Control Board (WBPCB) for its authenticity and originality. Ten water quality parameters namely Dissolved oxygen (DO), Electric conductivity (EC), pH, Sodium (Na+), Potassium (K+), Turbidity (TUR), Total Alkalinity (TA), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) were selected based on their importance in surface water quality monitoring, number of uses in literatures and experts' opinion. Data were gathered for a duration of ten years from 2013 to 2023 for four seasons: winter (January-February), summer (March-May), monsoon (June-September) and autumn (October-December) (https://mausam.imd.gov.in). Season wise average concentrations of the parameters for the selected locations are showed in Table 2, Table 3, Table 4 and Table 5 respectively.

Table 2: Concentrations of water quality parameters in winter

	[DO]	[EC]	[pH]	[Na^+]	[K^+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
Units	mg/L	(µs/cm)		mg/L	mg/L	NTU	mg/L	mg/L	mg/L	mg/L
Locations										
L-1	9.94	357.65	8.15	11.47	3.06	17.6	153.74	208.36	13.63	2.62
L-2	9.84	348.53	8.24	11.58	3.26	29.42	149.5	208.36	10.95	1.93
L-3	7.73	324.93	7.92	11.05	3.23	83.07	151.77	226.82	9.97	3.25
L-4	7.68	349.45	7.95	11.12	4.18	51.73	161.86	217.09	10.5	3.22
L-5	7.19	378.84	7.8	23.53	4.03	42.05	139.09	226.18	12.64	4.27
L-6	7.09	354.46	7.8	25.15	4.21	44.32	135.64	218.18	9.35	2.9
L-7	7.03	375.56	7.84	22.87	4.07	48.55	140.82	218.18	9.8	3.42
L-8	7.01	450.8	7.62	22.66	9.75	42.59	165	226.45	13.44	2.08
L-9	7.26	389.9	7.51	19.91	7.52	49.01	150.73	220.01	14.88	2.58

Table 3: Concentrations of water quality parameters in summer

	[DO]	[EC]	[pH]	[Na^+]	[K^+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
Units	mg/L	(µs/cm)		mg/L	mg/L	NTU	mg/L	mg/L	mg/L	mg/L
Locations										
L-1	6.87	319.37	7.94	13.88	3.97	23.31	124.28	191.09	12.3	3.1
L-2	6.76	332.27	7.82	14.53	4	75.77	126.54	195.27	11.86	2.43
L-3	6.41	338.77	7.91	11.74	3.73	156.03	142.55	215.27	12.86	2.89
L-4	6.25	347.48	7.96	14.84	4.02	50.45	136.27	218.36	11.69	3.96
L-5	5.87	340.82	7.85	28.31	4.83	52.33	143.64	208.73	13.18	4.11
L-6	5.64	379.69	7.77	31.47	4.5	75.18	150.36	272.55	11	3.05
L-7	6.36	347.84	7.75	26.51	4.4	60.94	138.45	213.55	9.79	3.55
L-8	6.72	452	7.84	37.82	3.5	110.9	178	289.91	22	3.83
L-9	6.43	440.23	7.63	19.85	5.1	136.2	140.09	315	22.7	2.18

Table 4: Concentrations of water quality parameters in monsoon

	[DO]	[EC]	[pH]	[Na^+]	[K^+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
Units	mg/L	(µs/cm)		mg/L	mg/L	NTU	mg/L	mg/L	mg/L	mg/L
Locations										
L-1	5.82	221.57	7.69	7.98	3.75	286.44	99.04	147.45	11.81	3.29
L-2	5.8	216.05	7.53	8.37	3.48	204.05	95.59	178.36	12.16	2.93
L-3	4.92	230.14	7.54	12.71	4.32	256.27	98.04	173.27	11.37	2.35
L-4	4.77	239.6	7.65	10.2	4.09	177	108.4	130.55	12.68	3.31
L-5	4.91	267.05	7.68	16.64	5.51	214.82	114	160.27	16.91	3.67
L-6	4.52	260	7.62	16.84	4.4	223	114.91	203.64	14.73	3.15
L-7	4.59	245.9	7.5	15.4	4.3	213.64	114.91	178	14.45	3.24
L-8	5.43	267.76	7.57	20.82	4.4	204.09	128.18	130.3	15.64	3.22
L-9	5.79	308.91	7.39	18.84	3.9	200.31	102.64	211.16	15.35	1.84

Table 5: Concentrations of water quality parameters in autumn

	[DO]	[EC]	[pH]	[Na^+]	[K^+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
Units	mg/L	(µs/cm)		mg/L	mg/L	NTU	mg/L	mg/L	mg/L	mg/L
Locations										
L-1	6.85	254.46	7.86	10.32	3.62	146.77	118.12	167.27	12.07	3.62
L-2	6.42	241.89	7.83	10	2.98	186.73	114.45	179.82	11.9	2.79
L-3	5.67	250.18	7.77	11.04	3.29	184.88	111.89	211.09	11.36	2.35
L-4	5.37	254.95	7.77	9.73	3.4	121.12	114.39	177.73	10.36	2.7
L-5	5.39	270.04	7.63	21.83	3.78	134.09	126.91	149.09	11.27	3.09
L-6	5.11	273.54	7.57	20.56	3.67	115.65	138.55	179.73	12.45	3.66
L-7	5.39	264.89	7.63	17.94	3.4	101.55	123.45	163	11.82	2.86
L-8	5.6	328.97	7.76	21.38	8.82	160.5	133.27	272.36	16.82	3.09
L-9	5.9	299.21	7.29	28.73	5.23	180.63	111.36	250	19.1	2.81

2.2 Application of decision-making tools:

Decision making is a difficult and complex task when it comes to river water quality assessment as condition of water quality of a river depends on so many factors as well as on the perception of decision makers. MCDMs are such techniques that help in reducing the difficulty, subjectivity and increase the robustness of decision-making process by providing optimized solution. Several algorithms and different techniques were developed to meet the purposes. The versatility of utilization and capacity of solving complex issues made the authors of this study to use analytical hierarchical process to determine water quality index of the lower stretch of river Ganga integrating possible sources of pollution. Detailed method of index calculation could be found in Sarkar (2020). The criterions were ranked according to Saaty's chart between 1 to 9 depending on purpose of water use, importance of the parameters in surface water quality, citation frequency and experts' opinion.

$$\boldsymbol{WQI} = \sum_{i=1}^{n} \boldsymbol{WiQi}$$

where, n = number of variables, W_i = relative weights calculated for individual variable and Q_i = experimental or field measured value of individual parameter.

Conventional methods used for water quality index calculation are subjected to specific water use and specific water quality parameters. In other way weights of individual parameters required their specific standards which are also subjected to different water use. Reduction of the subjectivity and complexity of calculation were the main aim to use AHP.

3. Results and discussion

3.1 Overall river water quality condition:

Changes in water quality parameters could be seen from the values represented in Table 2, 3 4 and 5. Concentration of dissolved oxygen was found between 9.94 in winter to 5.39 in autumn. It is a major parameter that helps to gauge the biological decomposition capacity of river (Naubi 2016). pH showed highest value of 8.15 in Baharampur in winter and in the rest of the locations it varied between 7 to 8 in other seasons. Degradation of pH may cause harm to the growth and expansion of living organisms of river water (Xiao 2019). Electric conductivity indicates total ions present in water in dissolved form (Gupta 2008) which is influenced by various effluent discharges into the river (Singh and Hussain 2016). Conductivity ranged between 325 to 390 µs/cm in winter, 320 to 452 µs/cm in summer, 216 to 309 µs/cm in monsoon and 242 to 329 µs/cm in autumn. It was observed that in summer and in winter the values are relatively higher than monsoon and autumn. Higher levels of conductivity were observed in Durgachak and Diamond Harbour regions that may be the effects of agricultural practices, shipping and port activities. The higher the level of conductivity in river water more it will be difficult to make water suitable for drinking (Ravikumar 2013). Total dissolved solids consist of inorganic salts like carbonate, bicarbonate, calcium, magnesium and iron.

The average amount of TDS in the river varied between 130 to 290 mg/L in four seasons. The growth of the aquatic species can be limited or even lead to death due to very high or low concentration of TDS in water (Subin and Husna 2013) as it indicates possibility of existence of synthetic chemicals that can be the cause of unbearable odor and color problematic to fish and other aquatic plants. Higher value of sodium and potassium in surface water denotes large amount of entry of domestic sewage in water (Bhat 2001). Concentration of sodium was found between 11 to 25 mg/L in winter, 11 to 38 mg/L in summer, 8 to 21 mg/L in monsoon and 9 to 29 in autumn. Saline water intrusion, mineral deposition, sewage mixing, industrial waste water mixing, detergents, others soaps, food processing products are mainly the cause of notable sodium concentration in water. Locations with large volume of population causing generation of large volume of municipal wastes, large- and small-scale industries that may be the reasons of higher concentration of sodium in river water. Potassium ranged between 3 to 9 mg/L in four seasons. Turbidity in water is caused by the dispersion of colloidal and fine particles. The values revealed the turbid nature of the river varying widely between 17 to 288 NTU. It seemed that turbidity in monsoon and autumn are higher compared to summer and winter due to increasing volume of water during that time. Alkalinity is the ability of water to countervail acids. It depends on carbonate, bicarbonate, calcium, magnesium hydroxide, different salts and phosphate, silicate, borate etc. Water tastes bitter when concentration of alkalinity is high, also unsuitable for vegetation as it harms the soils (Ravikumar 2013). Concentration of alkalinity from 95 to 162 mg/L will not cause any harm to the water treatment plant. Complete degradation of organic matters of surface water body, the amount of oxygen necessary is termed as BOD. High value of BOD indicates high concentration of organic contaminants (Bora 2017). BOD varied between 2 to 4 mg/L whereas variation of COD from 9 to 23 mg/L indicated presence of organic as well as inorganic matters which are the results of industrial effluents and agricultural discharges in water.

3.2 Correlation Analysis

Pearson correlation analysis was performed to understand the relation among the ten water quality parameters for four different seasons. Table 6, Table 7, Table 8 and Table 9 represent the correlations matrices with a p-value of 0.05. This was done to check the accuracy of the information on surface water quality parameters. Do is significantly in negative correlation with COD and positively correlated with BOD. Significant positive correlation between TDS-EC and Na^+-K^+ respectively confirmed the validation of qualitative analysis.

Table 6: Correlation among the water quality parameters in winter

Variables	[DO]	[EC]	[pH]	[Na^+]	[K^+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
[DO]	1									
[EC]	-0.407	1								
[pH]	0.849	-0.637	1							
[Na^+]	-0.725	0.588	-0.695	1						
[K^+]	-0.494	0.900	-0.779	0.464	1					
[TUR]	-0.566	-0.253	-0.356	-0.043	0.021	1				
[TA]	0.184	0.329	-0.004	-0.509	0.462	0.021	1			
[TDS]	-0.814	0.364	-0.713	0.462	0.457	0.701	0.018	1		
[COD]	-0.124	0.580	-0.364	0.058	0.565	-0.403	0.375	0.023	1	
[BOD]	0.451	-0.268	-0.139	0.255	-0.390	0.358	-0.494	0.451	-0.256	1

Table 7: Correlation among the water quality parameters in summer

Variables	[DO]	[EC]	[pH]	[Na^+]	[K^+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
[DO]	1.000									
[EC]	0.013	1.000								
[pH]	0.192	-0.583	1.000							
[Na^+]	-0.373	0.601	-0.363	1.000						
[K^+]	-0.541	0.124	-0.678	0.108	1.000					
[TUR]	0.059	0.543	-0.378	-0.005	-0.060	1.000				
[TA]	-0.168	0.751	-0.149	0.812	-0.248	0.415	1.000			
[TDS]	-0.179	0.953	-0.663	0.531	0.290	0.563	0.647	1.000		
[COD]	-0.291	0.883	-0.435	0.322	0.086	0.567	0.562	0.792	1.000	
[BOD]	0.291	-0.108	0.498	0.446	-0.207	-0.453	0.384	-0.229	-0.203	1.000

Table 8: Correlation among the water quality parameters in monsoon

Variables	[DO]	[EC]	[pH]	[Na^+]	[K^+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
[DO]	1.000									
[EC]	0.015	1.000								
[pH]	-0.249	-0.459	1.000							
[Na^+]	-0.211	0.845	-0.365	1.000						
[K^+]	-0.565	0.344	0.365	0.521	1.000					
[TUR]	0.199	-0.41	0.302	-0.341	-0.089	1.000				
[TA]	-0.426	0.43	0.149	0.743	0.558	-0.377	1.000			
[TDS]	-0.025	0.386	-0.607	0.232	-0.121	0.014	-0.3	1.000		
[COD]	-0.193	0.789	-0.086	0.835	0.682	-0.437	0.725	0.147	1.000	
[BOD]	0.367	-0.375	0.815	-0.158	0.439	-0.012	0.466	-0.596	0.2	1.000

Table 9: Correlation among the water quality parameters in autumn

Variables	[DO]	[EC]	[pH]	[Na+]	[K+]	[TUR]	[TA]	[TDS]	[COD]	[BOD]
[DO]	1.000									
[EC]	-0.272	1.000								
[pH]	0.371	-0.44	1.000							
[Na+]	-0.392	0.758	-0.868	1.000						
[K+]	-0.102	0.941	-0.138	0.512	1.000					
[TUR]	0.537	0.059	0.03	-0.043	0.198	1.000				
[TA]	-0.495	0.464	-0.038	0.376	0.391	-0.531	1.000			
[TDS]	-0.005	0.774	-0.291	0.437	0.82	0.551	-0.015	1.000		
[COD]	-0.085	0.82	-0.63	0.748	0.734	0.418	0.033	0.84	1.000	
[BOD]	0.136	0.177	0.01	0.18	0.108	-0.422	0.666	-0.229	0.035	1.000

3.3 Spatial and seasonal variation of water quality index:

Table 10 showed AHP calculated weights of the parameters. Consistency Ratio was checked and it came as 0.070<0.1. Results of WQI of four seasons by AHP, for all locations are presented in Table 11.

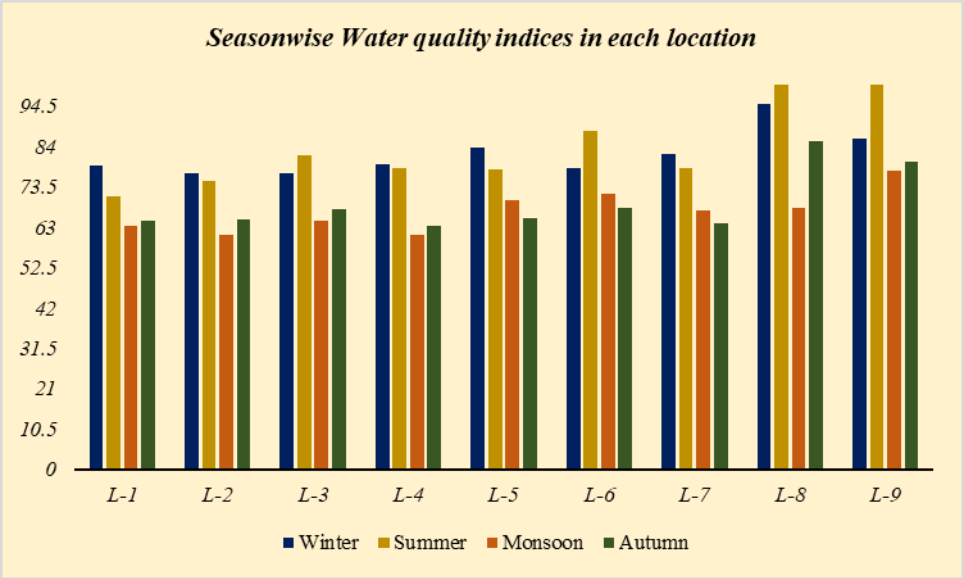


Figure 2: Analytical hierarchical process-based water quality index on Hugli River in nine locations for four seasons.

Table 10: Calculated weight of each parameter by analytical hierarchical process

Variables	Units	Weights
[DO]	mg/L	0.082
[EC]	µs/cm	0.143
[pH]		0.051
[Na^+]	mg/L	0.022
[K^+]	mg/L	0.016
[TUR]	NTU	0.041
[TA]	mg/L	0.045
[TDS]	mg/L	0.068
[COD]	mg/L	0.304
[BOD]	mg/L	0.229
∑Wi		1.001

Table 11: AHP based water quality index of nine selected locations in four seasons

Locations	Winter	Summer	Monsoon	Autumn
L-1	79.23	71	63.36	64.84
L-2	77.25	75.09	61.16	65.07
L-3	77.23	81.71	64.74	67.89
L-4	79.41	78.51	60.96	63.53
L-5	83.93	78.07	70.25	65.47
L-6	78.55	88.34	71.74	68.25
L-7	82.18	78.35	67.5	64.21
L-8	95.21	106.31	68.14	85.43
L-9	86.16	105.1	77.78	80.23

Obtained WQIs of nine locations in four seasons were classified using the water quality scale (Table 12). Table 11 represented WQI of winter, summer, monsoon and autumn of nine locations with a graphical representation in Fig-2. In monsoon and autumn WQI showed better results compared to summer and winter though all the values fall in the same range. WQI in monsoon ranged between 60.96 to 77.78. WQI of location 9 constantly showed poor results in every seasons. This region is associated with farming and agriculture activities compared to other locations that cause subsequent pollution to the river water. The highest value of WQI (>100) was recorded in location 8 in summer, poor water quality in monsoon and even very poor in autumn and winter according to scale. The lowest WQI as per scale 51 to 75 was documented in location 4 in monsoon. This place is moderately populated and has small scale industries. Water quality in this region could achieve better quality after proper treatment for domestic and industrial uses. From the overall water quality index calculation, it could be stated that water quality of the lower stretch of Ganga river experiences numerous threats to maintain its characteristics throughout the year as it is vulnerable to pollution possibilities. In monsoon and in autumn where water level and volume of water rises a bit the parameters get diluted and become comparatively less severe than that of dry seasons.

Table 12: Scale of water quality index

Range	Quality of Water
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unsuitable to any kind of water use without proper treatment

Using AHP as a calculator for water quality index helped to evaluate quality condition of the river considering different purpose of water uses in an integrated way. Similar pattern of water quality index of this stretch could be seen from Das 2021 that was conducted through a very small stretch.

4. Conclusion

The current study approaches to achieve an Analytical hierarchical process-based water quality index evaluation for overall knowledge on spatial and seasonal changes of water quality of the lower stretch of river Ganga. Nine locations along the stretch and ten quality parameters were chosen to analyze WQI in four different seasons. Among the values of water quality indices, it could be seen that condition of river water is better in monsoon and in autumn compared to summer and winter. In the dry seasons the quality of river degrades and that could impose challenges on water treatment plants while treating the river water to make it consumable. AHP adequately achieved the primary aim of the study to determine WQI minimizing the subjectivity of water use and complexity in water quality index calculation. The study suggests that decision making tools can be adopted for water

quality studies and evaluation of seasonal and spatial changes of WQI as it simplifies the calculation process while considering vast number of datasets. However, Overall water quality of a large river is dependent on several aspects. Categorization of different fields in water quality index calculation, identification of the most affecting parameters, application of appropriate tools and detailed quantitative and qualitative analysis may produce better results in the future.

References

[1] Akhtar, N., Ishak, M. I. S., Ahmad, M. I., Umar, K., MdYusuff, M. S., Anees, M. T., ... & Ali Almanasir, Y. K. (2021). Modification of the Water Quality Index (WQI) Process for Simple Calculation Using the Multi-Criteria Decision-Making (MCDM) Method: A Review. Water, 13(7), 905. https://doi.org/10.3390/w13070905.

[2] Baghapour, M. A., Shooshtarian, M. R., &Zarghami, M. (2020). Process mining approach of a new water quality index for long-term assessment under uncertainty using consensus-based fuzzy decision support system. Water Resources Management, 34(3), 1155-1172. https://doi.org/10.1007/s11269-020-02489-5.

[3] Bagla, P., Kumar, K., Sharma, N., & Sharma, R. (2021). Multivariate Analysis of Water Quality of Ganga River. Journal of the Institution of Engineers (India): Series B, 1-11. https://doi.org/10.1007/s40031-021-00555-z.

[4] Benedini M., Tsakiris G. (2013) Water Quality in the Context of Water Resources Management. In: Water Quality Modelling for Rivers and Streams. Water Science and Technology Library, vol 70. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-5509-3_1 .

[5] Bhat, S. A., Rather, S. A., & Pandit, A. K. (2001). Impact of effluent from Sheri-Kashmir institute of medical sciences (SKIMS), Soura on Anchar Lake. J Res Dev, 1, 30-37.

[6] Bora, M., & Goswami, D. C. (2017). Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India. Applied Water Science, 7(6), 3125-3135.

[7] Chakraborty, P., Khuman, S. N., Selvaraj, S., Sampath, S., Devi, N. L., Bang, J. J., &Katsoyiannis, A. (2016). Polychlorinated biphenyls and organochlorine pesticides in River Brahmaputra from the outer Himalayan Range and River Hooghly emptying into the Bay of Bengal: Occurrence, sources and ecotoxicological risk assessment. Environmental pollution, 219, 998-1006. https://doi.org/10.1016/j.envpol.2016.06.067

[8] Das, S., & Sarkar, R. (2021). Monitoring and evaluating the spatiotemporal variations of the water quality of a stretch of the Bhagirathi-Hugli River, West Bengal, India, using geospatial technology and integrated statistical methods. Environmental Science and Pollution Research, 28(13), 15853-15869. https://doi.org/10.1007/s11356-020-11655-6

[9] De Castro-Pardo, M., FernándezMartínez, P., Pérez Zabaleta, A., &Azevedo, J. C. (2021). Dealing with Water Conflicts: A Comprehensive Review of MCDM Approaches to Manage Freshwater Ecosystem Services. Land, 10(5), 469. https://doi.org/10.3390/land10050469

[10] Dutta, S., Dwivedi, A., & Kumar, M. S. (2018). Use of water quality index and multivariate statistical techniques for the assessment of spatial variations in water quality of a small river. Environmental monitoring and assessment, 190(12), 1-17. https://doi.org/10.1007/s10661-018-7100-x

[11] Duttagupta, S., Mukherjee, A., Das, K., Dutta, A., Bhattacharya, A., & Bhattacharya, J. (2020). Groundwater vulnerability to pesticide pollution assessment in the alluvial aquifer of Western Bengal basin, India using overlay and index method. Geochemistry, 80(4), 125601. https://doi.org/10.1016/j.chemer.2020.125601

[12] Duttagupta, S., Mukherjee, A., Bhattacharya, A., & Bhattacharya, J. (2020). Wide exposure of persistent organic pollutants (PoPs) in natural waters and sediments of the densely populated Western Bengal basin, India. Science of the Total Environment, 717, 137187. https://doi.org/10.1016/j.scitotenv.2020.137187

[13] Elkiran, G., Nourani, V., & Abba, S. I. (2019). Multi-step ahead modelling of river water quality parameters using ensemble artificial intelligence-based approach. Journal of Hydrology, 577, 123962. https://doi.org/10.1016/j.jhydrol.2019.123962

[14] Ghosh, S., Majumder, S., &Roychowdhury, T. (2019). Assessment of the effect of urban pollution on surface water-groundwater system of Adi Ganga, a historical outlet of river Ganga. Chemosphere, 237, 124507. https://doi.org/10.1016/j.chemosphere.2019.124507.

[15] Gorantla, S. S., & Kumar, G. P. (2020). Spatial distribution of groundwater quality indices using decision support system in Cheyyeru Watershed, YSR District, India. Spatial Information Research, 1-11. https://doi.org/10.1007/s41324-020-00355-5

[16] Gorenflo, L. J., & Warner, D. B. (2016). Integrating biodiversity conservation and water development: in search of long-term solutions. Wiley Interdisciplinary Reviews: Water, 3(3), 301-311. https://doi.org/10.1002/wat2.1142

[17] Gupta, S. (2022). AHP-based multi-criteria decision-making for forest sustainability of lower Himalayan foothills in northern circle, India—a case study. Environmental Monitoring and Assessment, 194(12), 1-11. https://doi.org/10.1007/s10661-022-10510-0

[18] Gupta, S., Mahato, A., Roy, P., Datta, J. K., & Saha, R. N. (2008). Geochemistry of groundwater, Burdwan District, West Bengal, India. Environmental Geology, 53(6), 1271-1282.

[19] 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

[20] Khuman, S. N., & Chakraborty, P. (2019). Air-water exchange of pesticidal persistent organic pollutants in the lower stretch of the transboundary river Ganga, India. Chemosphere, 233, 966-974. https://doi.org/10.1016/j.chemosphere.2019.05.223

[21] Khuman, S. N., Bharat, G., & Chakraborty, P. (2020). Spatial distribution and sources of pesticidal persistent organic pollutants in the Hooghly riverine sediment. Environmental Science and Pollution Research, 27(4), 4137-4147. https://doi.org/10.1007/s11356-019-06973-3

[22] Ma, Z., Song, X., Wan, R., & Gao, L. (2013). A modified water quality index for intensive shrimp ponds of Litopenaeusvannamei. Ecological Indicators, 24, 287-293. https://doi.org/10.1016/j.ecolind.2012.06.024

[23] Matta, G., Nayak, A., Kumar, A., & Kumar, P. (2020). Water quality assessment using NSFWQI, OIP and multivariate techniques of Ganga River system, Uttarakhand, India. Applied Water Science, 10(9), 1-12. https://doi.org/10.1007/s13201-020-01288-y

[24] Naresh C, G. H. O. S. E., &Dipankar, S. A. H. A. (2009). Synthetic detergents (surfactants) and organochlorine pesticide signatures in surface water and groundwater of greater Kolkata, India. Journal of Water Resource and Protection, 2009. 10.4236/jwarp.2009.14036

[25] Naubi, I., Zardari, N. H., Shirazi, S. M., Ibrahim, N. F. B., & Baloo, L. (2016). Effectiveness of Water Quality Index for Monitoring Malaysian River Water Quality. Polish Journal of Environmental Studies, 25(1).

[26] Othman, F., ME, A. E., & Mohamed, I. (2012). Trend analysis of a tropical urban river water quality in Malaysia. Journal of Environmental Monitoring, 14(12), 3164-3173. 10.1039/C2EM30676J

[27] Pagano, A., Giordano, R., &Vurro, M. (2021). A Decision Support System Based on AHP for Ranking Strategies to Manage Emergencies on Drinking Water Supply Systems. Water Resources Management, 35(2), 613-628. https://doi.org/10.1007/s11269-020-02741-y

[28] Paredes-Arquiola, J., Andreu-Álvarez, J., Martín-Monerris, M., & Solera, A. (2010). Water quantity and quality models applied to the Jucar River Basin, Spain. Water Resources Management, 24(11), 2759-2779. https://doi.org/10.1007/s11269-010-9578-z

[29] Panigrahi, A. K., &Pattnaik, S. (2021, March). Studies to Estimate the Pollution Load of Some South Bengal Rivers and Its Impacts: A Survey. In Proceedings of the Zoological Society (Vol. 74, No. 1, pp. 83-90). Springer India. https://doi.org/10.1007/s12595-020-00355-1

[30] Parmar, K. S., & Bhardwaj, R. (2015). Statistical, time series, and fractal analysis of full stretch of river Yamuna (India) for water quality management. Environmental Science and Pollution Research, 22(1), 397-414. https://doi.org/10.1007/s11356-014-3346-1

[31] Paul, D., & Sinha, S. N. (2013). Assessment of various heavy metals in surface water of polluted sites in the lower stretch of river Ganga, West Bengal: a study for ecological impact. Discovery Nature, 6(14), 8-13. Doi: 10.1.1.642.7015

[32] Paul, D. (2017). Research on heavy metal pollution of river Ganga: A review. Annals of Agrarian Science, 15(2), 278-286. https://doi.org/10.1016/j.aasci.2017.04.001

[33] Pourmand, E., Mahjouri, N., Hosseini, M., &Nik-Hemmat, F. (2020). A Multi-Criteria Group Decision Making Methodology Using Interval Type-2 Fuzzy Sets: Application to Water Resources Management. Water Resources Management, 34(13), 4067-4092. https://doi.org/10.1007/s11269-020-02657-7

[34] Rashidi, F., & Sharifian, S. (2022). A comparative analysis of three multi-criteria decision-making methods for land suitability assessment. Environmental Monitoring and Assessment, 194(9), 1-15. https://doi.org/10.1007/s10661-022-10259-6

[35] Ravikumar, P., Mehmood, M. A., & Somashekar, R. K. (2013). Water quality index to determine the surface water quality of Sankey Tank and Mallathahalli Lake, Bangalore Urban District, Karnataka, India. Applied water science, 3(1), 247-261.

[36] Rosińska, J., Rybak, M., Kowalczewska-Madura, K. et al. (2022) Spatio-temporal variations in water quality of a river–lake system during restoration treatments. Environ Monit Assess 194, 636. https://doi.org/10.1007/s10661-022-10307-1

[37] Salehi, S., JaliliGhazizadeh, M., &Tabesh, M. (2018). A comprehensive criteria-based multi-attribute decision-making model for rehabilitation of water distribution systems. Structure and Infrastructure Engineering, 14(6), 743-765. https://doi.org/10.1080/15732479.2017.1359633

[38] Sarkar, K., & Majumder, M. (2020). Application of AHP-based water quality index for quality monitoring of peri-urban watershed. Environment, Development and Sustainability, 1-19. https://doi.org/10.1007/s10668-020-00651-y

[39] Sharma, D., &Kansal, A. (2011). Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000–2009). Applied water science, 1(3), 147-157. https://doi.org/10.1007/s13201-011-0011-4

[40] Sharma, B. M., Bharat, G. K., Tayal, S., Larssen, T., Bečanová, J., Karásková, P., ... &Nizzetto, L. (2016). Perfluoroalkyl substances (PFAS) in river and ground/drinking water of the Ganges River basin: emissions and implications for human exposure. Environmental pollution, 208, 704-713. https://doi.org/10.1016/j.envpol.2015.10.050

[41] Sharma, B. M., Bečanová, J., Scheringer, M., Sharma, A., Bharat, G. K., Whitehead, P. G., ... &Nizzetto, L. (2019). Health and ecological risk assessment of emerging contaminants (pharmaceuticals, personal care products, and artificial sweeteners) in surface and groundwater (drinking water) in the Ganges River Basin, India. Science of the Total Environment, 646, 1459-1467. https://doi.org/10.1016/j.scitotenv.2018.07.235

[42] Singh, K. P., Malik, A., Mohan, D., & Sinha, S. (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—a case study. Water research, 38(18), 3980-3992. https://doi.org/10.1016/j.watres.2004.06.011

[43] Singh, S., & Hussian, A. (2016). Water quality index development for groundwater quality assessment of Greater Noida sub-basin, Uttar Pradesh, India. Cogent Engineering, 3(1), 1177155.

[44] Singh, S., Ghosh, N. C., Gurjar, S., Krishan, G., Kumar, S., &Berwal, P. (2018). Index-based assessment of suitability of water quality for irrigation purpose under Indian conditions. Environmental monitoring and

assessment, 190(1), 29. https://doi.org/10.1007/s10661-017-6407-3

[45] Subin, M. P., & Husna, A. H. (2013). An assessment on the impact of waste discharge on water quality of Priyar River lets in certain selected sites in the northern part of Ernakulum District in Kerala, India. International Research Journal of Environment Sciences, 2(6), 76-84.

[46] Tsakiris, George & ALEXAKIS, Dimitris. (2012). Water quality models: An overview. European Water. 37. 33-46.

[47] Varol, M. (2020). Spatio-temporal changes in surface water quality and sediment phosphorus content of a large reservoir in Turkey. Environmental Pollution, 259, 113860. https://doi.org/10.1016/j.envpol.2019.113860

[48] Vijay, S., &Kamaraj, K. (2021). Prediction of Water Quality Index in Drinking Water Distribution System Using Activation Functions Based Ann. Water Resources Management, 35(2), 535-553. https://doi.org/10.1007/s11269-020-02729-8

[49] Walker, D., Jakovljević, D., Savić, D., &Radovanović, M. (2015). Multi-criterion water quality analysis of the Danube River in Serbia: A visualisation approach. Water research, 79, 158-172. https://doi.org/10.1016/j.watres.2015.03.020

[50] Wu, Z., Wang, X., Chen, Y., Cai, Y., & Deng, J. (2018). Assessing river water quality using water quality index in Lake Taihu Basin, China. Science of the Total Environment, 612, 914-922. https://doi.org/10.1016/j.scitotenv.2017.08.293

[51] Xiao, J., Wang, L., Deng, L., & Jin, Z. (2019). Characteristics, sources, water quality and health risk assessment of trace elements in river water and well water in the Chinese Loess Plateau. Science of the Total Environment, 650, 2004-2012.

[52] Zeinalzadeh, K., &Rezaei, E. (2017). Determining spatial and temporal changes of surface water quality using principal component analysis. Journal of Hydrology: Regional Studies, 13, 1-10. https://doi.org/10.1016/j.ejrh.2017.07.002

[53] http://www.cpcbenvis.nic.in/waterpollution/2020/WQuality_River-Data-2020.pdf

[54] https://mausam.imd.gov.in