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Seasonal Variation of Water Quality Index at Raw Water Collection Point of Saidabad Water Treatment Plant and Its Impact On Plant Operations

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Abstract
This study was conducted to determine the seasonal variations of the water quality index at the raw water collection point of the Saidabad Water Treatment Plant (SWTP) and its impact on plant operations. Firstly, monthly water quality and plant operational data were collected from the SWTP and the Department of Environment (DoE). Commonly used water quality parameters i.e., Chemical Oxygen demand (COD), Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Alkalinity, Ammonia, Total Dissolved Solid (TDS), pH, Electrical Conductivity (EC), Temperature, and Fecal Coliform data have been collected and used for the study. Variations of water quality parameters and Water Quality Index (WQI) were analyzed for the raw water collection point of SWTP and the Demraghat point (Upstream of the raw water collection point of SWTP) of the Shitalakhya River. Widely used WQI methods (WAWQI, CCMEWQI, and NSFWQI Methods) were used for the determination of the WQI at the raw water collection point of the SWTP and Demraghat from the year 2017 to 2021. The ranges of WQI values were found between 49 to 224, and 42 to 90 by using WAWQI, and CCMEWQI methods, respectively at Demraghat point in pre-monsoon, monsoon, and post-monsoon periods from the year 2017 to 2021. It was found that WQI values were very high at the raw water collection point of SWTP using the WAWQI method compared with the Demraghat point of the Shitalakhya River due to higher concentration of Ammonia and lower DO values. DO level and Ammonia concentration were found exceeded the permissible limits set by DoE for most cases from the year 2017 to 2021. Overall, the condition of the waterbody of the Shitalakhya River was found very poor from the year 2017 to 2021.

1. Introduction

Increased pollution and adverse effects of climate change have led to the deterioration of surface water quality worldwide (Zhang et al., 2017). Notable causes of the changes in water availability and water quality include urbanization and industrialization (Hasan et al., 2019). The water quality of a source can be assessed using physical, chemical and biological parameters, which can be hazardous to human health if such parameters were to exceed the standard limits. Quantifying the water quality parameters with reference to the Water Quality Index (WQI) is a standard approach for assessing the suitability of water resources for aquatic and human consumption (Horton, 1965). Saidabad Water Treatment Plant (SWTP) is the major surface water treatment plant in Dhaka, which pumps raw water from the Shitalakhya River at Sarulia Pumping Station which is why it is important to determine the WQI value at the raw water collection point at the region.

Major industrial developments have been established on the banks of the Shitalakhya River, which also assimilates a major portion of domestic and industrial wastes from the metropolitan and Narayanganj City. The overall water quality of this river is crucial for ecological and commercial factors, as well as for the supply of safe drinking water since the largest surface water treatment plant in Bangladesh collects raw water from the Shitalakhya River.

Razee et al. (2019) studied the concentrations of Cu, Zn, Fe, Mn, Ni, and Cr in sediments of the Shitalakhya River in the Polash-Ghorashal area of Narsingdi District, Bangladesh. They collected 36 soil samples from nine sampling points at different locations in the Shitalakhya River to determine the concentration of Cu, Zn, Fe, Mn, Ni, Cr, and the samples were analyzed by atomic absorption spectrophotometer (AAS). The obtained results were compared with national and international standards. The levels of heavy metal concentrations in sediments were found to decrease in the order of Fe > Mn > Zn > Ni > Cu > Cr, respectively. The heavy metal concentration in the sediment of Shitalakhya was below the recommended safe limits of heavy metals by WHO, FAO, and other international standards for the studied area. The contamination factor (CF) of Zn and Cu at a sampling point shows higher (> 1) values due to the influence of external discrete sources (e.g., wastage catalysts of ZnO and CuO).

Alam et al. (2020) studied the water quality of the Shitalakhya River. The study was conducted to assess the surface water quality of the Shitalakhya River from January 2017 to December 2018. Temperature, pH, EC, TDS, TSS, BOD5, Alkalinity, Total Hardness, Calcium Hardness, Magnesium Hardness, Chloride, Dissolved Silica, Total Iron concentration, and Turbidity parameters were considered in that study. Results obtained from the study show that most of the parameters were within the permissible limit except Turbidity, Total Suspended Solid (TSS), Dissolved Silica (SiO2), and BOD5. They suggested that the use of river water can pose serious problems to human health and aquatic ecosystem via the biological food chain. This research also suggested a special preference for better management of the river water to protect the health of the aquatic ecosystem of the river.

Rahman et al. (2020) studied the hydrological and morphological characteristics of the Shitalakhya River and the quality of water and its effects. They collected and analyzed the hydrological data and showed a declining trend in the maximum annual discharge and water level. They also reported that the variations of cross-sectional area, top width, average width, and minimum bed level are not changing rapidly with time. They also conducted a statistical analysis of water quality parameters such as Dissolved Oxygen, Salinity, pH, Total Dissolved Solids, Electrical Conductivity, and Concentration of Iron from the year 2012 to 2017 using the data at Narayanganj station.

Pia et al. (2020) conducted a study on the chemical properties of the Shitalakhya River for water bodies based on its chemical parameters such as Total Suspended Solids, pH, Electric Conductivity, Total Dissolved Solids, Dissolved Oxygen, Biological Oxygen Demand, Chemical Oxygen Demand, Total Nitrogen, Chlorine, Total Phosphorous, Sulfur, and Potassium.

Chowdhury et al. (2020) conducted a study and found that the water quality of the Shitalakhya River was poor near Haripur power station, Narayanganj, Bangladesh using data from the year 2013 to 2018. Three different methods were used in that study to evaluate the WQI: The WAWQI Method, the CCMEWQI Method, and the NSFWQI Method. They used some essential parameters i.e., pH, total dissolved solids, dissolves oxygen, biochemical oxygen demand, electrical conductivity, chloride, turbidity, color, Silica, Iron, and Phosphate for calculating the WQI. However, they did not report any analysis for water treatment costs and did not consider the influence on the Sarulia water treatment plan due to the deterioration of WQI.

It has been identified from literature review that the study of WQI values estimation has not been conducted yet near the raw water collection point of SWTP of the Shitalakhya River. Thus, the specific objectives of this study were to: (1) determine the water quality index value at the raw water collection point of SWTP, (2) identify the variation of water quality and WQI in the dry and monsoon period, (3) determine the impact of WQI value on the plant operation during dry and monsoon period. The study will be conducted to assess the quality of physical and biological health of the raw water at the pumping station of SWTP using the different methods of WQI as well as identifying the seasonal variability and assessing the overall plant operational cost based on the WQI values.

2. Study Area

Water quality parameters data from two different locations have been collected, namely, Demraghat and Sarulia (at the raw water collection point of SWTP) shown in Figure 1. The Department of Environment (DoE) measures water quality data at the Demraghat station of the Shitalakhya River. The raw water collection point of SWTP at Sarulia also performs the tests of different water quality parameters to quantify the quality of water throughout the year by DWASA. Different industries and power plants have been found to be situated on the bank of the Shitalakhya River, disposing of water into the river without pre-treatment. The river receives effluents from five jute mills, two fertilizer factories, one sugar mill, one cement industry, one textile industry, one dairy plant, two food processing industries, one hardboard mill, one paper mill and one joint thermal power plant within 13 km range of the flowing Ghorashal region. In addition, numerous smaller industries are situated on the bank of the river which use water from the Shitalakhya River as the main source for different operations including cooling, process, steam generation, safety and miscellaneous purposes due to which the water quality of this portion of the river is deteriorating perilously.

The Shitalakhya River has a length of about 108 km, originating from the Old Brahmaputra and the lower Banar River, meeting with the Balu River at Rupganj and falling into the Dhaleshwari River at Kalagachia. The Shitalakhya runs nearly analogous to the Brahmaputra and after passing by Narayanganj joins the Dhaleswari in Munsiganj. The minimum and maximum widths of the Shitalakhya River are 151m and 392m respectively with the average width of the river being 228m. Discharge of this river varies from 74 to 1375 cumecs round the year in different locations. Currently, several heavy industries including the Adamjee jute mills, stand on the banks of the Shitalakhya with three thermal powerhouses located at Palash, north of Ghorashal and another at Siddhirganj also situated on the bank. Frequent launches move out along the river to different parts of Bangladesh. The river goes under tidal effect for about five months of the year but never overflows its banks. The river course of the Shitalakhya River is presented in Figure 2 on the next page.

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Figure 1: Study area map showing the location of water quality measuring stations

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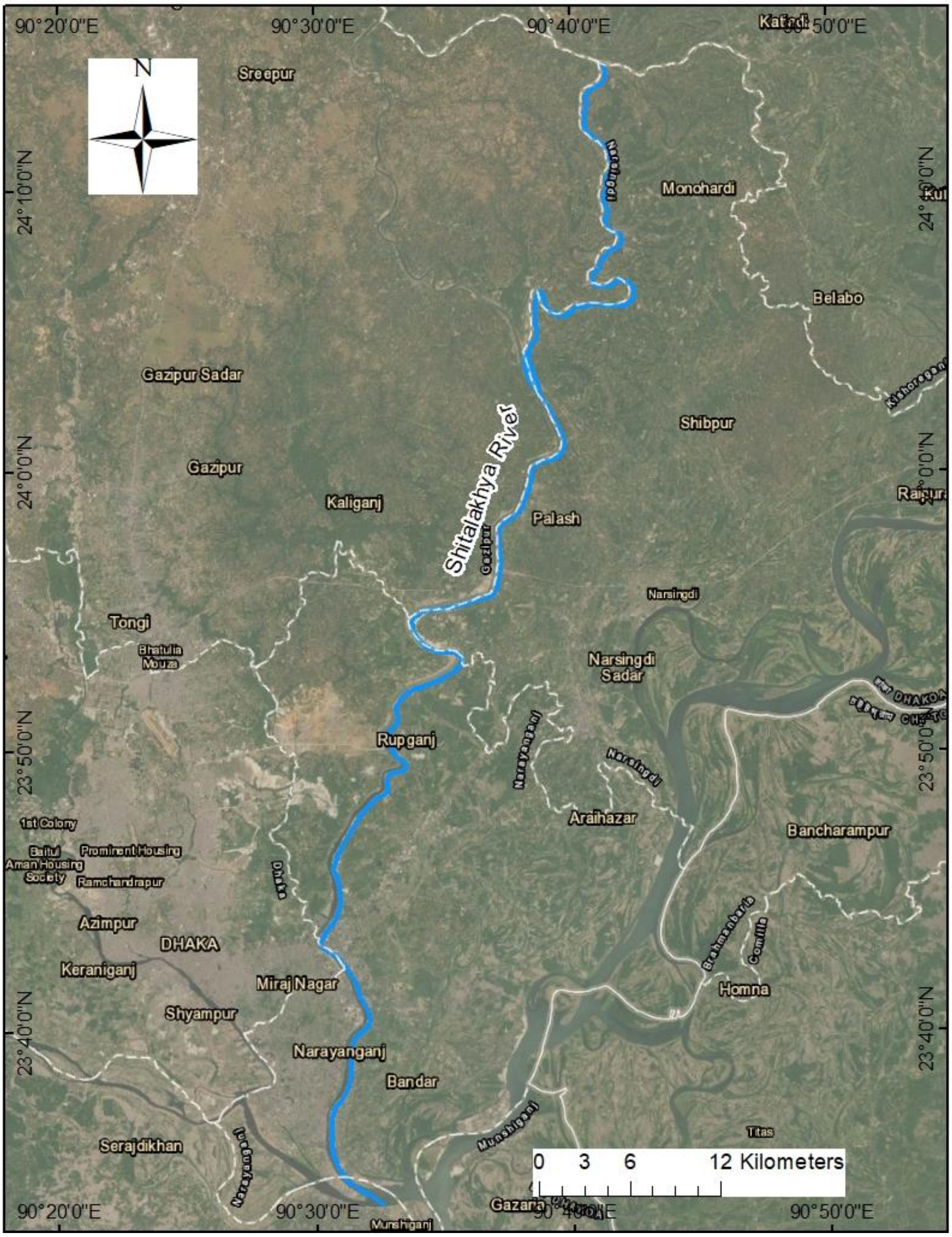

Figure 2: Course of Shitalakhya River

3. Methodology

WQI is a single value and effective tool for predicting the water quality of surface water. These values of WQI assist to find the seasonal and spatial variations of water quality of the Shitalakhya River. A schematic diagram of the methodology is given below:

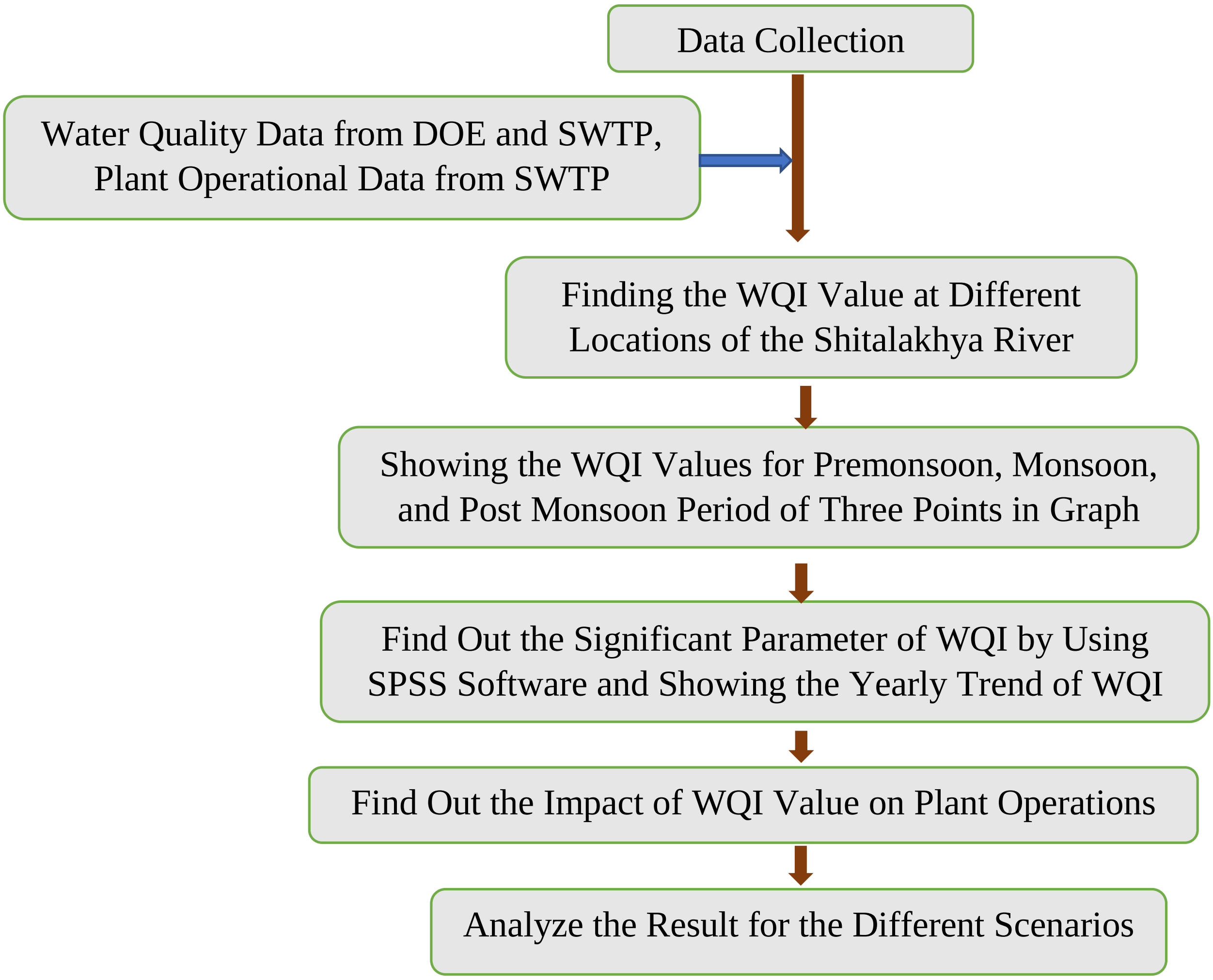

Figure 3: Schematic Diagram of Methodology

3.1 Equations for Different Methodology of WQI

WQI near the SWTP plant will be determined by the following three methods:

i. Weighted Arithmetic WQI Method:
The method has been widely used by various scientists and the calculation of WQI was made by using the following equation:
$WQI = \sum Q_i W_i / \sum W_i$ ……………………………………………………..…..1
The quality rating scale (Qi) for each parameter is calculated by using this expression:
$Q_i = 100[(V_i - V_o / S_i - V_o)]$……………………………2
where, V_i is the estimated concentration of ith parameter in the analyzed water, V_o is the ideal value of this parameter in pure water V_o= 0 (except pH =7.0 and DO = 14.6 mg/l), S_i is recommended standard value of the ith parameter. The unit weight (W_i) for each water quality parameter is

calculated by using the following formula:

$W_i = K / S_i$……………………………………………………………………..……3

Where, K = proportionality constant and can also be calculated by using the following equation:

$K = 1 / \sum(1/S_i)$…………………………………………………………………4

ii. National Sanitation Foundation Water Quality Index (NSF WQI):

The water quality data will be recorded and transferred to a weighting curve chart, where a numerical value of Q_i is obtained. The mathematical expression for NSF WQI is given by:

$\mathrm{WQI} = \sum_{i=1}^{n} Q_i W_i$…………………………………………………………………....5

Q_i = sub-index for i^{th} water quality parameter; W_i = weight associated with i^{th} water quality parameter; n = number of water quality parameters.

iii. Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI):

The calculation of index scores in the CCME WQI method will be obtained by using the following relation:

$$WQI = 100 - \frac{\sqrt{{F_1}^2 + {F_2}^2 + {F_3}^2}}{1.732}$$ ……………………………………………………….....…..6

Where Scope (F_1) = Number of variables, whose objectives are not met;

F_1= [No. of failed variables /Total no. of variables] *100…………………...……………7

Frequency (F_2) = Number of times by which the objectives are not met;

F_2 = [No. of failed tests/Total no. of tests] *100……………………………………………8

And, Amplitude (F_3)) = Amount by which the objectives are not met.

$$Excursion_i = [Failed\ test\ value_i\ / Objective_j] - 1$$ ………………………..……...…9

$$normalized\ sum\ of excursions,\ nse = \frac{\sum_{i=1}^{n} excursion_i}{No.of\ Tests}$$ …………..……………..……10

$$F_3 = [\mathrm{nse}/0.01\mathrm{nse} + 0.01]$$ ……………………………………………...…………11

3.2 Equations for Analyzing Correlation and Multiple Regression

Correlation analysis measures the association between two or more variables. Two variables are positively associated when large values of one variable tend to occur with large values of the other variables, and small values tend to occur together as well. Two variables are negatively associated when large values of one variable tend to occur with small values of the other variables and vice versa. Pearson correlation coefficient, denoted by r, measures the direction and strength of the linear relationship between two quantitative variables. It measured as:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}$$ ………………………………...……………………..….12

$$= \frac{\sum x_i y_i - n\,\overline{xy}}{\sqrt{(\sum(x_i^2 - n\bar{x}^2)(\sum y_i^2 - n\bar{y}^2)}}$$

where,

r = correlation coefficient

x_i = values of the x-variable in a sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

(i) The value of r always lies between -1 and +1.

(ii) -1 refers to the perfect negative linear relationship between the variables.

(ii) +1 refers to the perfect positive linear relationship between the variables.

Regression Analysis – Multiple Linear Regression

Multiple linear regression analysis is essentially similar to the simple linear model, with the exception that multiple independent variables are used in the model. The mathematical representation of multiple linear regression is:

$$\mathbf{Y = a + b}X_1 + \mathbf{c}X_2 + \mathbf{d}X_3 + \epsilon \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

where,

Y – Dependent variable
X_1, X_2, X_3 – Independent (explanatory) variables
a – Intercept
b, c, d – Slopes
ϵ – Residual (error)

Multiple linear regression follows the same conditions as the simple linear model. However, since there are several independent variables in multiple linear analyses, there is another mandatory condition for the model:

- **Non-collinearity:** Independent variables should show a minimum correlation with each other. If the independent variables are highly correlated with each other, it will be difficult to assess the true relationships between the dependent and independent variables.

3.3 Data Collection and Compilation

Data has been collected to find prevailing conditions; establish the comparison of WQI in pre-monsoon, monsoon, and post-monsoon periods in different locations of the Shitalakhya River, and effects of the operational cost of SWTP on the future demand for treated water. The list of data and their respective sources are presented in Table-1.

Table 1: List of data collected from different sources

Data Type	Period	Frequency	Source
Water Quality Data at Demraghat	2017 to 2021	Monthly Data	DoE
Water Quality Data at Raw Water Collection Point of SWTP	2017 to 2021	Monthly Average Data	SWTP
Plant Operational Cost	2017 to 2021	Monthly Data	SWTP
Water Level Data	2017 to 2021	Daily Data	BWDB

Water quality and plant operational data have been collected from 2017 to 2021 from the SWTP. Before 2017 the SWTP had not used data compilation software for the preservation of all data.

Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Ammonia, Alkalinity, Total Dissolved Solids (TDS), Turbidity, Electrical Conductivity (EC), pH, Temperature, and Fecal Coliform has been considered for estimating the WQI and WQ of Shitalakhya River.

WQI of the Shitalakhya River was determined at Demraghat point, the raw water collection point of SWTP by using the Canadian Council of Ministers of Environment Water Quality Index method (CCMEWQI), National Sanitation Foundation Water Quality Index method (NSFWQI), and Weighted Arithmetic Water Quality Index Method (WAWQI). Also, the calculated WQI near the Haripur power station, Narayanganj by Chowdhury et al. (2020) was used to analyze the spatial variation of WQI in the river.

A GIS Map has been developed for a better understanding of the intensity of WQI at different locations during different periods pre-monsoon, monsoon, and post-monsoon.

Values of water quality parameters in two locations of Shitalakhya River (Demraghat, and Raw Water Collection point of SWTP) have been compared with the permissible limit of the Environmental Quality Standard (EQS) of Bangladesh from the year 2017 to 2021. The physicochemical condition of the water bodies for two locations of Shitalakhya River has been determined in the period of pre-monsoon, monsoon, and post-monsoon. Maximum, minimum values, mean, and standard deviations of parameters have been determined in this study.

The impact of the water quality index in the different periods on plant operations has been shown in this study. The significant parameter has been determined for increasing the operational cost of SWTP. Periodical trend of the operational cost of SWTP has been shown in this study.

4. Results and Discussion

Selected water quality parameters were analyzed at the raw water collection point of SWTP and Demraghat point. Data of all selected parameters are divided into three periods' pre-monsoon, monsoon, and post-monsoon. Pre-monsoon, monsoon, and post-monsoon periods consist of February to May, June to September, and October to January, respectively as followed in SWTP. Environmental Quality Standard (EQS) for inland water was proposed by the DoE. It was gazette in 1997 by the Bangladesh government.

Table 2: Water Quality parameters at SWTP

Parameters	**Unit**	**Bangladesh Standard for Drinking Water (DoE)**	**WHO Standard for Drinking Water**	**Bangladesh Environmental Quality Standard for Inland Water**	**Min**	**Max**	**Mean**	**Standard Deviation**
COD	mg/l	4		200	10.67	49.50	25.95	15.67
DO	mg/l	6	6.5 - 8.00	≥5	0.65	4.00	2.11	1.17
Ammonia	PPM			≤5	0.53	12.65	4.80	4.41
Alkalinity	mg/l			150	52.67	268.50	146.17	74.66
TDS	mg/l	1000	300	2100	74.28	483.28	239.60	142.28
Turbidity	NTU	10	< 5		14.83	51.24	32.68	11.75
EC	µmhoms/cm			1200	154.60	795.76	443.86	230.14
pH	6.5-8.5	6.5-8.5	6.5-8.5	6-9	6.96	7.44	7.29	0.15
Temperature	°C	20-30		20-40	21.46	29.97	26.64	2.57
Fecal Coliform	CFU/100 mL	0	0	<5000	7867.99	124761.03	51711.56	43967.81

4.1 Water Quality Parameters at SWTP

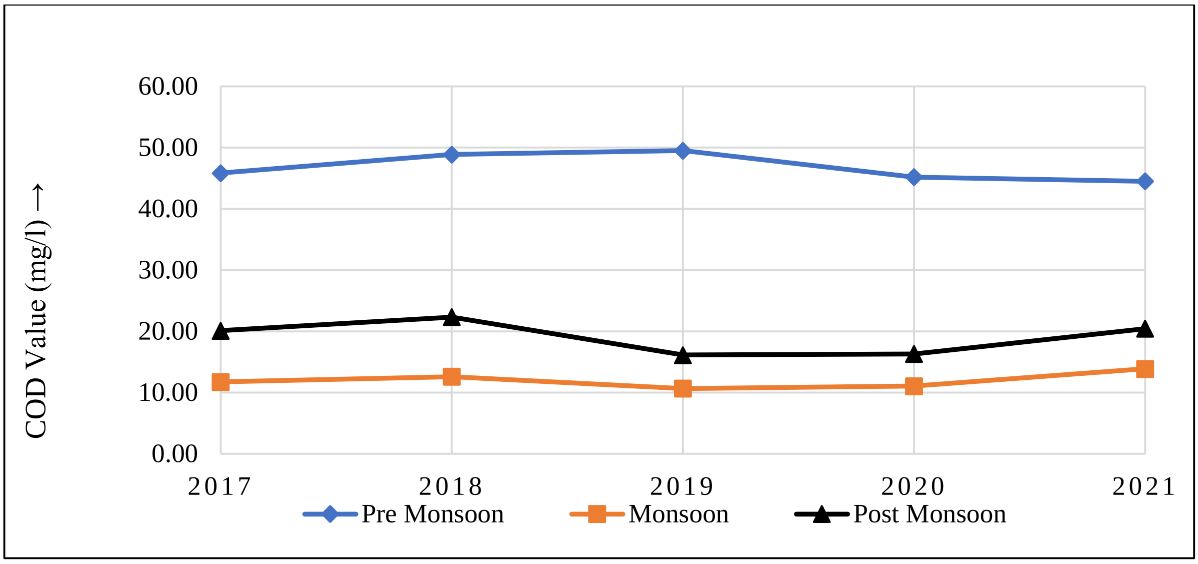

Figure 4: Seasonal variation of COD value from the year 2017 to 2021 at SWTP

The COD value varied from 44.50 mg/l to 49.50 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the COD value varied from 10.67 mg/l to 13.38 mg/l from the year 2017 to 2019. At the same time in the post-monsoon period, the COD value varied from 16.14 mg/l to 22.33 mg/l. The maximum (49.50 mg/l) and the minimum COD (10.67 mg/l) values were found in the pre-monsoon and post-monsoon periods, respectively within the year 2017 to 2021. Figure 4 shows the COD value was high in the pre-monsoon period from the year 2017 to 2021. The COD value was found within the EQS limit from the year 2017 to 2021.

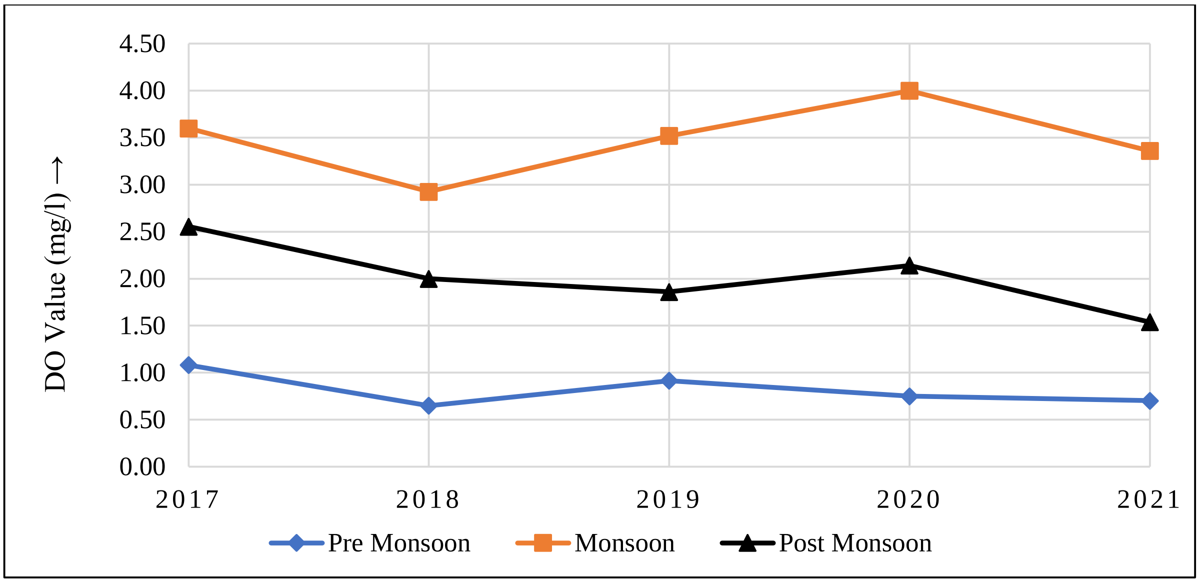

Figure 5: Seasonal variation of DO value from the year 2017 to 2021 at SWTP

The DO value of river water varied from 0.65 mg/l to 1.08 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the DO value varied from 2.93 mg/l to 4.00 mg/l from the year 2017 to 2021. At the same time in the post-monsoon period, the DO value varied from 1.54 mg/l to 2.56 mg/l. The maximum (4.00 mg/l) and the minimum DO (0.65 mg/l) values were in the monsoon and pre-monsoon periods respectively within the year 2017 to 2021. Figure 5 shows the DO value was better in the monsoon period from the year 2017 to 2021. Overall, DO values did not meet the EQS.

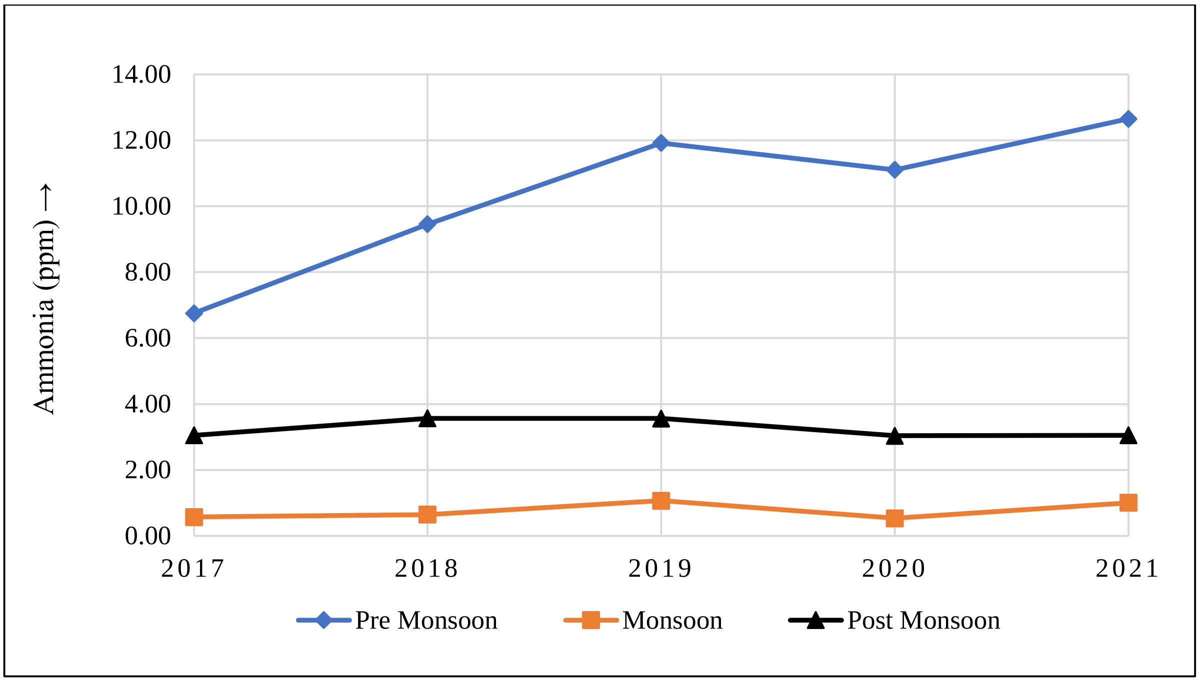

Figure 6: Seasonal variation of Ammonia value from the year 2017 to 2021at SWTP

The concentration of Ammonia in river water varied from 6.76 ppm to 12.65 ppm in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the Ammonia value varied from 0.57 ppm to 1.07 ppm from the year 2017 to 2021. At the same time in the post-monsoon period, the Ammonia value varied from 3.04 ppm to 3.57 ppm. The maximum (12.65 ppm) and the minimum Ammonia values (0.57 ppm) were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 6 shows the Ammonia concentration of river water was within the EQS limit in the monsoon and post-monsoon periods from the year 2017 to 2021.

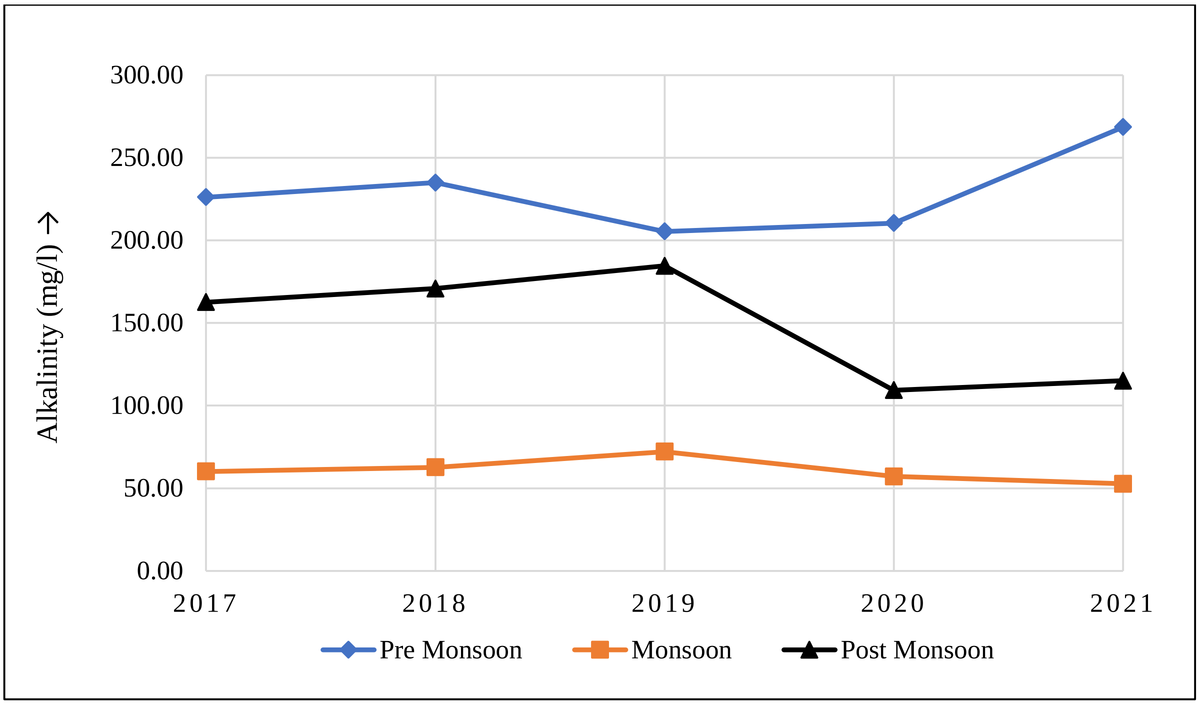

Figure 7: Seasonal variation of Alkalinity value from the year 2017 to 2021at SWTP

The Alkalinity in river water varied from 205.34 mg/l to 268.50 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the Alkalinity value varied from 52.67 mg/l to 72.17 mg/l from the year 2017 to 2021. At the same time in the post-monsoon period, the Alkalinity value varied from 109.33 mg/l to 184.56 mg/l. The maximum (268.5 mg/l) and the minimum Alkalinity values (52.67 mg/l) were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 7 shows that Alkalinity was within the EQS limit in the monsoon period from the year 2017 to 2021.

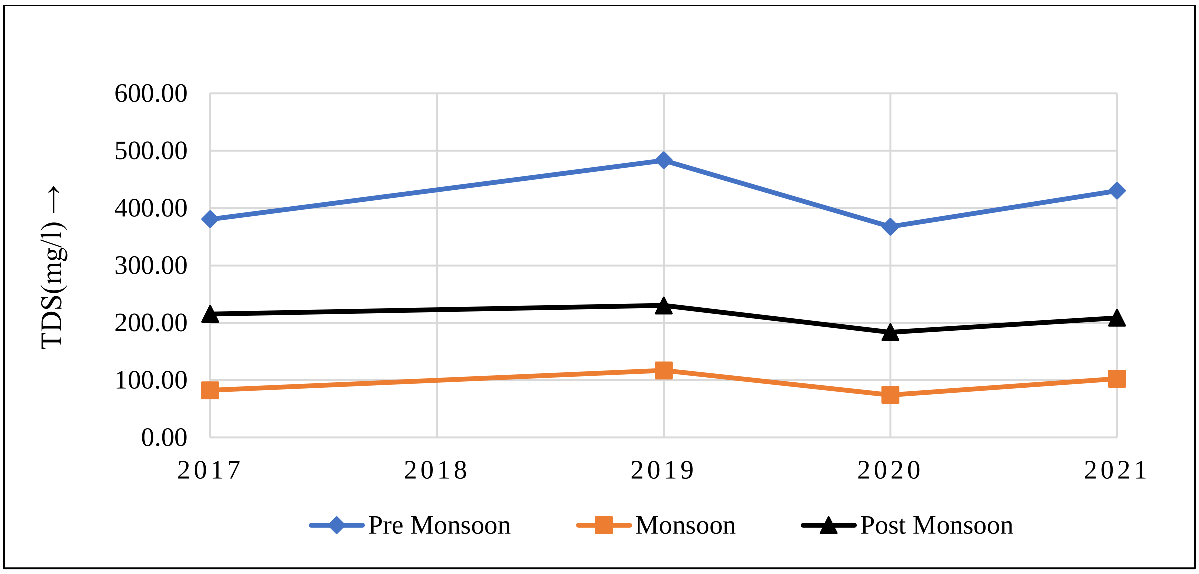

Figure 8: Seasonal variation of TDS value from the year 2017 to 2021at SWTP

The TDS in river water varied from 367.53 mg/l to 483.28 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the TDS value varied from 72.48 mg/l to 116.93 mg/l from the year

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2017 to 2021. At the same time in the post-monsoon period, the TDS value varied from 183.63 mg/l to 230.18 mg/l. The maximum (483.28 mg/l) and the minimum (72.48 mg/l) TDS values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. All values of TDS were within the EQS limit in all three periods from the year 2017 to 2021.

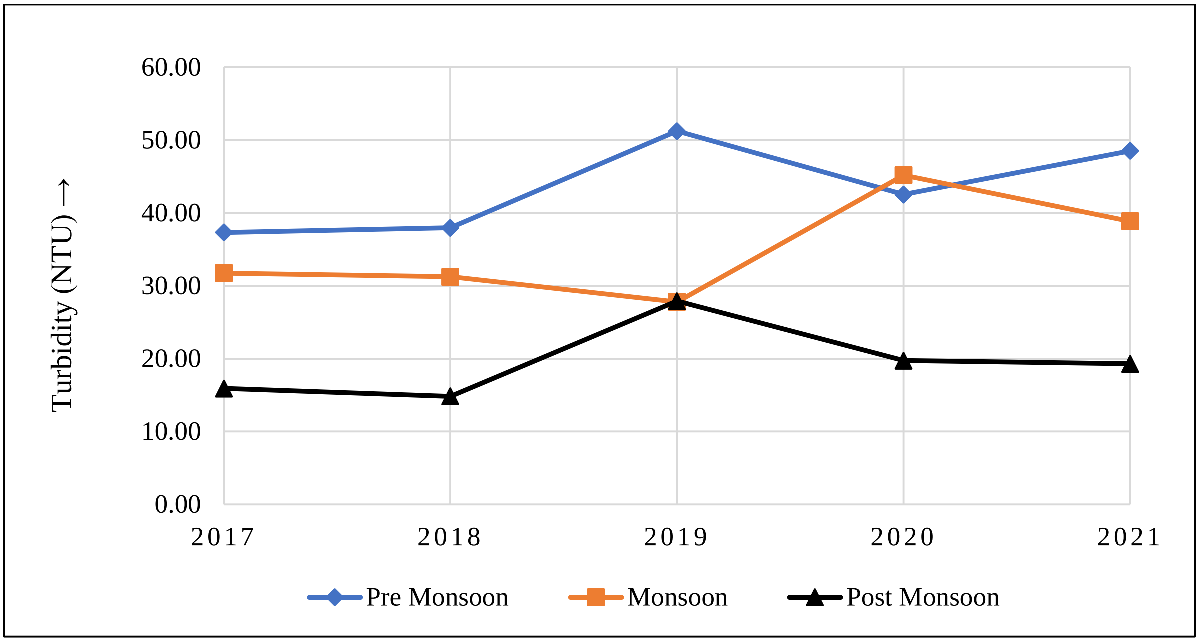

Figure 9: Seasonal variation of Turbidity value from the year 2017 to 2021at SWTP

The Turbidity in river water varied from 37.33 NTU to 48.54 NTU in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the Turbidity value varied from 27.79 NTU to 45.20 NTU from the year 2017 to 2021. At the same time in the post-monsoon period, the Turbidity value varied from 14.83 NTU to 27.91 NTU. The maximum (48.54 NTU) and the minimum (14.83 NTU) Turbidity values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 9 shows that Turbidity was higher in the premonsoon period. All values of Turbidity were found not within the EQS limit in all three periods from the year 2017 to 2021.

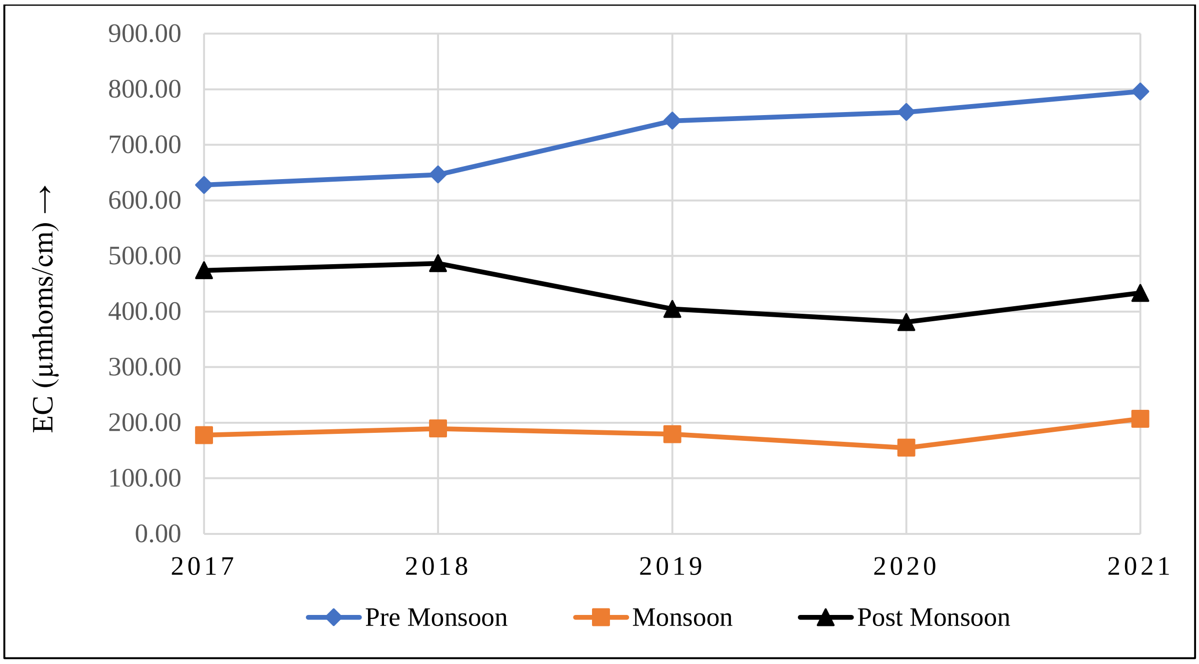

Figure 10: Seasonal variation of EC value from the year 2017 to 2021at SWTP

The EC in river water varied from 627.70 µmhoms/cm to 795.76 µmhoms/cm in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the EC value varied from 154.60 µmhoms/cm to 206.70 µmhoms/cm from the year 2017 to 2021. At the same time in the post-monsoon period, the EC value varied from 380.80 µmhoms/cm to 486.78 µmhoms/cm. The maximum (795.76 µmhoms/cm) and the minimum (154.6 µmhoms/cm) EC values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 10 shows that EC was higher in the pre-monsoon period. All values of EC were found within the EQS limit in all three periods from the year 2017 to 2021.

The pH in river water varied from 7.29 to 7.44 in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the pH value varied from 6.96 to 7.31 from the year 2017 to 2021. At the same time in the post-monsoon period, the pH value varied from 7.17 to 7.44. The maximum (7.44) and the minimum (6.96) pH values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 11 shows that pH was higher in the pre-monsoon period but all values of pH were found within the EQS limit in three periods from the year 2017 to 2021.

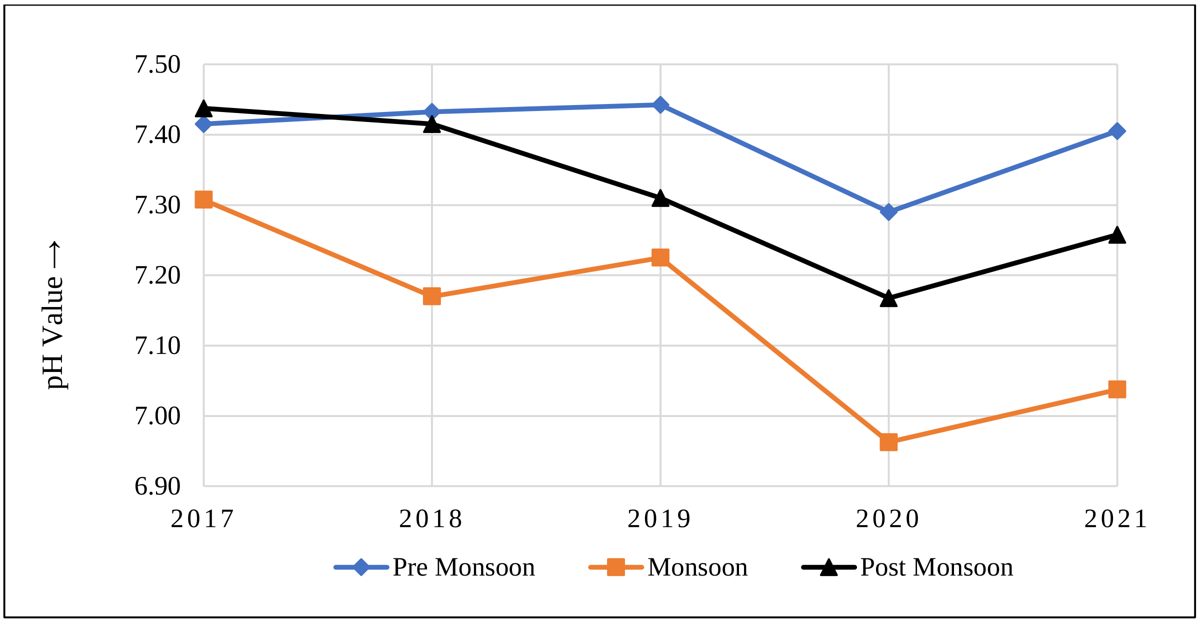

Figure 11: Seasonal variation of pH value from the year 2017 to 2021 at SWTP

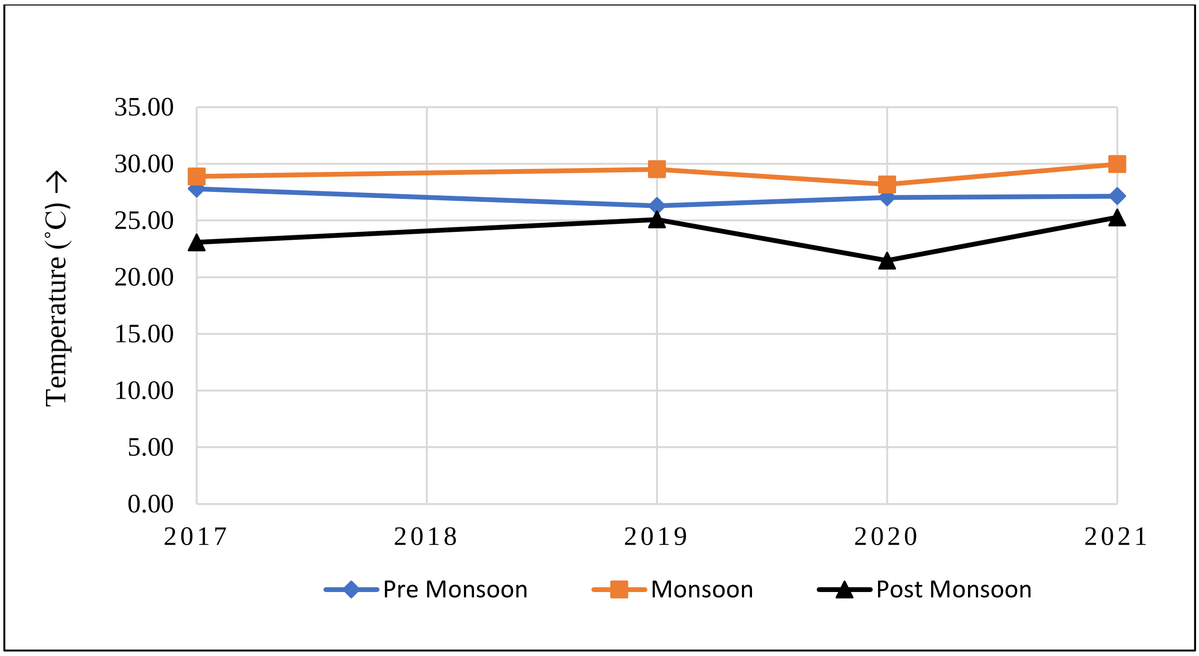

Figure 12: Seasonal variation of Temperature value from the year 2017 to 2021 at SWTP

The Temperature in river water varied from 26.29˚C to 27.80˚C in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the Temperature value varied from 28.88˚C to 29.97˚C from the year 2017 to 2021. At the same time in the post-monsoon period, the temperature value varied from 21.46˚C to 25.27˚C. The maximum (29.97˚C) and the minimum (21.46˚C) Temperature values were found in the monsoon and post-monsoon periods respectively within the year 2017 to 2021. Figure 12 shows that temperature was higher in the monsoon period. All values of temperature were found within the EQS limit in all three periods from the year 2017 to 2021.

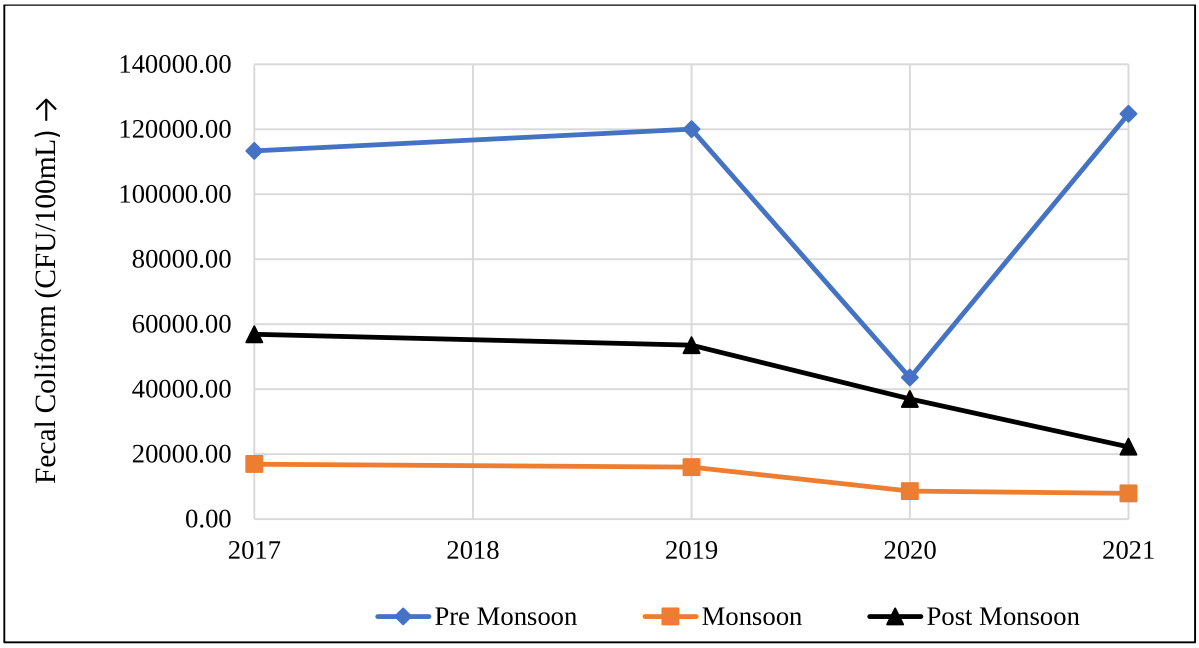

Figure 13: Seasonal variation of FC value from the year 2017 to 2021 at SWTP

The FC in river water varied from 43502.22 CFU/100mL to 124761.03 CFU/100mL in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the FC value varied from 7867.98 CFU/100mL to 16911.5 CFU/100mL from the year 2017 to 2021. At the same time in the post-monsoon period, the FC value varied from 22217.54 CFU/100mL to 56881.25 CFU/100mL. The maximum (124761.03 CFU/100mL) and the minimum (7867.98 CFU/100mL) FC values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 13 shows that temperature was higher in the pre-monsoon period. All values of FC were found not within the EQS limit in all three periods from the year 2017 to 2021.

4.2 Water Quality Parameters at Demraghat

Different water quality parameters of Demraghat location along with Bangladesh and WHO for drinking water standards and basic statistical components (Minimum Value, Maximum Value, Mean and Standard Deviation) are presented and discussed in the following section.

Table 3: Water Quality parameters at Demraghat

Parameters	**Unit**	**Bangladesh Standard for Drinking Water (DoE)**	**WHO Standard for Drinking Water**	**Bangladesh Environmental Quality Standard for Inland Water**	**Min**	**Max**	**Mean**	**Standard Deviation**
COD	mg/l	4		200	12.00	86.00	44.52	21.56
BOD	mg/l	0.2	< 5.00	50	2.23	51.93	16.40	13.17

DO	mg/l	6	6.5 - 8.00	≥5	0.01	5.00	2.20	1.57
Alkalinity	mg/l			150	35.00	344.00	148.23	87.88
TDS	mg/l	1000	300	2100	39.27	381.50	190.81	95.53
Turbidity	NTU	10	< 5		15.49	72.50	34.60	19.13
EC	µmhoms/cm			1200	150.55	751.50	409.61	209.08
pH		6.5-8.5	6.5-8.5	6-9	7.03	7.26	7.17	0.08
Temperature	°C	20-30		20-40	22.10	32.10	25.84	3.70

The COD value at Demraghat varied from 58.00 mg/l to 86.00 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the COD value varied from 12.67 mg/l to 34.5 mg/l from the year 2017 to 2019. At the same time in the post-monsoon period, the COD value varied from 28.33 mg/l to 41.00 mg/l. The maximum (86.00 mg/l) and the minimum COD (12.67 mg/l) values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 14 shows the COD value was high in the premonsoon period from the year 2017 to 2021. The COD value was found within the EQS limit from the year 2017 to 2021.

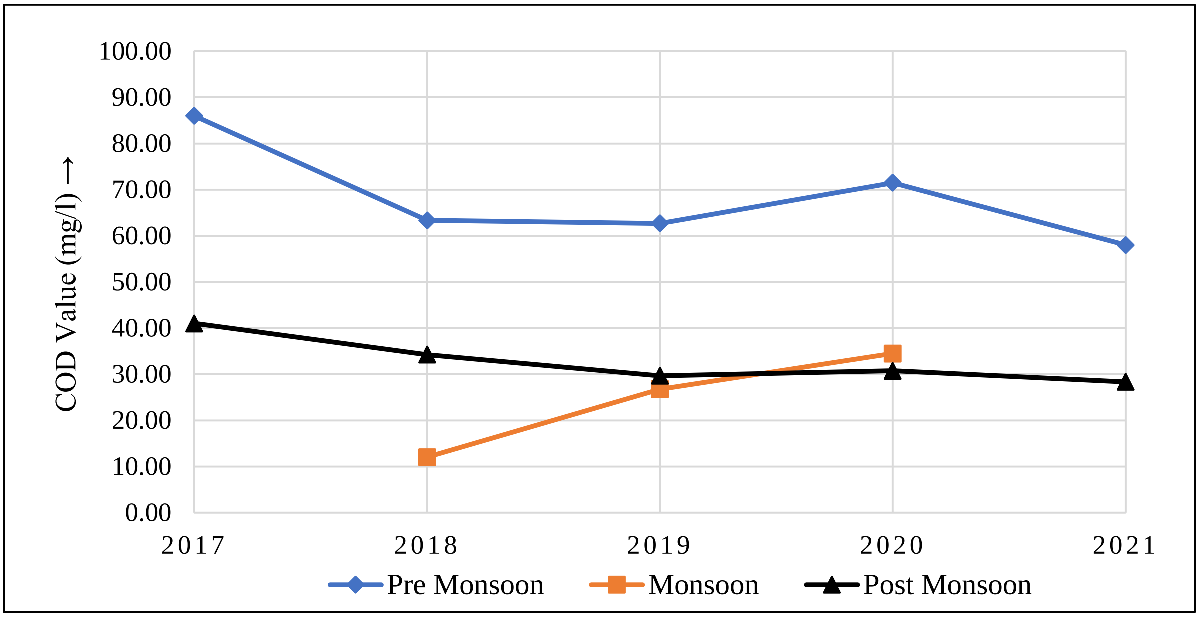

Figure 14: Seasonal variation of COD value from the year 2017 to 2021 Demraghat

The BOD value varied from 17.33 mg/l to 51.93 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the BOD value varied from 2.23 mg/l to 9.8 mg/l from the year 2017 to 2019. At the same time in the post-monsoon period, the BOD value varied from 7.80 mg/l to 11.13 mg/l. The maximum (51.93 mg/l) and the minimum (2.23 mg/l) BOD values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 15 shows the BOD value was high in the premonsoon period from the year 2017 to 2021. The COD value was found within the EQS limit from the year 2017 to 2021 except in the year 2018.

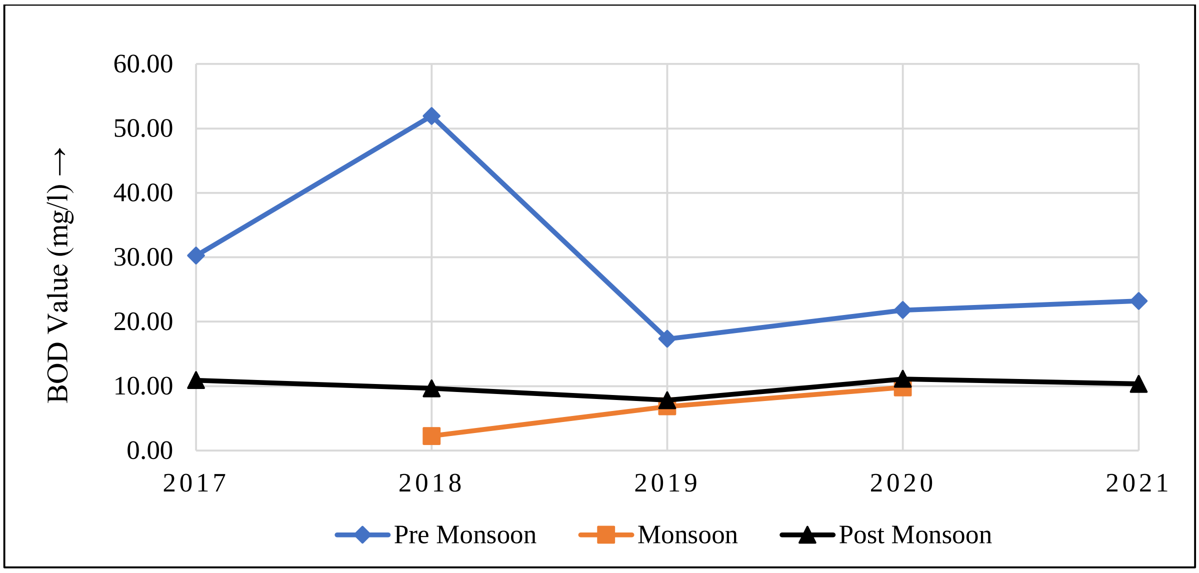

Figure 15: Seasonal variation of BOD value from the year 2017 to 2021 Demraghat

The DO value of river water varied from 0.01 mg/l to 1.00 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the DO value varied from 2.75 mg/l to 4.35 mg/l from the year 2017 to 2021. At the same time in the post-monsoon period, the DO value varied from 1.41 mg/l to 3.00 mg/l. The maximum (4.35 mg/l) and the minimum (0.01 mg/l) DO values were in the monsoon and pre-monsoon periods respectively within the year 2017 to 2021. Figure 16 shows the DO value was better in the monsoon period from the year 2017 to 2021. The DO value was not met with the EQS.

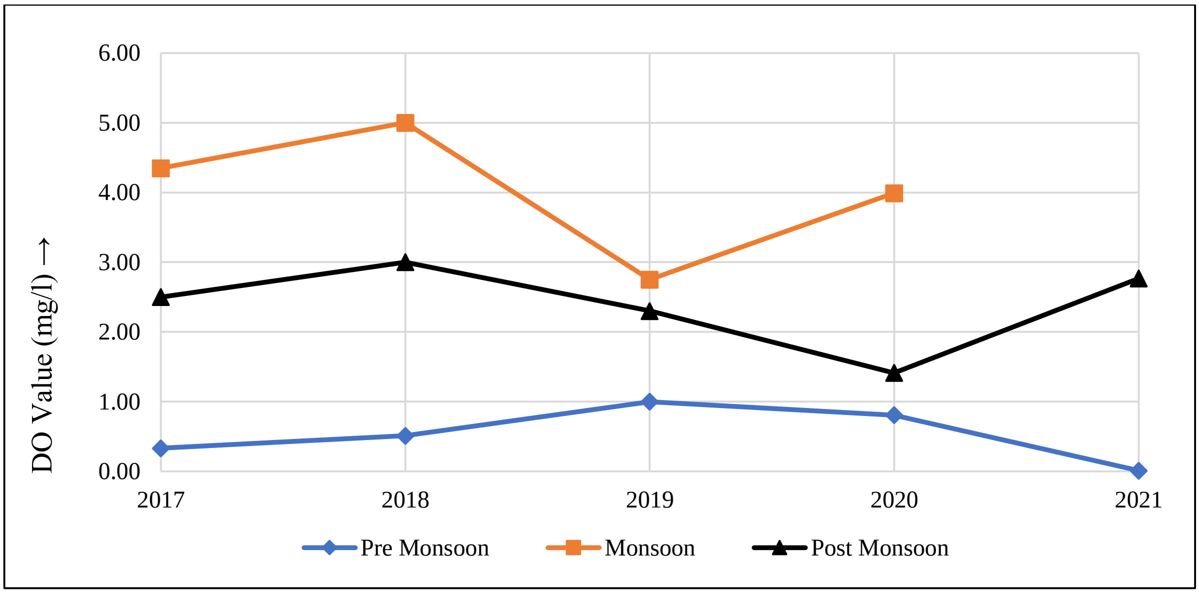

Figure 16: Seasonal variation of DO value from the year 2017 to 2021 Demraghat

The Alkalinity in river water varied from 60.33 mg/l to 344 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the Alkalinity value varied from 64 mg/l to 204 mg/l from the year 2017 to 2021. At the same time in the post-monsoon period, the Alkalinity value varied from 35.00 mg/l to 153.67 mg/l. The maximum (344 mg/l) and the minimum (35.00 mg/l) Alkalinity values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 17 shows that Alkalinity was within the EQS limit in the monsoon period from the year 2017 to 2021.

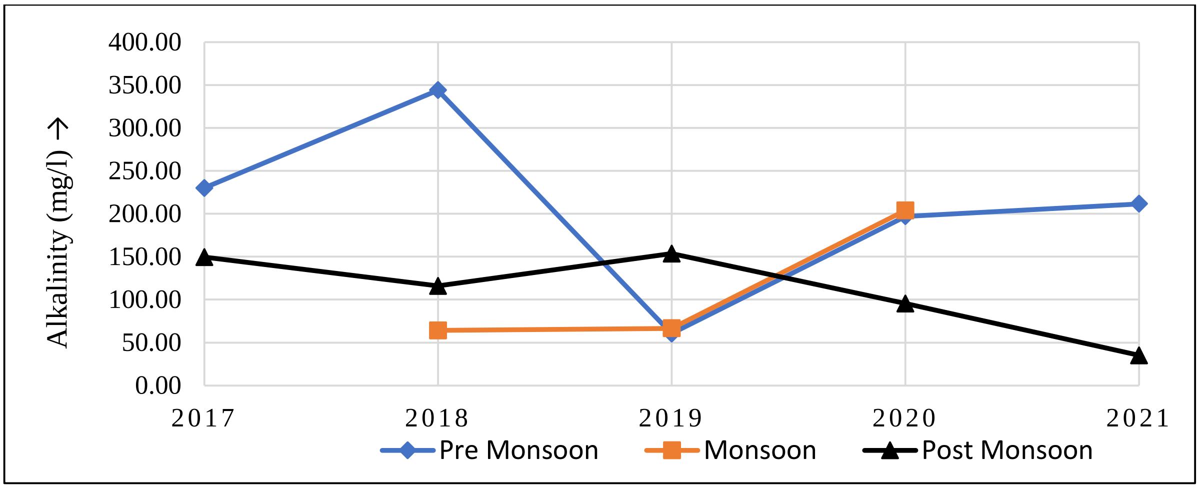

Figure 17: Seasonal variation of Alkalinity value from the year 2017 to 2021 Demraghat

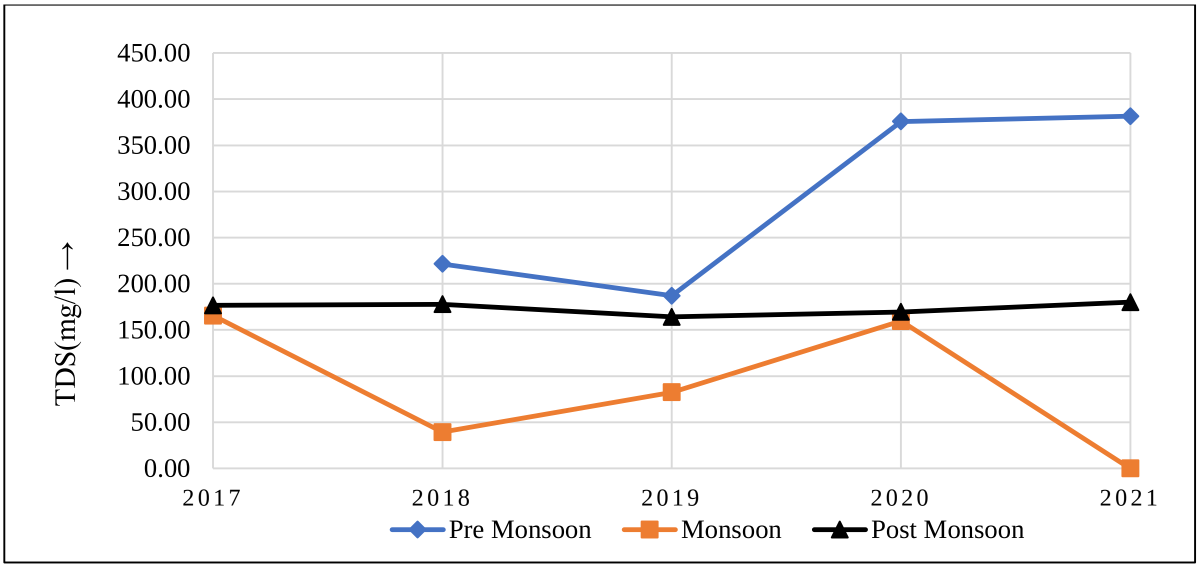

Figure 18: Seasonal variation of TDS value from the year 2017 to 2021 Demraghat

The TDS in river water varied from 187.00 mg/l to 381.50 mg/l in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the TDS value varied from 39.27 mg/l to 165.41 mg/l from the year 2017 to 2021. At the same time in the post-monsoon period, the TDS value varied from 164.17 mg/l to 180.07 mg/l. The maximum (381.50 mg/l) and the minimum (39.27mg/l) TDS values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. All values of TDS were within the EQS limit in all three periods from the year 2017 to 2021.

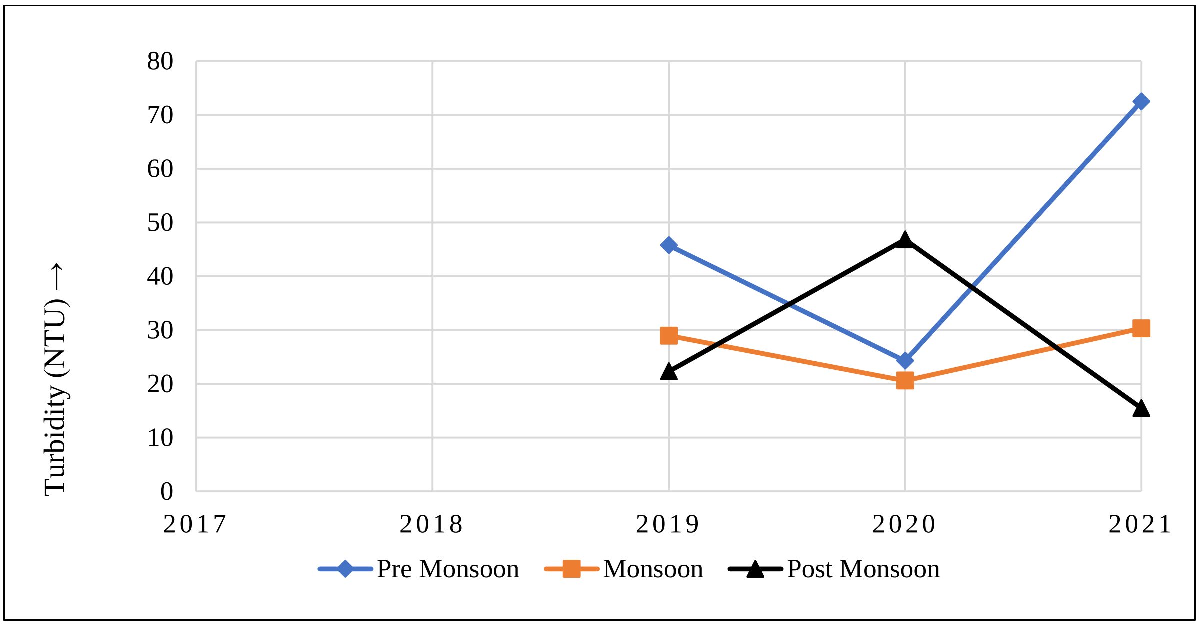

Figure 19: Seasonal variation of Turbidity value from the year 2017 to 2021 Demraghat

The Turbidity in river water varied from 24.30 NTU to 72.50 NTU in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the Turbidity value varied from 20.6 NTU to 30.32 NTU from the year 2017 to 2021. At the same time in the post-monsoon period, the Turbidity value varied from 15.49 NTU to 46.83 NTU. The maximum (72.50 NTU) and the minimum (15.49 NTU) Turbidity values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 19 shows that Turbidity was higher in the premonsoon period. All values of Turbidity were found not within the EQS limit in all three periods from the year 2017 to 2021.

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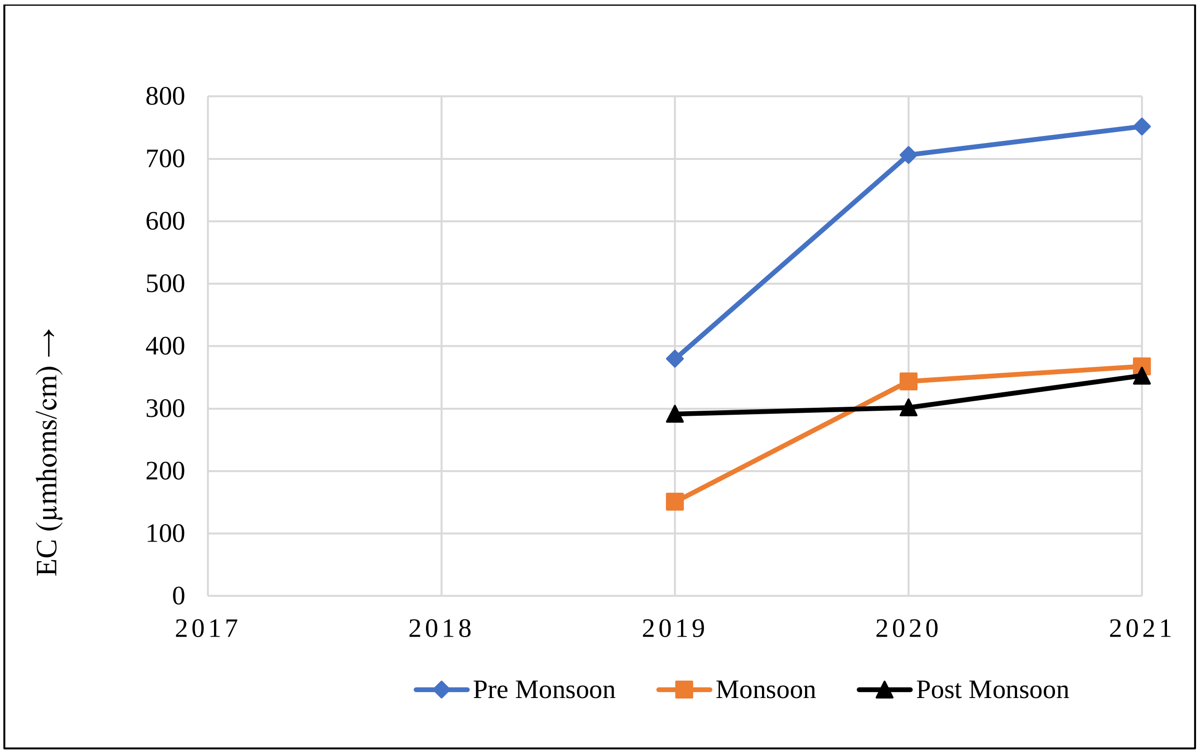


Figure 20: Seasonal variation of EC value from the year 2017 to 2021 Demraghat

The EC in river water varied from 379.67 µmhoms/cm to 751.50 µmhoms/cm in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the EC value varied from 150.55 µmhoms/cm to 367.40 µmhoms/cm from the year 2017 to 2021. At the same time in the post-monsoon period, the EC value varied from 291.33 µmhoms/cm to 352.67 µmhoms/cm. The maximum (751.50 µmhoms/cm) and the minimum (150.55 µmhoms/cm) EC values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 20 shows that EC was higher in the premonsoon period. All values of EC were found within the EQS limit in all three periods from the year 2017 to 2021.

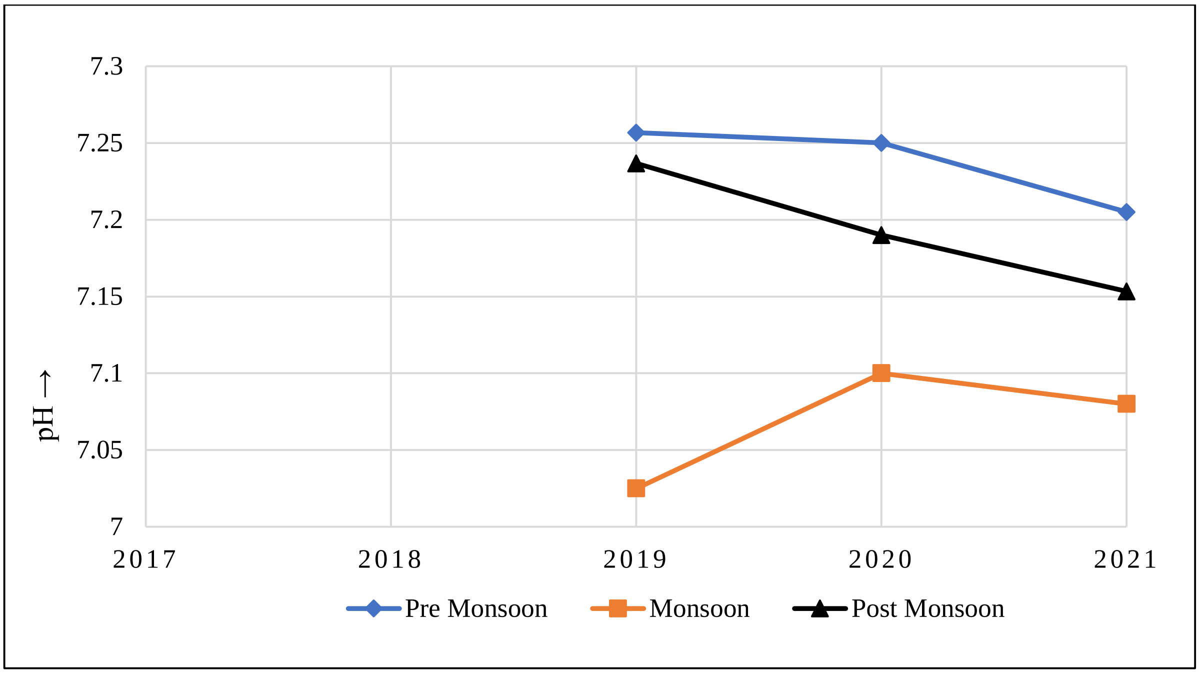


Figure 21: Seasonal variation of pH value from the year 2017 to 2021 Demraghat

The pH in river water varied from 7.21 to 7.26 in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the pH value varied from 7.03 to 7.10 from the year 2017 to 2021. At the same time in the post-monsoon period, the pH value varied from 7.15 to 7.24. The maximum (7.26) and the minimum (7.03) pH values were found in the pre-monsoon and monsoon periods respectively within the year 2017 to 2021. Figure 21 shows that pH was higher in the premonsoon period. All values of pH were found within the EQS limit in all three periods from the year 2017 to 2021.

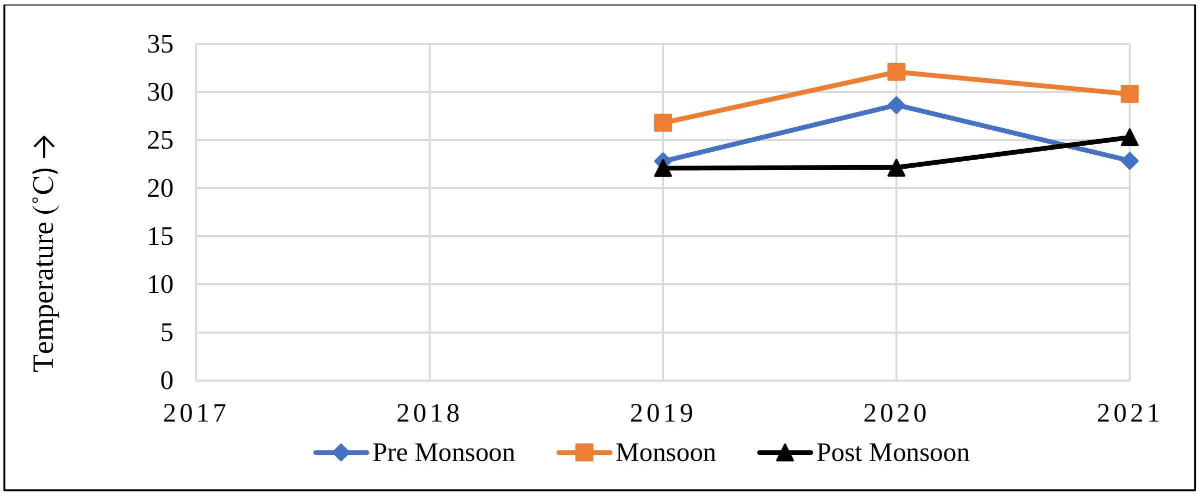


Figure 22: Seasonal variation of Temperature value from the year 2017 to 2021 Demraghat

The Temperature in river water varied from 22.80˚C to 28.65˚C in the pre-monsoon period from the year 2017 to 2021. In the monsoon period, the Temperature value varied from 26.8.80˚C to 32.10˚C from the year 2017 to 2021. At the same time in the post-monsoon period, the temperature value varied from

22.10˚C to 25.30˚C. The maximum (32.10˚C) and the minimum (22.10˚C) Temperature values were found in the monsoon and post-monsoon periods respectively within the year 2017 to 2021. Figure 22 shows that temperature was higher in the monsoon period. All values of temperature were found within the EQS limit in all three periods from the year 2017 to 2021.

It has been observed that the water quality values have been deteriorating for those two locations by analyzing the data from the year 2017 to 2021. The unplanned industrial development and lack of proper effluent treatment plant may have impacted the poor quality of the water at the raw water collection point of SWTP and Demraghat locations.

4.3 WQI Value Calculation

4.3.1 WQI at Raw Water Collection Intake of SWTP

In the WAWQI method sub water quality index for various parameters has been calculated from the year 2017 to 2021. Water quality data from 2014 to 2016 is not available at SWTP because they did not use any automatic data compilation software from 2014 to 2016. Figure 23 represents the seasonal water quality index values for the year 2017 to 2021. It has been observed that most of the water quality parameters exceed permissible limits throughout the year as presented in the previous section. The worst scenario was visible for pre-monsoon and post-monsoon seasons among all the data. However, water quality parameters were slightly better in the monsoon period. According to the rating of arithmetic index value for WQI (Table 4), only the monsoon season of 2018 showed improvement in water quality due to maximum water quality parameters (COD, Ammonia, pH, and EC) value were found within the EQS limit. In the WAWQI method, WQI values varied from 160 to 214, 91 to 99, and 100 to 113 in the premonsoon, monsoon, and post-monsoon periods, respectively.

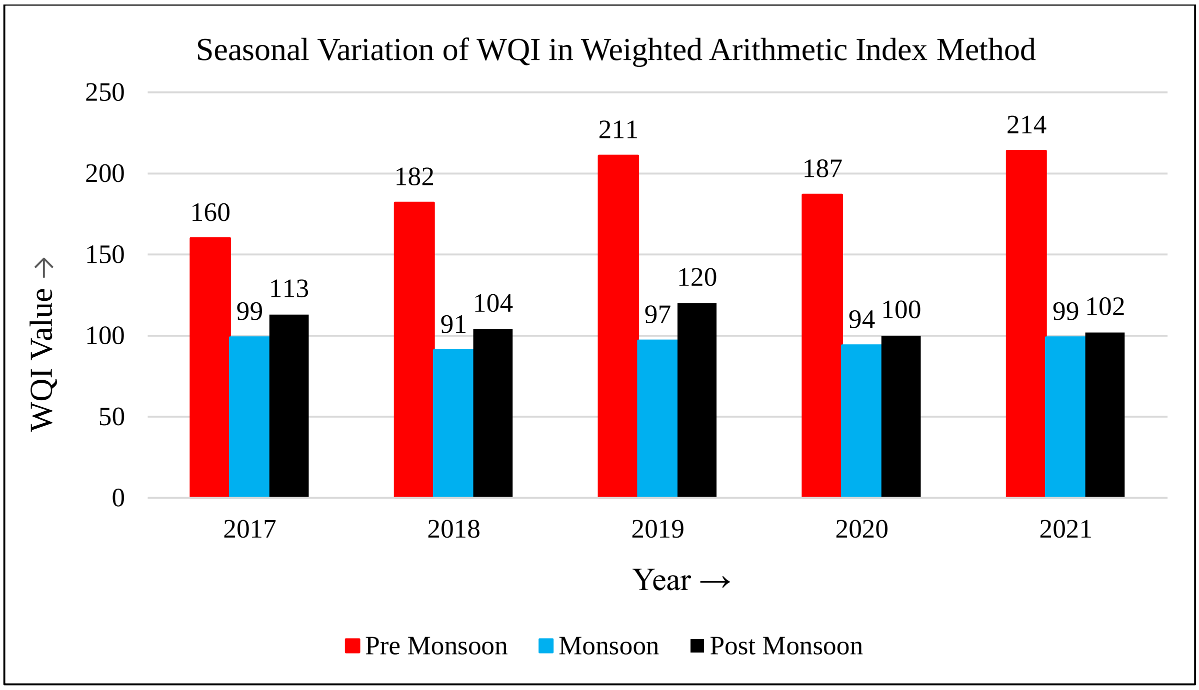


Figure 23: Seasonal Variation of WQI using the Weighted Arithmetic Method

Figure 24 represents the pre-monsoon, monsoon, and post-monsoon periods of CCMEWQI values from the year 2017 to 2021. In the CCMEWQI method, three to five parameters exceeded the permissible limit of standard value out of ten parameters. DO level and concentration of ammonia are found below the standard value within the study periods (2017 to 2021). Alkalinity is found to increase from the year 2017 to 2021. WQI value of the pre-monsoon period varies from 34 to 39 from the year 2017 to 2021 which has indicated the poor quality of water. Fair water quality has been found only in the monsoon period of 2018 and 2020. WQI value of the monsoon period varies from 55 to 72 from the year 2017 to 2021 which has indicated the marginal and fair quality of water. WQI value of the post-monsoon period varies from 41 to 59 from the year 2017 to 2021 which has indicated the poor and marginal quality of water.

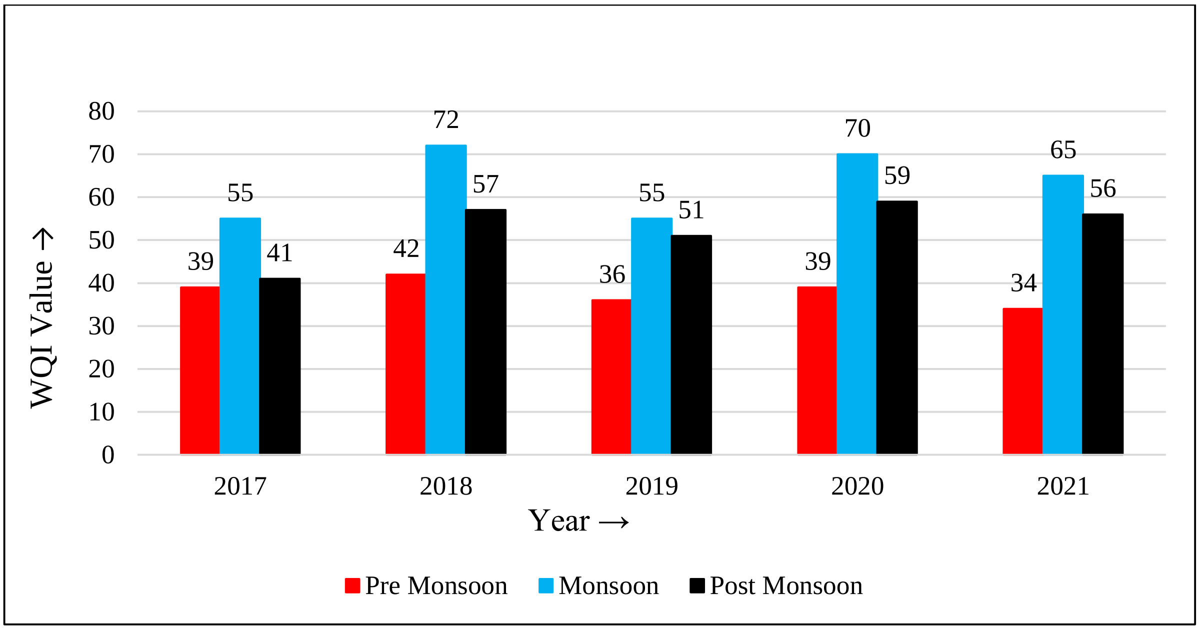


Figure 24: Seasonal Variation of WQI using the CCMEWQI Method

Figure 25 shows the seasonal variation of the water quality index in the NSF method from the year 2017 to 2021 at the intake point of SWTP. WQI value has been found worst in the pre-monsoon season from the year 2017 to 2021. WQI value has been found 32 to 41 in the monsoon and post-monsoon period from the year 2017 to 2021. Significant improvement in water quality has not been observed from the year 2017 to 2021.

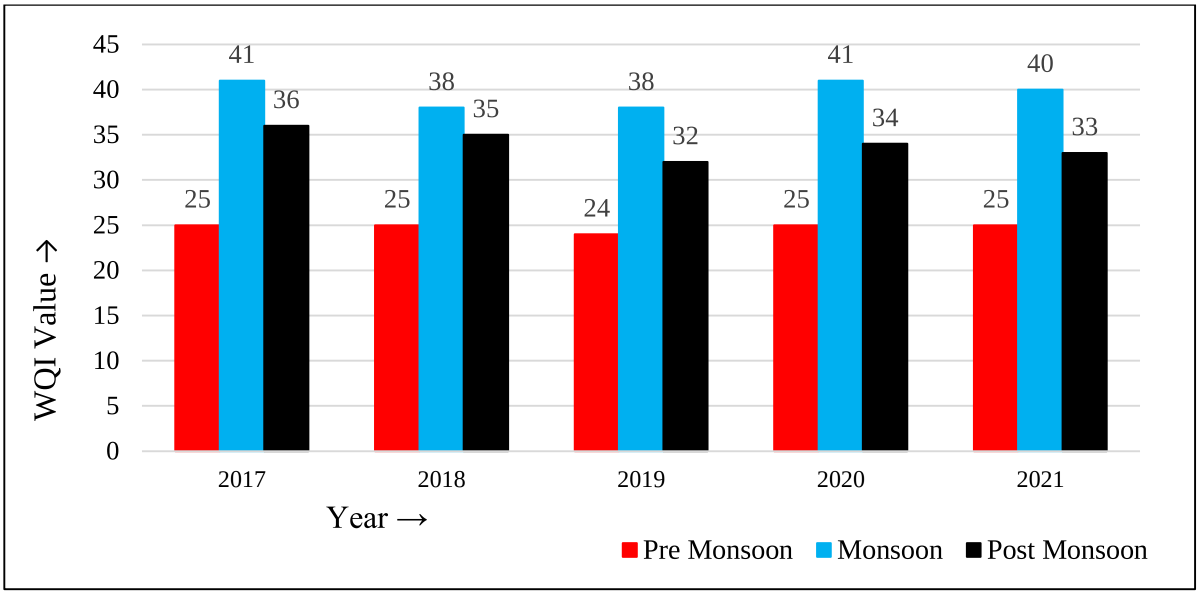


Figure 25: Seasonal Variation of WQI using the NSFWQI Method

4.3.2 WQI at Demraghat Point

In the WAWQI method sub water quality index for various parameters have been determined during the year 2014 to 2021. Figure 25 compares the seasonal water quality index values for different years. It has been found that most of the water quality parameters exceed permissible limits throughout the year.

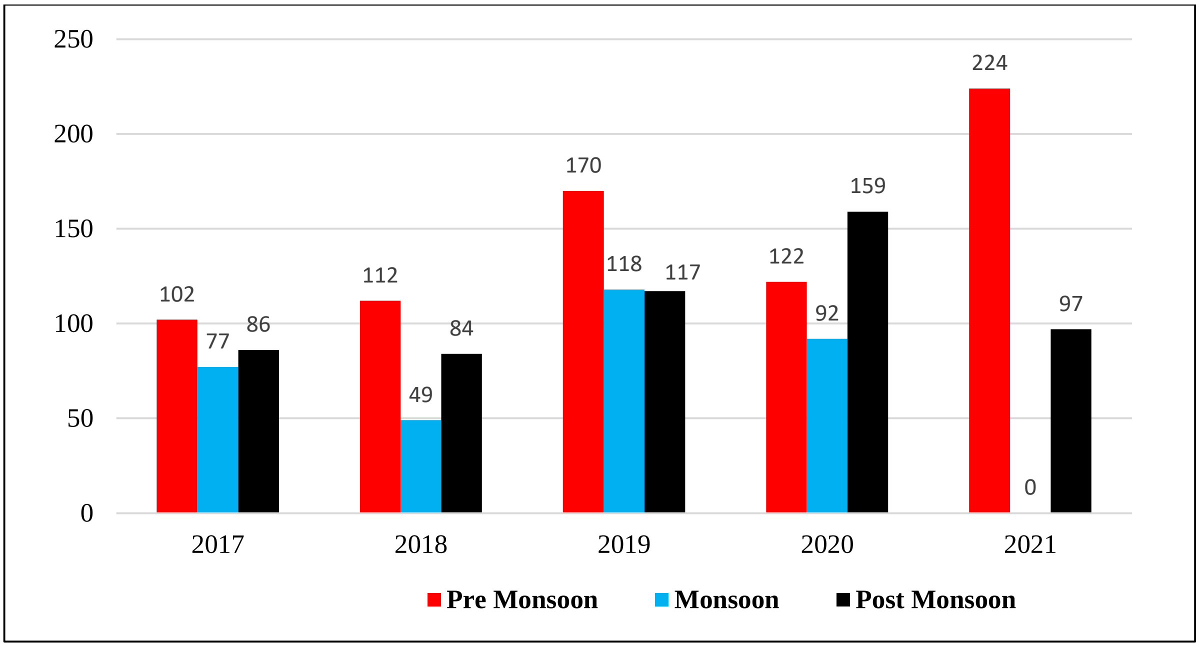


Figure 25: Seasonal Variation of WQI using the Weighted Arithmetic Method

The worst scenario is visible in pre-monsoon season for most of the year. However, water quality parameters were slightly better in the monsoon period which eventually made the index value barely within the limit to be considered good water quality. According to the rating of arithmetic index value (Table 5), only the monsoon season of 2018 showed good water quality.

In the CCMEWQI method, three to five parameters are exceeded the permissible limit of standard value out of nine parameters. DO level is found in most of the months below the standard value over the year 2014 to 2021. Alkalinity is increasing from the year 2017 to 2021. WQI value of the pre-monsoon period varies from 37 to 44 from the year 2014 to 2021 except in 2019 which has indicated the poor quality of water. Good water quality has been found only in the monsoon period of the year 2018. In the WAWQI method, WQI values varied from 102 to 224, 49 to 118, and 84 to 159 in the premonsoon, monsoon, and post-monsoon periods respectively.

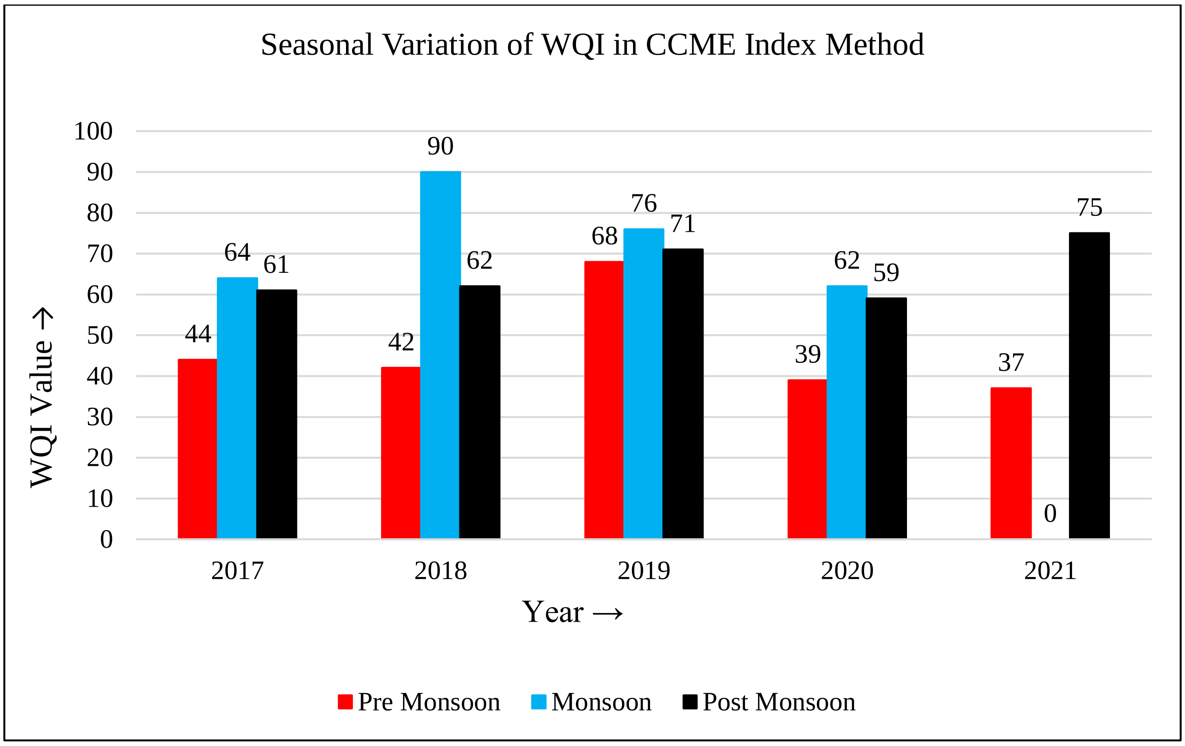


Figure 26: Seasonal Variation of WQI using the CCMEWQI Method

WQI values of the post-monsoon period have been found 59 to 75 in the CCMEWQI method which means water quality was marginal from the year 2017 to 2021 except in 2019 and 2021. WQI values of the post-monsoon period have been found 37 to 44 in the CCMEWQI method which means water quality was poor from 2017 to 2021. It has been noticed that in the monsoon period number of failures is respectively low, on the other hand in the pre-monsoon and post-monsoon periods the number of failures was high.

4.3.3 WQI at Haripur Power Plant

This portion of the analysis has been taken from the paper of Chowdhury et al. (2020) results. To determine the WQI by Weighted Arithmetic Method, the sub-water quality index for various parameters was estimated. Figure 27 compares the seasonal water quality index values for different years. It was found most of the water quality parameters exceed permissible limits throughout the year. The worst scenario was visible in post-monsoon season for most of the year. However, water quality parameters were slightly better in the monsoon period which eventually made the index value barely within the limit to be considered good water quality. According to the rating of arithmetic index value (Table 6), only the monsoon season of 2018 showed good water quality.

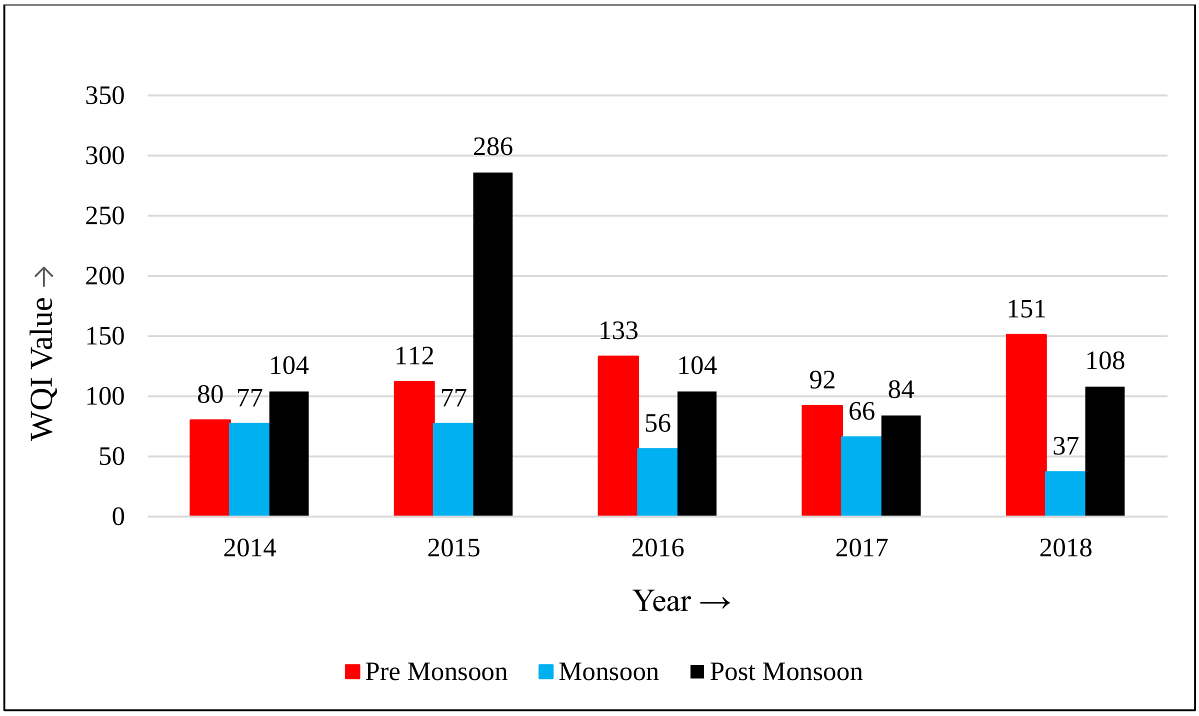


Figure 27: Seasonal Variation of WQI using the Weighted Arithmetic Method

Figure 28 present the seasonal variation in water quality for the different years by NSF method. According to the NSF method, the water quality was degrading with time. Among the 5 different years, the scenario was awful for the year 2018 almost throughout the year.

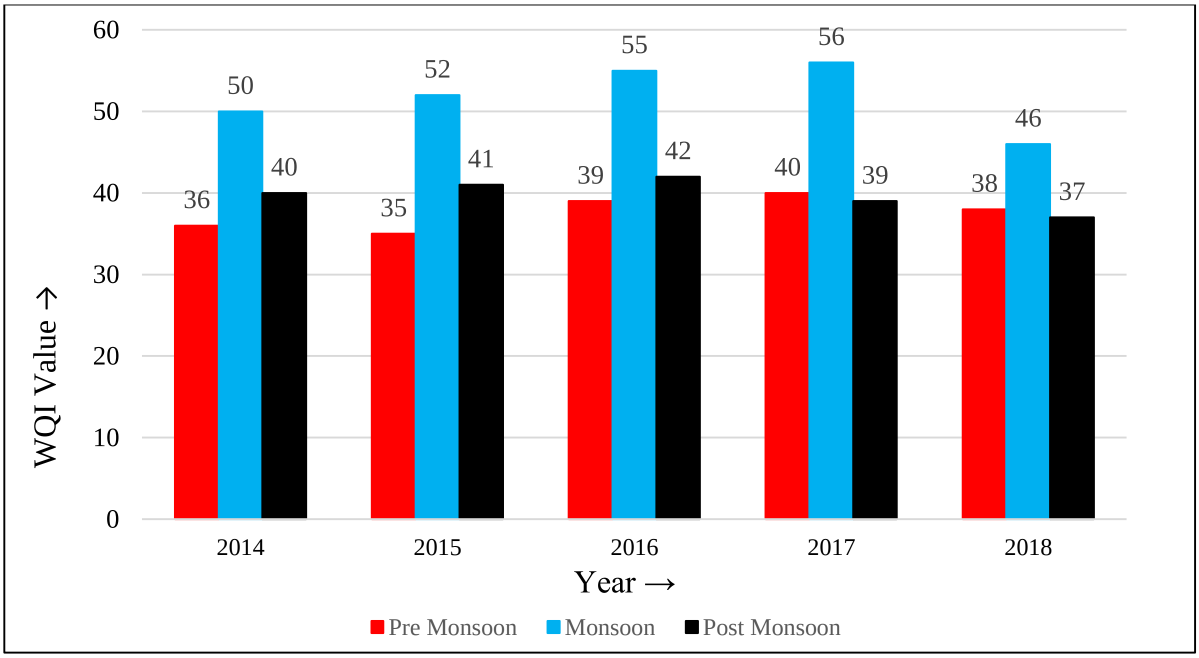


Figure 28: Seasonal Variation of WQI using the NSFWQI Method

Figure 29 shows the particular year, April was the month that falls within pre-monsoon and experienced the poorest water quality. According to this method, the parameters were far away from the standard values in post-monsoon.

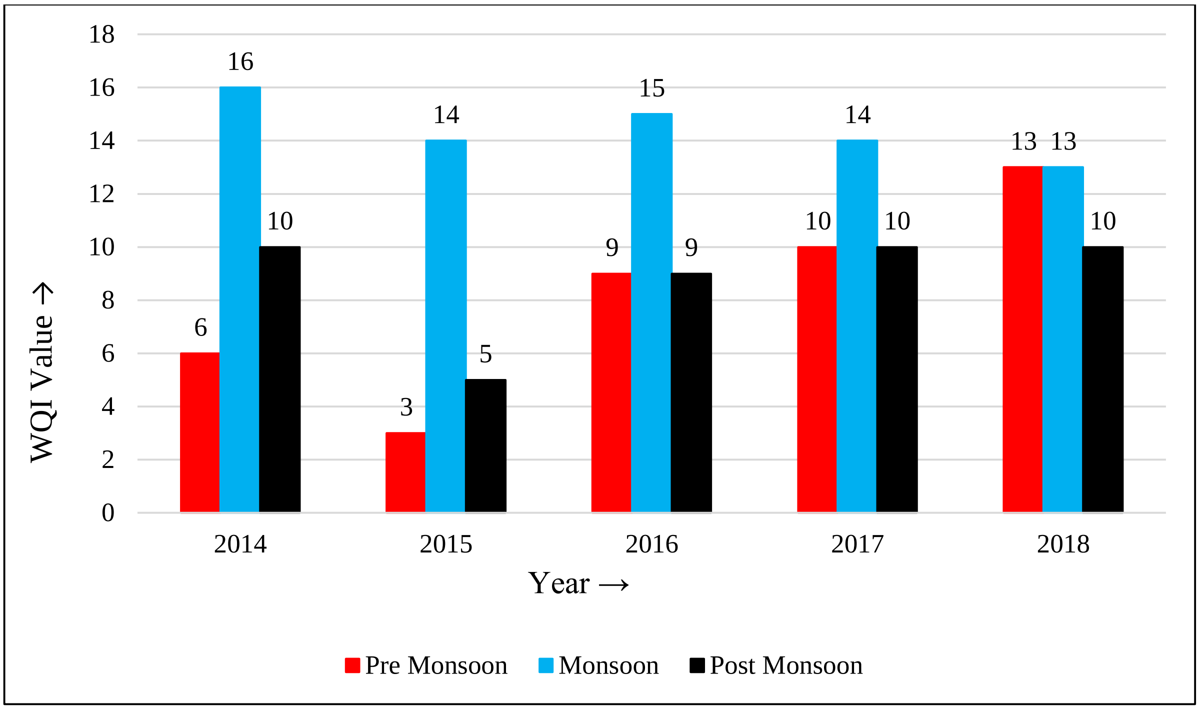


Figure 29: Seasonal Variation of WQI using the CCMEWQI Method

4.4 Comparison of WQI Among Three Methods

Tables 4, 5 and 6 compare the seasonal water quality index method from the years 2017 to 2021 in two methods at the intake point of SWTP, and Demraghat respectively. There was almost no variation among the three different methods for assessing water quality index values. Good quality of water was only found in the monsoon period of the year 2018 in both methods WAWQI and CCMEWQI at Demraghat point. In the CCMEWQI method, Fair water quality has been found in the monsoon period of 2018 at SWTP, Fair water quality is found in round the year 2019, and the post-monsoon period of 2021 at Demraghat.

Table 4: WQI value for the period of 2017-2021 according to different methods considering the corresponding rating at the intake point of SWTP.

WQI Method	**Season**	**2017**		**2018**		**2019**		**2020**		**2021**	
		WQI Value	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**

WAI	Pre - Monsoon	160	Unsuitable for drinking after conventional treatment	182	Unsuitable for drinking after conventional treatment	211	Unsuitable for drinking after conventional treatment	187	Unsuitable for drinking after conventional treatment	214	Unsuitable for drinking after conventional treatment
	Monsoon	99	Very Poor	91	Very Poor	97	Very Poor	94	Very Poor	99	Very Poor
	Post Monsoon	113	Unsuitable for drinking after conventional treatment	104	Unsuitable for drinking after conventional treatment	120	Unsuitable for drinking after conventional treatment	100	Very Poor	102	Unsuitable for drinking after conventional treatment
CCME	Pre - Monsoon	39	Poor	42	Poor	36	Poor	39	Poor	34	Poor
	Monsoon	55	Marginal	72	Fair	55	Marginal	70	Fair	64	Marginal
	Post Monsoon	41	Poor	57	Marginal	51	Marginal	59	Marginal	56	Marginal
NSF	Pre - Monsoon	25	Very Poor	25	Very Poor	24	Very Poor	25	Very Poor	25	Very Poor
	Monsoon	41	Poor	38	Poor	38	Poor	41	Poor	40	Poor
	Post Monsoon	36	Poor	35	Poor	32	Poor	34	Poor	33	Poor

Table 5: WQI value for the period of 2017-2021 according to different methods considering the corresponding rating at the Demaraghat point.

	Season	**2017**	**2018**	**2019**	**2020**	**2021**

WQI Method		**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**
WAI	Pre-Monsoon	102	Unsuitable for drinking	112	Unsuitable for drinking	170	Unsuitable for drinking	122	Unsuitable for drinking	224	Unsuitable for drinking
	Monsoon	77	Very Poor	49	Good	118	Unsuitable for drinking	92	Very Poor	NA	
	Post Monsoon	86	Very Poor	84	Very Poor	117	Unsuitable for drinking	159	Unsuitable for drinking	97	Very Poor
CCME	Pre-Monsoon	44	Poor	42	Poor	68	Fair	39	Poor	37	Poor
	Monsoon	64	Marginal	90	Good	76	Fair	62	Marginal	NA	
	Post Monsoon	61	Marginal	62	Marginal	71	Fair	59	Marginal	75	Fair

Table 6: WQI value for the period of 2014-2018 according to different methods considering the corresponding rating at the Haripur power plant.

WQI Method	**Season**	**2014**		**2015**		**2016**		**2017**		**2018**	
		WQI Value	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**	**WQI Value**	**WQI Rating**
WAI	Pre-Monsoon	80	Very Poor	112	Unsuitable for drinking after conventional treatment	133	Unsuitable for drinking after conventional treatment	92	Unsuitable for drinking after conventional treatment	151	Unsuitable for drinking after conventional treatment
	Monsoon	77	Very Poor	77	Very Poor	56	Poor	66	Poor	37	Good

	Post Monsoon	104	Unsuitable for drinking after conventional treatment	286	Unsuitable for drinking after conventional treatment	104	Unsuitable for drinking after conventional treatment	84	Unsuitable for drinking after conventional treatment	108	Unsuitable for drinking after conventional treatment
CCME	Pre - Monsoon	6	Poor	3	Poor	9	Poor	10	Poor	13	Poor
	Monsoon	16	Poor	14	Poor	15	Poor	14	Poor	13	Poor
	Post Monsoon	10	Poor	5	Poor	9	Poor	10	Poor	10	Poor
NSF	Pre-Monsoon	36	Poor	35	Poor	39	Poor	40	Poor	38	Poor
	Monsoon	50	Poor	52	Moderate	55	Moderate	56	Moderate	46	Poor
	Post Monsoon	40	Poor	41	Poor	42	Poor	39	Poor	37	Poor

In this analysis, NSFWQI has not been calculated due to unavailability of data at Demraghat point only covering the four parameters from my selected parameters out of nine in this method. But data of specified nine parameters are required for determining NSFWQI. The water quality rating of the two methods is found mostly similar. The worst condition of water quality has been observed in the pre-monsoon period in both methods from the year 2017 to 2021 except the year 2019. Good condition of water quality has been found in the monsoon period of the year 2018 in both two methods.

4.5 Multiple Regression Analysis for Identifying Significant Variable

Multiple regression analyses were performed using the statistical software SPSS (version 26), to identify statistically significant variables controlling the WQI value. Data screenings have been conducted to ensure no violation of the assumptions of normality, linearity, multi collinearity, and homoscedasticity. Four data-checking methods were analyzed among the data: firstly, boxplots of each variable were studied and the presence of outliers in the dataset was checked. Secondly, an inspection of the normal probability plot of standardized residuals as well as the scatterplot of standardized residuals against standardized predicted values was assessed. After that Mahalanobis distance was checked, which did not exceed the data, indicating that multivariate outliers are not of concern. Finally, relative tolerances of ten predictors (e.g., minimum = 0.017) in the regression model indicated that multi collinearity would not interfere with the outcome of the regression model. The statistical analysis results indicated that ten parameters accounted for 99.8% of the variability in perceived stress, R^2= 0.998, adjusted R^2= 0.994, F (10, 4) = 231.664, p<.0001, where the variable ammonia showed a higher beta value (beta = 0.811, p < .001). If the scores of Ammonia are increased by one standard deviation, the WQI scores would be likely to drop by 0.811 standard deviation units. Therefore, Ammonia, DO, and Turbidity was found the most significant variable for predicting the WQI value using the WAI method. The WQI value of the WAI method is controlled by the concentration of ammonia in raw water at 81.1% and the rest of the percentage at 18.9% is controlled by the other nine parameters.

Analyzing the results, it has been observed that four variables Dissolved Oxygen (p = 0.004), Ammonia (p = 0.007), Total Dissolved Solids (p = 0.013), and Turbidity (p = 0.019) are statistically significant for WQI values calculation using an α value of 0.05. However, it has been observed that the operational cost significantly increases if the Ammonia concentration increases at the raw water collection point of SWTP.

Table 7: Coefficient of multiple regression analysis

Parameters	**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
	B	**Std. Error**	**Beta**		
Chemical Oxygen Demand	175.535	311.796	.035	.563	.604
Dissolve Oxygen	-.966	1.897	-.035	-.509	.004
Ammonia	.876	.173	.811	5.058	.007
Alkalinity	63.767	53.661	.110	1.188	.300
Total Dossolved Solid	9466.863	4855.323	.237	1.950	.013
Turbidity	.379	1.264	.021	.300	.019
Electrical Conductivity	188.097	1622.402	.015	.116	.913
pH	-1.220	2.593	-.025	-.470	.663
Temperature	3.433	4.769	.029	.720	.511
Fecal Coliform	-5.922	5.416	-.125	-1.093	.336

4.6 Spatial Distribution of WQI Values

In Figure 30, spatial variations of WQI values in three locations of Shitalakhya River by using the WQI method for the year 2017 are presented. The result shows that the water quality at Sarulia point, at the raw intake of SWTP, was the worst among the three locations for the year 2017. Water quality was found comparatively better near the Haripur Power Plant of Shitalakhya River. The highest value of WQI was found in the range of 285.92 to 335.64 which was recorded at Sarulia, Intake of SWTP during the post-monsoon period. However, during the monsoon period, the WQI value varies from 64.95 to 78.98, which is comparatively better than pre and post-monsoon. Figure 4.37 represents the spatial variation of WQI among three locations of Shitalakhya River for the year 2018. The water quality has been found better at Demraghat than the Sarulia, Intake of SWTP around the year 2018 from the. Water quality is comparatively better near the Haripur Power Plant of Shitalakhya River in 2018. WQI value varies from 32.79 to 81.12 in the monsoon period which is comparatively better than the other two periods in all three locations.

Figure 31 represents the spatial variation of WQI among three locations of Shitalakhya River for the year 2018. The water quality has been found better at Demraghat than the Sarulia, Intake of SWTP around the year 2018 from the. Water quality is comparatively better near the Haripur Power Plant of Shitalakhya River in 2018. WQI value varies from 32.79 to 81.12 in the monsoon period which is comparatively better than the other two periods in all three locations.

Figure 32 represents the spatial variation of WQI among two locations of Shitalakhya River for the year 2019. The water quality has been found better at Demraghat and the Sarulia, Intake of SWTP in the monsoon period around the year 2019 while Figure 39 shows the spatial variation of WQI among two locations of the Shitalakhya River for the year 2020. The water quality index value has been found 157.63 to 232.14 in the pre-monsoon period at Sarulia near the intake of SWTP which indicated water quality was comparatively worse than the other two seasons of 2020. Figure 40 presents the spatial variation of WQI among two locations of the Shitalakhya River for the year 2021. The water quality index value has been found 157.63 to 232.14 in the pre-monsoon period at Demraghat and Sarulia near the intake of SWTP which indicated water quality was comparatively worse than the other two seasons of 2021.

Figure 33 shows the spatial variation of WQI among two locations of the Shitalakhya River for the year 2020. The water quality index value has been found 157.63 to 232.14 in the pre monsoon period at Sarulia near the intake of SWTP which indicated water quality was comparatively worse than the other two seasons of 2020.

Figure 3 presents the spatial variation of WQI among two locations of the Shitalakhya River for the year 2021. The water quality index value has been found 157.63 to 232.14 in the pre monsoon period at Demraghat and Sarulia near the intake of SWTP which indicated water quality was comparatively worse than the other two seasons of 2021.

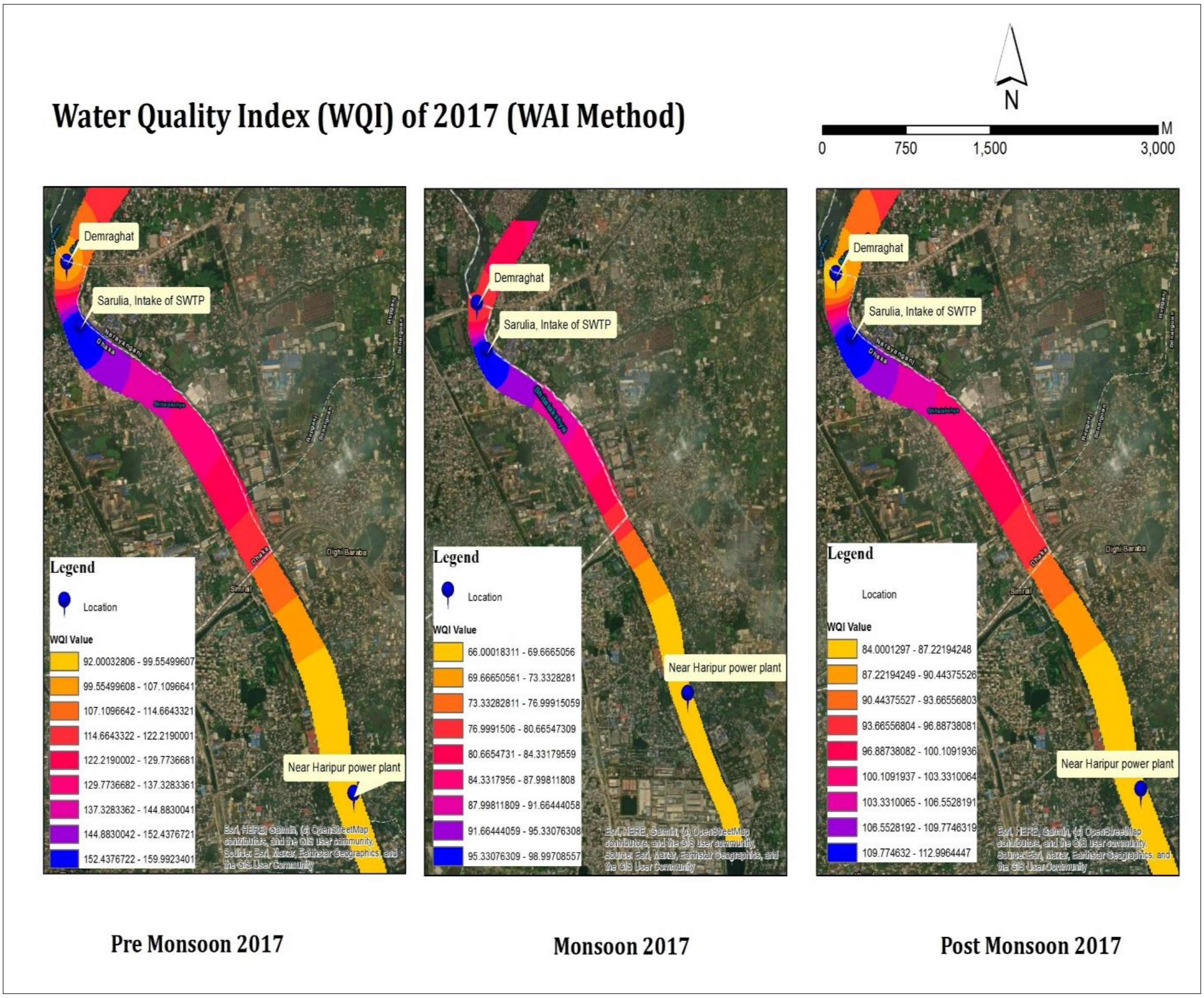


Figure 30: Shows the Spatial Variation of WQI in Different Seasons of the Year 2017

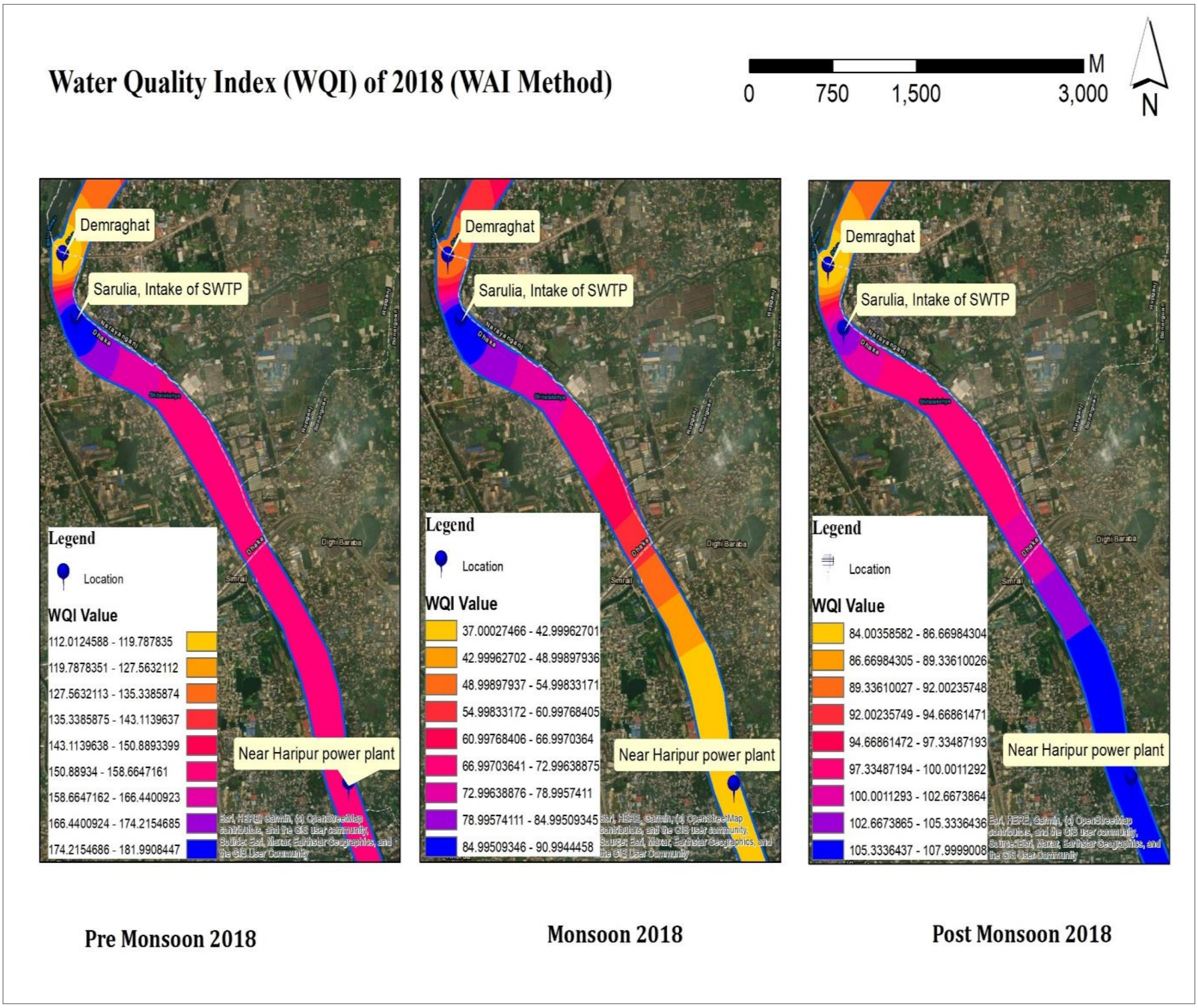
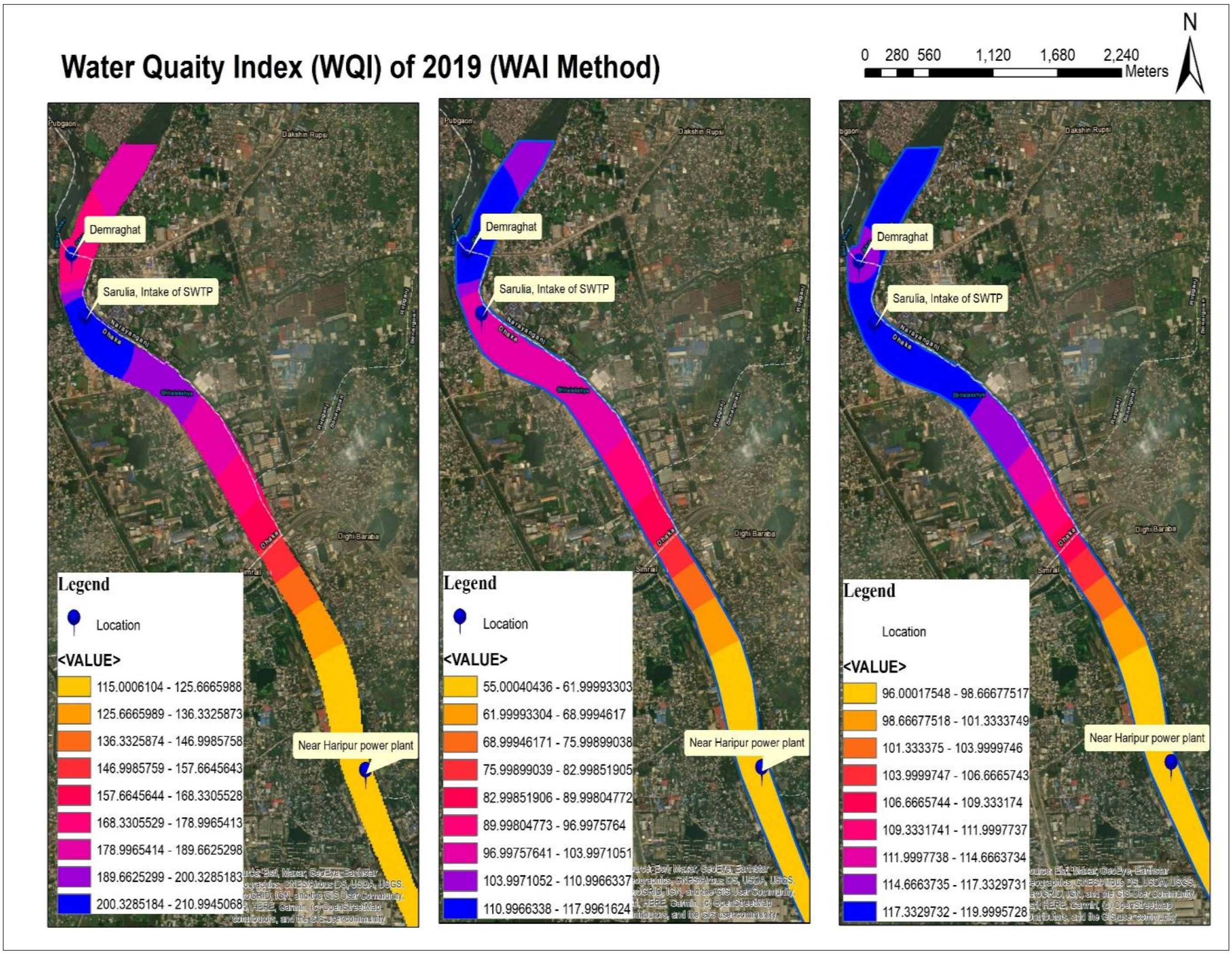


Figure 31: Shows the Spatial Variation of WQI in Different Seasons of the Year 2018



Pre-monsoon 2019 **Monsoon 2019** **Post Monsoon 2019**

Figure 32: Shows the Spatial Variation of WQI in Different Seasons of the Year 2019

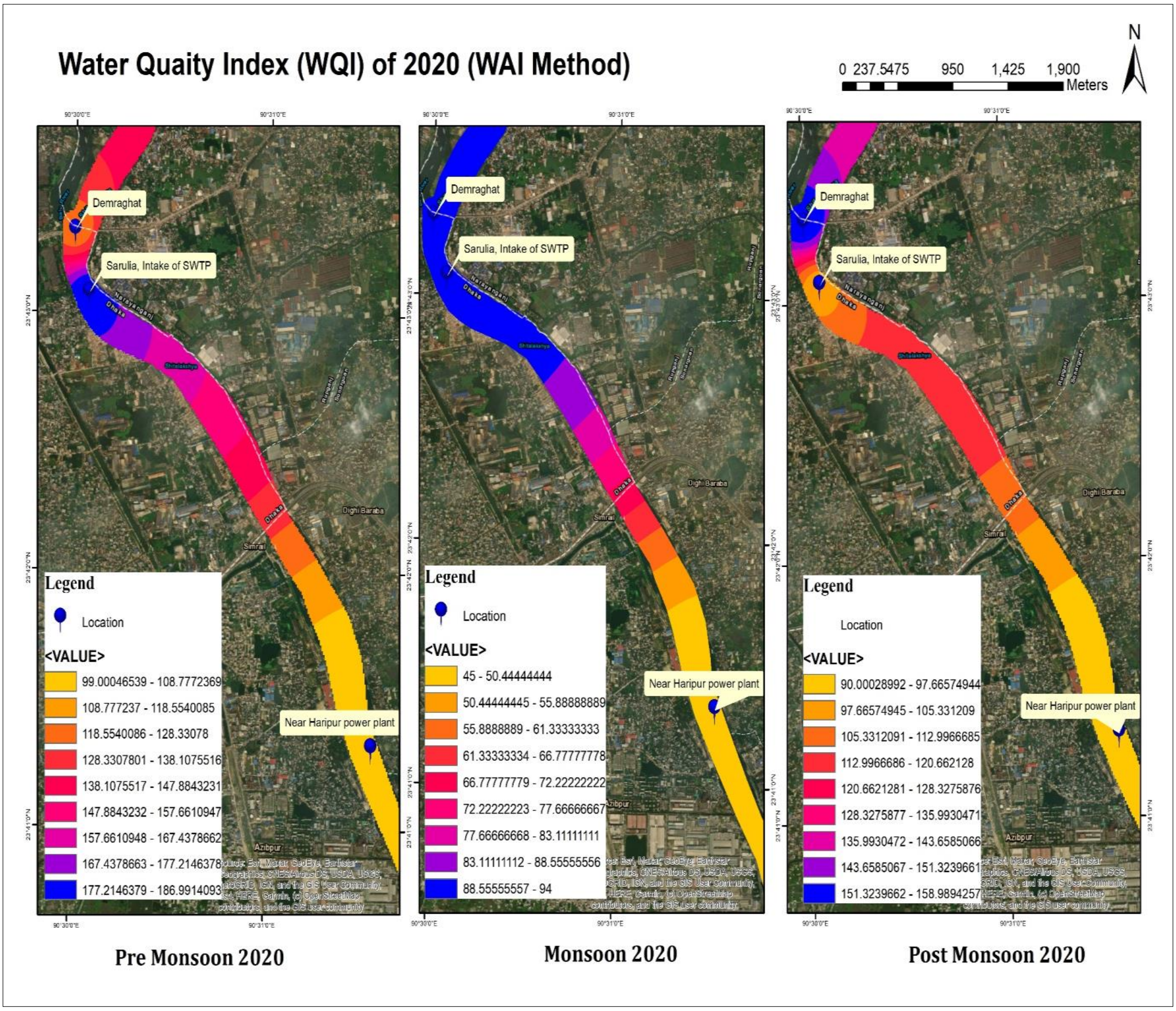


Figure 33: Shows the Spatial Variation of WQI in Different Seasons of the Year 2020

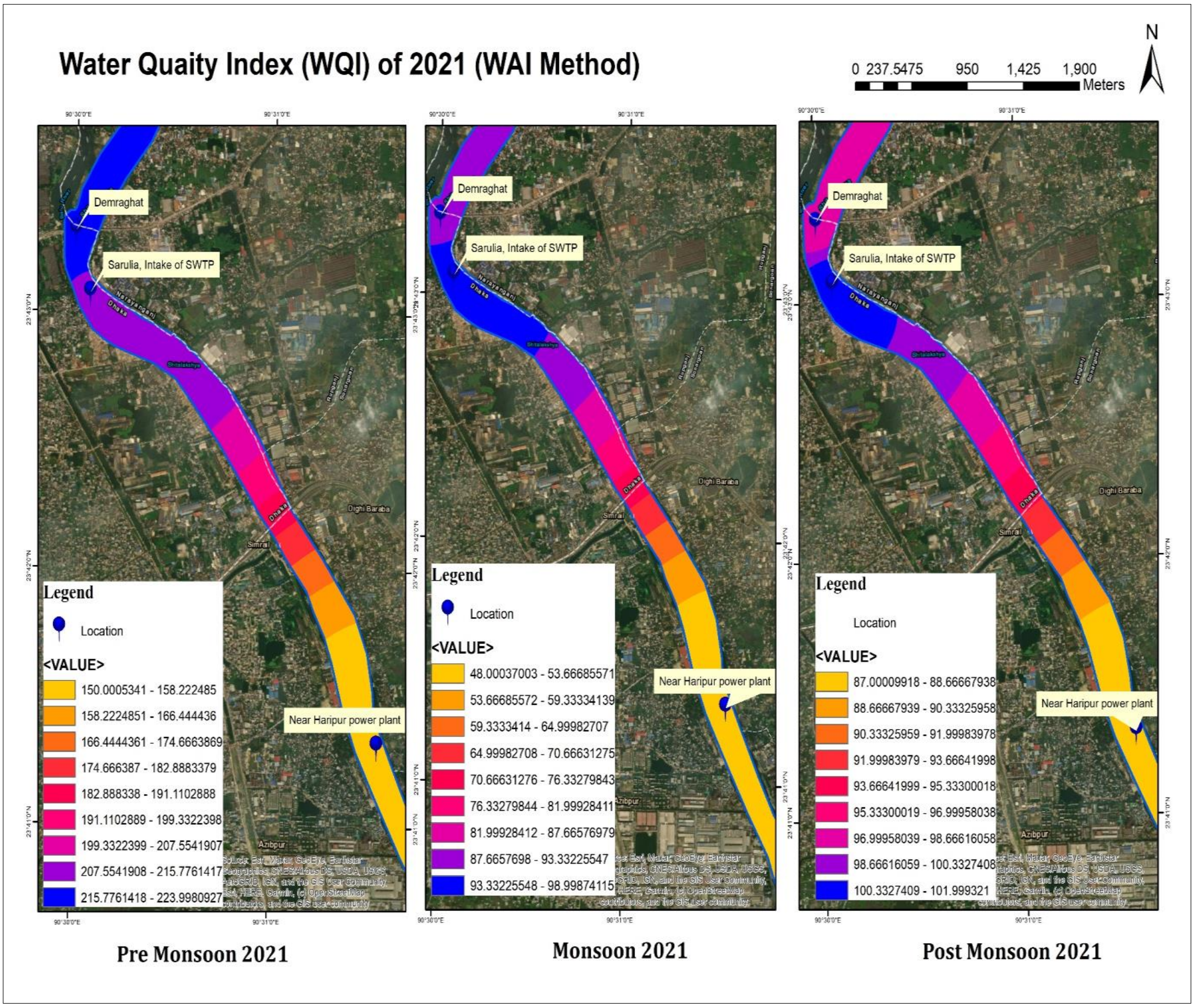


Figure 34: Shows the Spatial Variation of WQI in Different Seasons of the Year 2021

4.7 Comparison of WAWQI with Water Level at Demraghat Point

WL level data of Demraghat station was collected from the Bangladesh Water Development Board (BWDB) for the analysis. The values of WAWQI have been compared with the value of WL at Demraghat point of the Shitalakhya River from the year 2017 to 2021 and presented in Figure 35 to 39. As stated before, the average WL from the daily WL data has been used and compared with the respective WQI values for the pre-monsoon, monsoon, and post-monsoon periods. Figure 14 (a) to (e) show that in general, when the water level is higher the value of WAWQI is lower. As per the rating of WAWQI when the WQI value is lower the water quality is comparatively better compared with higher WQI values. The WQI index values were found inversely proportional with the WL values, as the WL values increased, the WQI values were decreasing. However, for the year 2020, the WQI value increased significantly during post monsoon period though the water level was higher. It has been observed that the flood water prolonged in the year 2020 and the surrounding areas were under water for a long time, which could have impacted higher WQI values. In the monsoon period of the year 2017 to 2021, water levels varied between 4.08m to 4.77m at that time WQI values varied from 49 to 118.

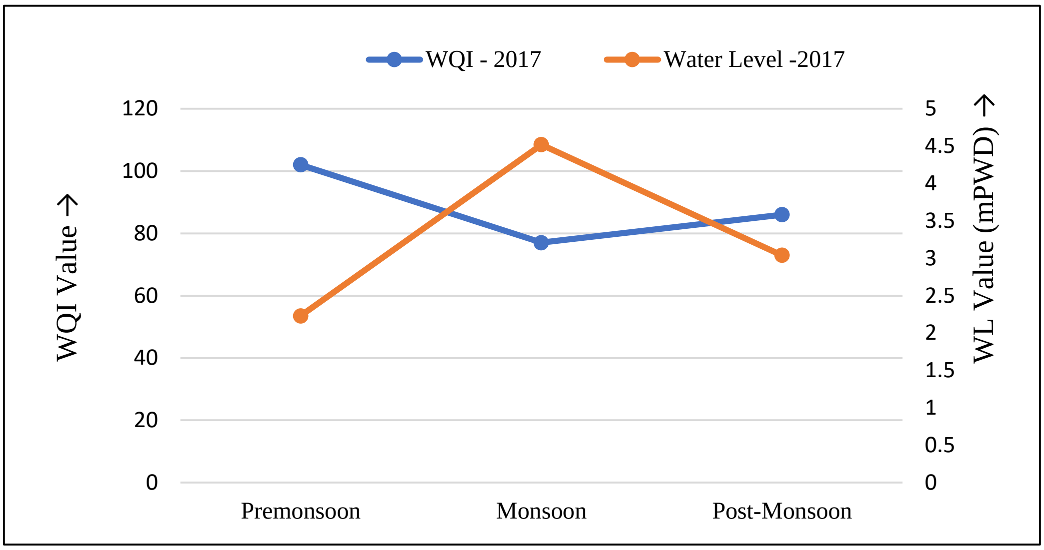


Figure 35: Comparison between Values of WAWQI and WL in the year 2017

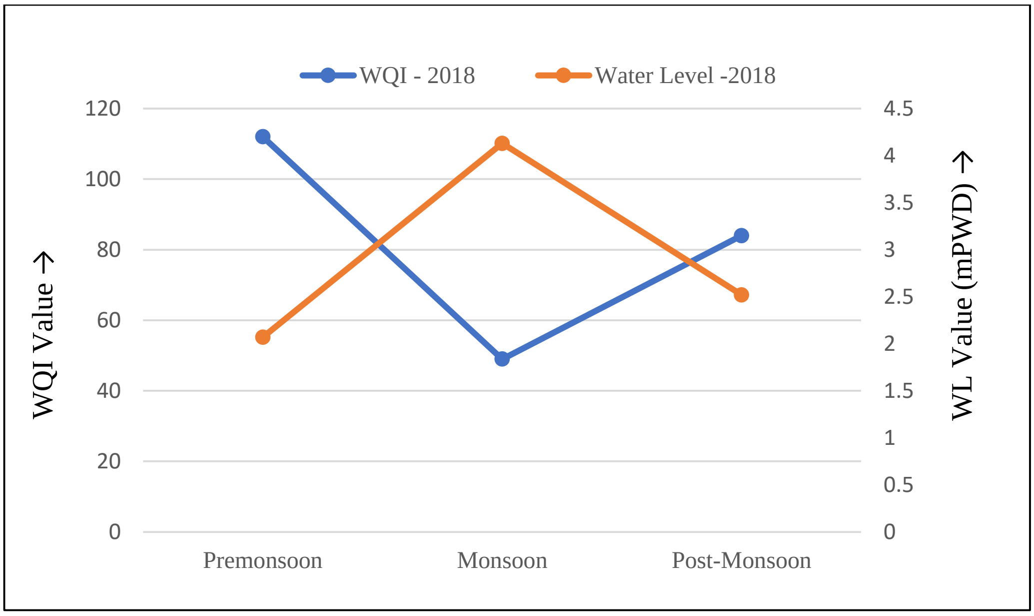


Figure 36: Comparison between Values of WAWQI and WL in the year 2018

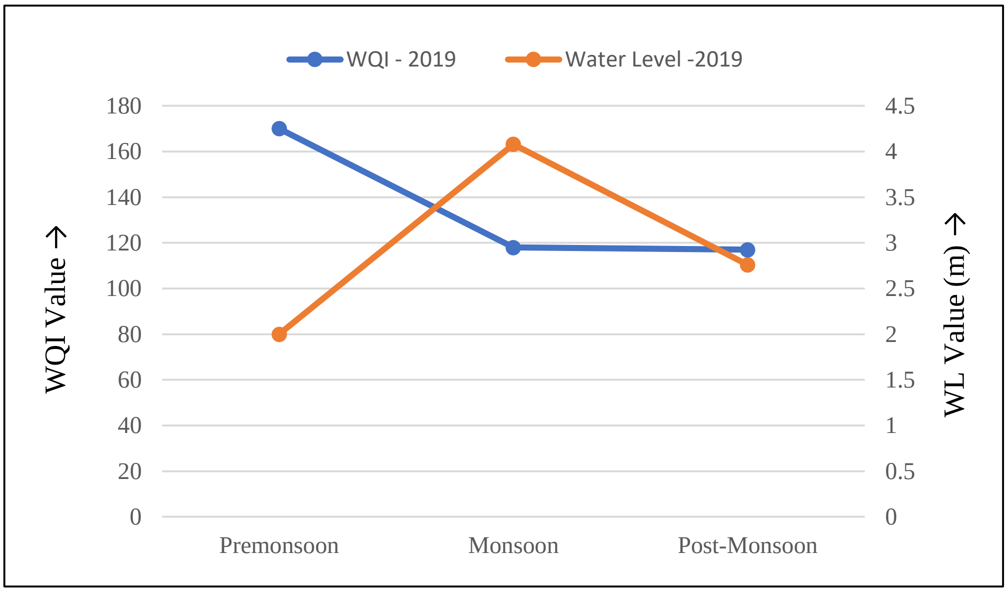


Figure 37: Comparison between Values of WAWQI and WL in the year 2019

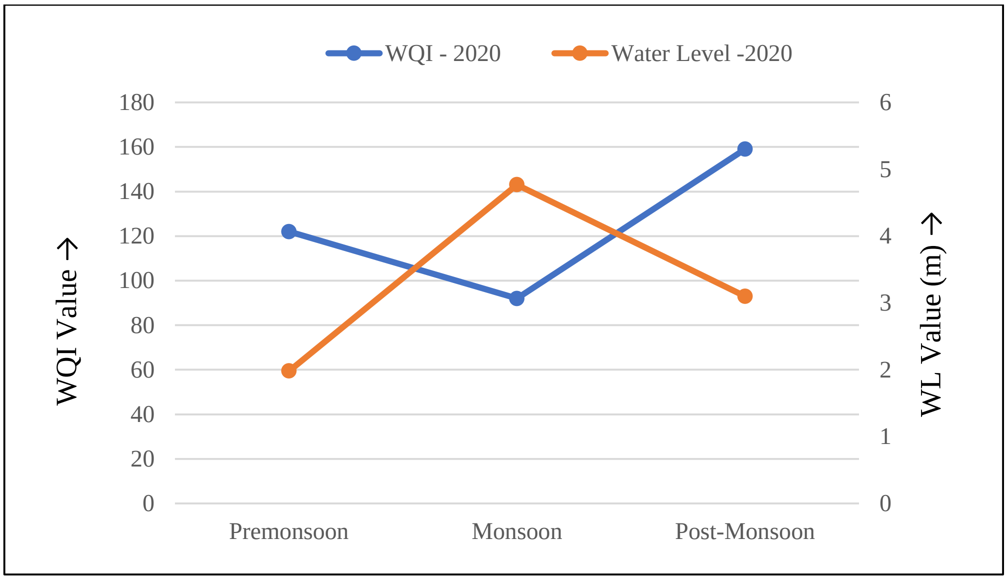


Figure 38: Comparison between Values of WAWQI and WL in the year 2020

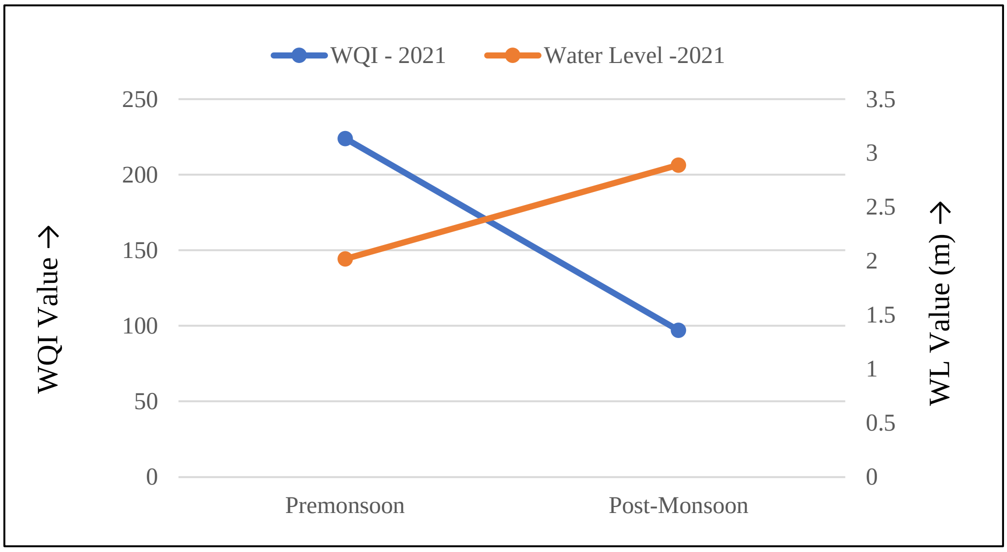


Figure 39: Comparison between Values of WAWQI and WL in the year 2021

4.8 Effect of WQI on Plant Operational Cost

WQI of pre-monsoon, monsoon, and post-monsoon have been determined from the year 2017 to 2021 at the raw water collection point of SWTP by using three methods of WQI. During that period, the operational cost has also been analyzed. The operational cost of SWTP is divided into two categories: fixed cost and variable cost. Fixed costs included the salary of operational and security staff. Variable costs included chemical dosages for the treatment of raw water, utility, and maintenance costs. The unit variable cost of water treatment from the years 2017 to 2021 is presented in Tables 7 to 11.

Table 7: Unit cost for water treatment and corresponding WQI values for the year 2017

Period	**WAWQI Value**	**Rating**	**NSFWQI Value**	**Rating**	**CCMEWQI Value**	**Rating**	**Per Cubic Meter Cost (BDT) of Treated Water**
Pre-monsoon	160	Unfit for Consumption	25	Very Poor	39	Poor	4.05
Monsoon	99	Very Poor	41	Poor	55	Marginal	2.25
Post-Monsoon	113	Unfit for Consumption	36	Poor	41	Poor	2.97

Table 8: Unit cost for water treatment and corresponding WQI values for the year 2018

Period	**WAWQI**	**Rating**	**NSFWQI Value**	**Rating**	**CCMEWQI**	**Rating**	**Per Cubic Meter Cost (BDT) of Treated Water**
Pre-monsoon	182	Unfit for Consumption	25	Very Poor	42	Poor	4.28
Monsoon	91	Very Poor	38	Poor	72	Fair	2.45
Post-Monsoon	104	Unfit for Consumption	35	Poor	57	Marginal	3.05

Table 9: Unit cost for water treatment and corresponding WQI values for the year 2019

Period	**WAWQI Value**	**Rating**	**NSFWQI Value**	**Status**	**CCMEWQI**	**Rating**	**Per Cubic Meter Cost (BDT) of Treated Water**
Pre-monsoon	211	Unfit for Consumption	24	Very Poor	36	Poor	6.2
Monsoon	97	Very Poor	38	Poor	55	Marginal	5.05
Post-Monsoon	120	Unfit for Consumption	32	Poor	51	Marginal	3.52

Table 10: Unit cost for water treatment and corresponding WQI values for the year 2020

Period	**WAWQI Value**	**Rating**	**NSFWQI Value**	**Rating**	**CCMEWQI Value**	**Rating**	**Per Cubic Meter Cost (BDT) of Treated Water**
Pre-monsoon	187	Unfit for Consumption	25	Very Poor	39	Poor	6.81
Monsoon	94	Very Poor	41	Poor	70	Fair	5.64
Post-Monsoon	100	Very Poor	34	Poor	59	Marginal	6.06

Table 11: Unit cost for water treatment and corresponding WQI values for the year 2021

Period	**WAWQI Value**	**Rating**	**NSFWQI Value**	**Rating**	**CCMEWQI Value**	**Rating**	**Per Cubic Meter Cost (BDT) of Treated Water**
Pre-monsoon	214	Unfit for Consumption	25	Very Poor	34	Poor	7.25
Monsoon	99	Very Poor	40	Poor	64	Marginal	4.72
Post-Monsoon	102	Unfit for Consumption	33	Poor	56	Poor	6.83

Figure 40 shows the unit cost from 2017 to 2021 varies from 4.05 BDT to 7.25 BDT during the pre-monsoon period. Analyzing the data, it has been found that unit operational cost was very high when the concentration of ammonia in raw water was high. During the pre-monsoon period, the WQI values were also significantly high. From the plant's operational perspective, it was observed that pre-treatment procedures are required (when the concentration of Ammonia in raw water is greater than 2 ppm) for reducing the high Ammonia concentration in raw water. The percentage of increase in plant operation cost has been calculated using 2017 year as base data. From the calculations, a significant jump in operational costs was found from the year 2018 to 2019. This significant jump in cost occurred due to increased plant maintenance cost and utility costs. However, the variations among other years varied between 11% to 15%.

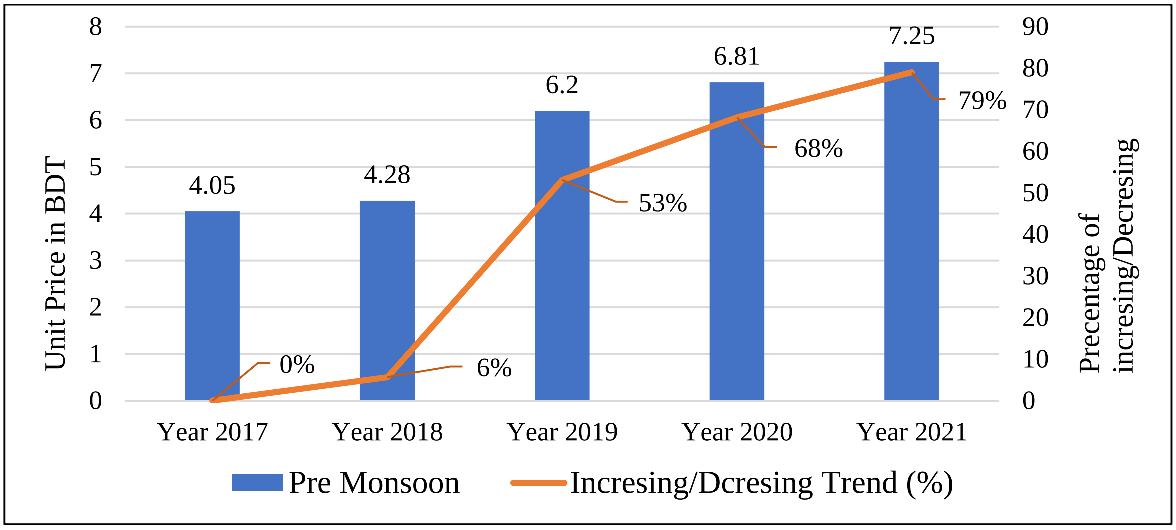


Figure 40: Yearly trend of unit cost (BDT) for water treatment during the pre-monsoon period

Similar to the pre-monsoon period, the plant operational cost was analyzed for the monsoon period and presented in Figure 41.

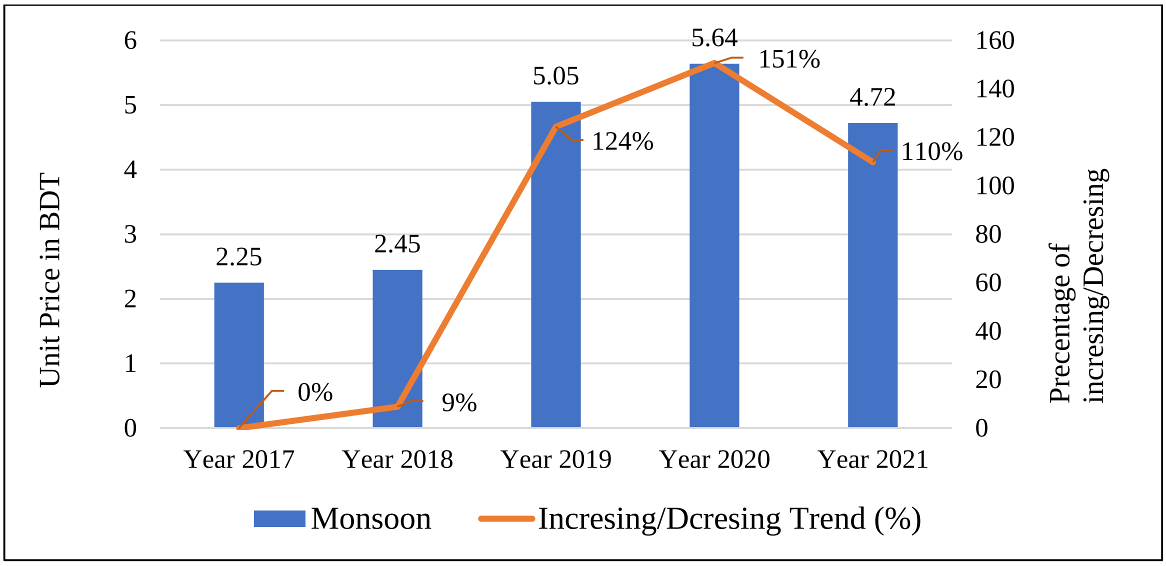


Figure 41: Yearly trend of unit cost (BDT) for water treatment during the monsoon period

Figure 42 shows the unit operating cost during the years 2017 to 2021, which varies from 2.97 BDT to 6.83 BDT. The purification cost of raw water was moderate in this season than the pre-monsoon season but higher than in the monsoon season due to the high concentration of ammonia in raw water as well as water quality has been found bad in this season than the monsoon season found to from the WQI. The increasing percentage of unit prices was high in the year 2020.

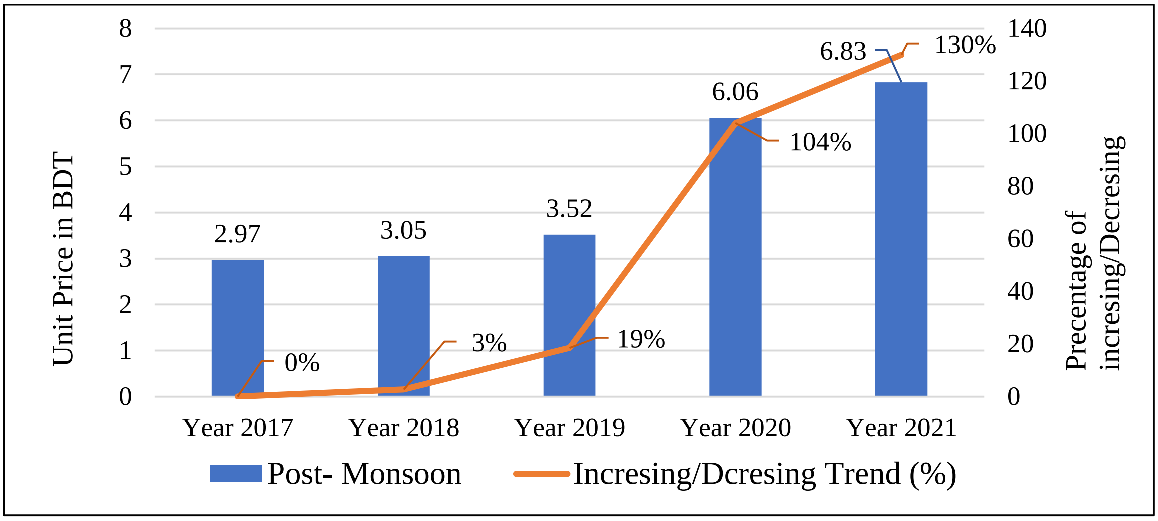


Figure 42: Yearly trend of unit cost (BDT) for water treatment during the post-monsoon period

5. Conclusion

Water quality and water quality index vary from the river to river and pollution of the peripheral river of Dhaka city is increasing day by day. Shitalakhya is one of the polluted peripheral rivers of Dhaka city. Industrial development is one of the main causes of pollution in the Shitalakhya river. SWTP collects raw water from the Shitalakhya river. It is difficult to draw a general conclusion about a particular river water quality. So, the study of the water quality index at the raw water collection point of SWTP is very crucial to our country.

Shitalakhya is a vital river in Bangladesh not only for economic reasons but also for domestic usage of this river. SWTP draws water from this river at Sarulia for mitigating the water demand of city dwellers. WQI values have been calculated in the raw water collection point (Sarulia) and Demraghat by using NSFWQI, CCMEWQI, and WAWQI methods from the year 2017 to 2021. The unit cost of treated water has also been evaluated by using the operational cost from the years 2017 to 2021 for the pre-monsoon, monsoon, and post-monsoon periods.

In this study, the collected data on water quality parameters (BOD, COD, DO, Ammonia, Alkalinity, TDS, Turbidity, pH, EC, Temperature, and Fecal Coliform) was compared with the permissible limit of EQS value from the year 2017 to 2021 at two points of the Shitalakhya River. WQI values have been calculated in the raw water collection point (Sarulia) and Demraghat by using NSFWQI, CCMEWQI, and WAWQI methods from the year 2017 to 2021. The unit cost of treated water has been calculated by using the operational cost from the years 2017 to 2021 for the pre-monsoon, monsoon, and post-monsoon periods.

Findings from this study suggest consideration of the concentration of Ammonia as a water quality parameter in Demraghat point since the concentration of Ammonia in river water plays a vital role in increasing the WQI value in the WAWQI method. It is recommended to physically collect the samples of water quality parameters from the study points and perform tests in the lab for comparison of results with the collected water quality data of DoE and SWTP. DO, Ammonia, Total Dissolved Solid and Turbidity have great importance in predicting the water quality of any water body and thus it is recommended to find the pollutant source for these parameters in future studies. Since the presence of microbiological parameters plays an important role in predicting the water quality of any water body, it is further recommended to consider more microbiological parameters for future studies. The mapping of industrial development on the bank of the Shitalakhya River should also be contemplated for future studies.

Competing Interests

The authors declare no competing interests.

Financial Disclosure Statement

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Data Availability

All data generated or analyzed during this study are included in this article.

Author Contribution

- Conception and Design: Mr. Sohel Talukdar
- Acquisition of Data: Mr. Sohel Talukdar
- Analysis and Interpretation of Data: Mr. Sohel Talukdar, Mr. Rizq Amin Mahmud Khan
- Drafting of the Article: Mr. Sohel Talukdar, Mr. Rizq Amin Mahmud Khan

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