Al-Nahrain Journal of Science
ANJS, Vol.27(3), September, 2024, pp. 9-23

Characterization of Cottage Textile Dyeing Effluent of Sirajganj District in Bangladesh

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Article's Information

Received: 10.11.2023
Accepted: 04.08.2024
Published: 15.09.2024

Keywords:
Effluent
Environment
Heavy metals
Physicochemical parameters
Textile dye
Toxic

Abstract

The textile dying industry is one of the most important industrial sectors in Bangladesh. The discharged untreated effluent from different industries adds to the environment a wide variety of harmful chemicals, which cause severe damage to the water. The present study aimed to characterize the discharged effluent surrounding the areas of cottage textile dyeing industries. The effluent samples were collected from different locations of the four upazilas (administrative regions) in Sirajganj district in three seasons, namely the pre-monsoon, monsoon, and post-monsoon, covering two years. The study considered the major physicochemical and chemical parameters, including biological oxygen demand (BOD), chemical oxygen demand (COD), heavy metals, and anions. The analysis results showed that most of the physicochemical parameters, including EC, pH, TDS, TSS, turbidity, BOD, COD, organic matter (OM), total hardness (TH), the cationic and anionic parameters, and trace metals, including Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, and Pb, in effluent samples exceeded the Department of Environment, Bangladesh (DoE-BD) standard, 2008. The most toxic heavy metals, such as Cr, Mn, Cd, and Pb, were found to be higher than the standard permissible limit in all of the collected samples, indicating heavy metal pollution in the area. The analysis results of the Fourier-transform infrared spectroscopy (FTIR) showed that the effluent samples contained toxic functional groups, like azo, cyano, etc., indicating higher levels of pollution due to the discharge of untreated textile dyeing effluent.

http://doi.org/10.22401/ANJS.27.3.02
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1. Introduction

A large volume of effluent from many industries that are dumped into the environment poses a serious hazard to the ecosystem [1-3]. An adequate number of handlooms and power looms are scattered in Bangladesh, but most of them are located in the Sirajgang district. Various kinds of natural, azo, and toxic dyes are used in the cottage textile industries [4]. Discharge of untreated or poorly treated effluent, sewage, sludge, and solid waste into open spaces and water bodies causes environmental degradation [5-8]. The most common uses are (local name) Brown BR, Gray Atic, Violet Atic, Brown Br (China T), Vate Khaki, Hidon Blue, Gernet, Ms. BR, Poltu BR, Sodium (pata), Custic China, Gray Hart Bart, Swice Black, Hidrosgerman, Yellow 5g, Vat ret (Piagi), Pinker, Brown R, etc. [9, 10]. The most important parameters in effluent from the textile dyeing industry are ammonia (NH_3), chemical oxygen demand (COD), biological oxygen demand (BOD), pH value, total suspended solids (TSS), total dissolved solids (TDS), total organic carbon (TOC), electro-conductivity (EC), dissolved oxygen (DO), chloride (Cl^-), and nitrate (NO_3^-). A study showed metals and heavy metals in dyeing effluents, including Na, K, Mg, Al, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb., which are extensively used as color pigments for dyes that have serious environmental concerns [11, 12]. As a result, environmental degradation has become a threat to several villages in the studied areas. Regarding the number quantity of industries and their effluent discharge rates, the waste management procedures of the cottage textile dying industries are insufficient [13]. The poor quality of the water may be significantly impacted by the careless discharge of industrial effluents and other wastes [14-18]. There is not a single effluent treatment plant in the cottage industrial areas of Sirajganj district. Hence, effluents discharged through open drains and underground pipelines from the cottage industries hurt on public health, livestock, fish, wildlife, and other biodiversity [19, 20]. Local people and other living animals have been facing severe problems. Few published reports were found about the characterization and impacts of textile dye effluents on the environment, located in Savar in Dhaka, Tongi in Gazipur, and Naraynganj districts. So far, no detailed research on the untreated textile dyeing effluent of Sirajganj district, Bangladesh, has been published. Hence, the present study findings would explore the present scenarios around cottage textile dyeing areas in the districts. The objective of the study was to characterize cottage textile dyeing effluent to understand the present status of pollutants and identify their sources.

2. Materials and Methods

2.1. The study area

The study area is a district of Rajshahi division in Bangladesh, named Sirajganj. It consisted of four Upazilas, in the Sirajganj district, named Kazipur, Belkuchi, Shajadpur, and Sirajganj Sadar (Figure 1).

2.2. Sample collection

The samples were chosen based on their industrial locations. The effluent samples were collected from various discharge points, attached drains, and surrounding areas of different dyeing units. The sample collection time was classified into three seasons, such as the pre-monsoon, monsoon, and post-monsoon periods of every year. A total of 96 samples were collected over the two years. All the water samples were collected and stored according to standard sampling methods [21].

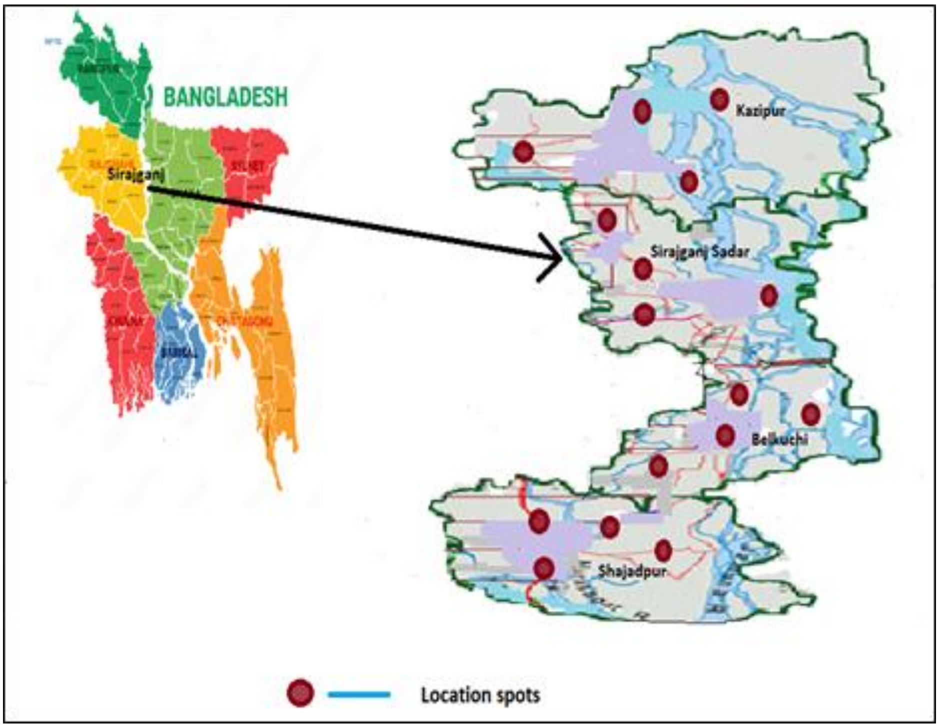

Figure 1. The study area

2.3. Sample preparation and samples analysis

All the parameters of the samples were analyzed using standard methods of analysis. Temperature, electrical conductivity (EC), pH, and dissolved oxygen (DO) of water samples were instantaneously ascertained in the field among the entire physicochemical parameters. The other physicochemical parameters, such as total suspended solids (TSS), total dissolved solids (TDS), turbidity, TH, BOD, COD, total organic carbon (TOC), anionic parameters, including Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, and PO_4^{3-}, cationic parameters, including Na^+, K^+, Mg^{2+}, Ca^{2+}, and heavy metals such as Cr, Mn, Fe, Pb, Ni, Co, Cu, Zn, and Cd of the samples, were investigated following the standard methods of analysis [22]. The empirical data were then analyzed using different computer software.

3. Results and Discussion

3.1. Characterization of effluent

3.1.1. Physicochemical parameters of effluent

The major physicochemical parameters, such as temperature, EC, pH, DO, TSS, TDS, turbidity, TH, BOD, COD, and TOC of effluent samples and their period-based characteristics, including the pre-monsoon, monsoon, and post-monsoon period for two years, were determined, and the levels of pollution in the effluents were measured by comparing the observed values of the various parameters with the standard value recommended by the Department of Environment, Bangladesh (DoE-BD, 2008) [23], and their analytical outcomes are interpreted below.

3.1.1.1. Temperature

The temperature of the effluent is an important factor, and it impacts the admissibility of inorganic constituents and chemical contaminants. The temperature of the effluent was found to be between 19.46 and 35.55 °C. The highest mean temperature was found at 34.16 °C, and the lowest was at 20.02 °C (Figure 2), which is within the standard permissible limit recommended by the DoE-BD. The various temperatures of the effluent samples showed the impact of seasonal variations. The maximum temperature was found to be 35.55 °C in the monsoon period of 2021. The minimum temperature was found to be 19.46 °C in the post-monsoon period of 2021. The results indicate that the effluent temperature varies with seasonal temperature (Table 1) and follows the order of the monsoon > pre-monsoon > post-monsoon. Jinwal and Dixit (2008) supported the present finding, where the effluent temperature was recorded in Bhopal, India [24].

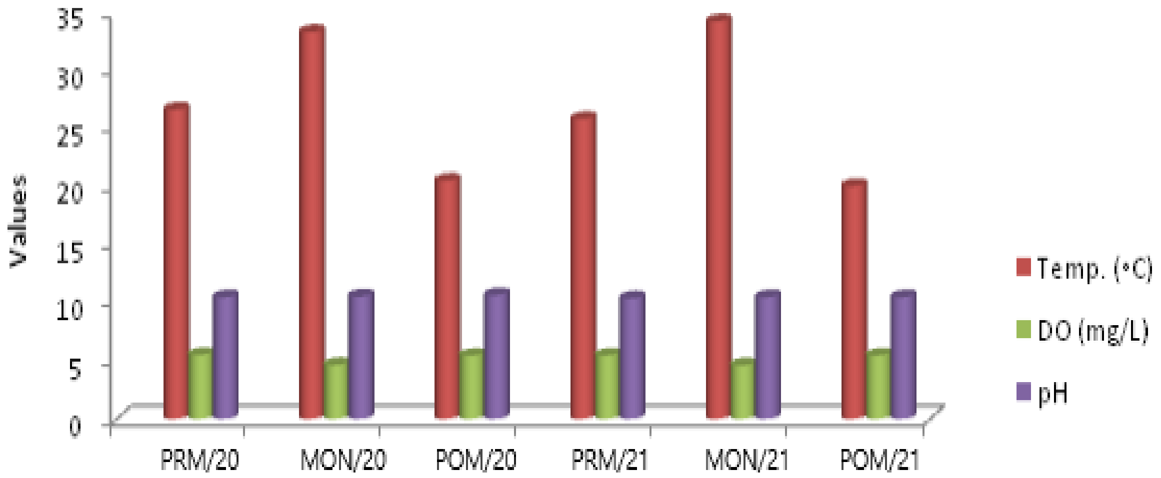

Figure 2. Seasonal variation of average temperature, DO, and pH of effluent samples for 2020-2021.

Table 1. Characterization and seasonal variation of temperature, DO, EC, and pH of effluent samples from 2020-2021.

Parameters	Period ↓	Minimum			Maximum			Mean±SD			Standard
		Pre-monsoon	Monson	Post-monsoon	Pre-monsoon	Monson	Post-monsoon	Pre-monsoon	Monson	Post-monsoon	DoE-BD (2008)
Temp. (°C)	2020	25.6	32	19.46	27.6	34.5	21.97	26.6±0.700	33.25±0.87	20.48±0.86	40
	2021	24.82	32.47	19.27	26.77	35.5	20.78	25.79±0.66	34.16±0.96	20.02±0.52	
	Biyearly (Average)	20.02			34.16			26.89±0.52			
DO (mg/L)	2020	4.32	3.55	4.26	6.76	5.65	6.52	5.51±0.67	4.64±0.54	5.44±0.62	4.5-8
	2021	4.18	3.68	4.25	6.46	5.42	6.55	5.45±0.58	4.60±0.41	5.45±0.59	
	Biyearly (Average)	4.60			5.51			5.85±0.59			
pH	2020	9.35	9.45	9.52	12.95	12.80	13.25	10.48±1.15	10.54±1.07	10.65±1.10	6-9
	2021	9.31	9.19	9.35	12.34	12.85	12.95	10.38±0.96	10.48±1.06	10.48±1.15	
	Biyearly (Average)	10.38			10.65			10.50±1.08			

3.1.1.2. Dissolve oxygen (DO)

The effluent had a DO ranging from 3.55 mg/L to 6.76 mg/L. Figure 2 shows that the mean DO ranges from 4.60 mg/L at the lowest to 5.51 mg/L at the maximum, all of which are within the DoE-BD (2008) suggested standard tolerable level [23]. Seasonal variation was evident in the various DOs of the collected effluent samples. The highest DO recorded in 2020's pre-monsoon season was 6.76 mg/L. During the 2020 monsoon season, the lowest DO was determined to be 3.55 mg/L (Table 1). The majority of the effluent samples have less DO (less than 5 mg/L) than the DoE-BD (2008) standard [23]. A research report on the wastewater from the textile-dying industries in Narayanganj showed a similar observation [25].

3.1.1.3. pH

The samples of effluent had pH values ranging from 9.19 to 13.2. It was found that in 2020, during the post-monsoon period, the maximum pH was 13.25. During the 2021 monsoon season, the lowest pH was found to be 9.19 (Figure 2). The majority of the effluent samples are found to have pH values greater than the DoE-BD standard (2008) [23]. Figure 2 shows that the mean pH ranged from 10.65 to 10.38, both of which were significantly higher than the DoE-BD's standard permitted limit. Because H_2O_2 and NaOH were used as bleaching and kier agents, the pH of the cottage textile dying industries was higher. The various pH values of the collected effluent samples show seasonal variations (Table 1) and follow the order of pre-monsoon > post-monsoon > monsoon. The results indicated that the higher pH values found in the pre-monsoon period were due to the high concentration of effluent, and the lower pH values found in the monsoon period were due to the dilution of the effluent with rainwater during the monsoon period. Kuldip *et al.* (2013) supported the present finding, where the pH of the effluent samples in Bhathinda district of Punjab, northwest India, varied from 8.65 to 12.4 and was found to be higher in pre-monsoon than monsoon [26].

3.1.1.4. Electrical conductivity (EC)

The EC of the effluent varied from 9774 µS/cm to 28800 µS/cm. The minimum EC was found in the pre-monsoon period of 2020. Most of the effluent samples in the study area contain a higher EC than the DoE-BD standard (2008) [23]. The maximum mean EC was found to be 16383 (Figure 3 and Table 2). The EC was found to be about 8 to 24 times higher than the DoE-BD standard. The average concentrations of EC were found to be higher than the DoE-BD standard (2008). The results indicate that the EC of effluent samples varied with seasons (Figure 3), and the highest was found in the pre-monsoon period. Sundar and Saseetharan (2008) supported the present finding, where the EC of effluent measured in pre-monsoon in Tamil Nadu, India, was higher than the monsoon [27]. The EC of effluent samples increased in the pre-monsoon due to a decrease in water volume. A similar research study described the value of the EC of effluent, which varied from 3320 µS/cm to 24500 µS/cm in Visakhapatnam, Andhra Pradesh, a port city in India [28].

3.1.1.5. Total suspended solids (TSS)

In the effluent samples, the TSS values ranged from 1193 mg/L (during the post-monsoon season of 2020) to 2415 mg/L (during the monsoon period of 2020), with 1681 mg/L being the highest average value. It is found that the TSS concentrations in the effluent samples are between 11 and 24 times higher than the DoE-BD standard (Figure 3 and Table 2). The high TSS value of all samples is because clay, algae, and bacteria decompose organic particles in the effluent samples [29]. The findings show that the TSS of effluent samples varied with the seasons (Figure 3), with the sequence of monsoon < post-monsoon < pre-monsoon. The effluent of the textile dying industry in Narayanganj was studied by Sultana et al. (2009) and illustrated the findings that the TSS value ranged from 736 to 1960 mg/L, with an average value of 1123 mg/L [25]. Those results were similar to those of the present study.

3.1.1.6. Total dissolved solids (TDS)

The TDS in the collected samples ranged from 5424 mg/L to 13633 mg/L. The highest TDS value was found in the pre-monsoon period of 2020, and the lowest was found in the monsoon period of 2020. The various TDS values of collected effluent samples showed seasonal variations (Figure 3) and followed the sequence of monsoon < post-monsoon < pre-monsoon. During the monsoon period, the increase in the water volume was due to a decrease in TDS. The analysis results showed that the effluent samples contain 2 to 6 times higher TDS values than the tolerable limit of DoE-BD (Figure 3 and Table 2). A report showed that the TDS ranged from 6405 mg/L to 7378 of the influents at the Centra effluent treatment plant (CETP) in Savar, Dhaka, Bangladesh [30], which supported the present study.

3.1.1.7. Turbidity

The effluent turbidity in the study area was found between 67.14 FTU to 199.8 FTU (Figure 3 and Table 2). The maximum turbidity was found in the monsoon season of 2020. The minimum value was found in the pre-monsoon of 2020. The study results showed that the effluent samples had turbidity concentrations about 3–10 times higher than the DoE-BD standard. The fish culture of the study area becomes threaded due to high turbidity. The high turbidity indicates pollutants, harmful bacteria, and the presence of pathogenic microorganisms, which are indicators of hazardous events throughout, affecting gill function [31]. Another report showed the turbidity of effluent varying from 78.14 to 290.8 FTU in Patancheru, Andhra Pradesh, India, where the values were similar to study one [32].

Table 2. Characterization and seasonal variation of turbidity, TH, EC, TSS, and TDS of effluent samples from 2020-2021.

Parameters	Period ↓	Minimum			Maximum			Mean±SD			Standard
		Pre-monsoon	Monson	Post-monsoon	Pre-monsoon	Monson	Post-monsoon	Pre-monsoon	Monson	Post-monsoon	DoE-BD
Turb. (NTU)	2020	68.80	67.14	74.63	199.8	174.93	162.81	131.06±36.4	117.52±27.4	112.88±25.5	20
	2021	75.61	78.42	63.25	167.9	164.8	153.2	118.88±25.6	112.51±24.1	111.68±27.8	
	Biyearly	111.68			131.06			117.42±27.83			
TH (mg/L)	2020	430	416	410	826	802	776	588.12±121.86	561±102.65	562±98.91	200-500
	2021	408	395	382	756	744	788	560.25±108.79	551.43±91.76	544.8±109.2	
	Biyearly	544.81			588.12			561.27±105.62			
EC (μS/cm)	2020	9774	10654	10887	26520	27250	28800	16008±5167	16201±5473	16383±5646	1200
	2021	9976	10004	10633	26812	27380	27352	15567±5481	15890±5621	16009±5444	
	Biyearly	15567			16383			16010±5472			
TSS (mg/L)	2020	1375.2	1202.4	1197	2188.8	2415.6	2167.2	1681.52±237.6	1598.24±322.9	1571.66±28	100
	2021	1274.4	1193.4	1216.8	2280.6	2206.8	2248.2	1612.8±286.07	1541.8±286.15	1557.55±27	
	Biyearly	1541.80			1681.52			1593.92±283.42			
TDS (mg/L)	2020	5609.45	6165.5	5519.2	14428.	12697.	13633.9	9249.93±2539	8680.72±2398	8860.96±2782	2100
	2021	5619.9	5424.1	5515.4	13360	12483	12685.7	8832.05±2398	8512.05±2399	8644.79±2405	
	Biyearly	8512.05			9249.93			8796.65±2487.27			

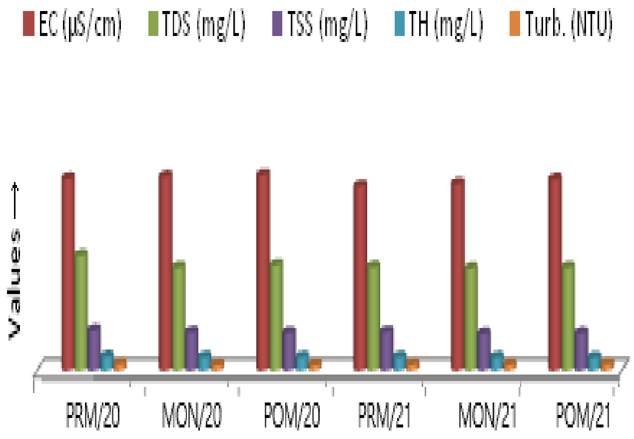

Figure 3. Seasonal variation of average EC, TDS, TSS, TH, and turbidity of effluent samples for 2020-2021.

3.1.1.8. Total hardness (TH)

The values of the total hardness (TH) of effluent samples varied from 382 mg/L to 826 mg/L (Figure 3 and Table 2). The maximum value of TH was found in the pre-monsoon period of 2020, and the lowest value of total hardness (TH) was found in the monsoon period of 2021. In the analysis, the TH values of collected effluent samples showed little seasonal variation (Figure 3) and followed the sequence of post-monsoon <monsoon < pre-monsoon. During the monsoon period, the values of TH of the collected samples decreased due to an increase in water volume. On the other hand, the dye concentration increased in the pre-monsoon period due to the evaporation of the effluent. For this reason, the TH of effluent samples becomes higher in the pre-monsoon and post-monsoon periods than in the monsoon period. Usually, higher values of TH in the pre-monsoon period indicated the presence of a higher content of calcium carbonate, bicarbonate, and chloride in the dyes and other chemicals, whereas lower values of TH indicated the opposite in the monsoon period. The analysis results of TH illustrate that the effluent samples in the pre-monsoon and post-monsoon periods fell under the hard to very hard category, while the monsoon samples fell within the hard categories. Islam, M.R., and Mostafa (2020) supported the present findings, where the TH of effluent was found to be higher in the pre-monsoon and post-monsoon periods than in the monsoon in the Rajshahi BSCIC industrial area in Bangladesh [12]. A similar observation was made by Nusrat *et al.* (2010) around the Oshnavieh area, northwest of Iran, where the TH values varied from 325 to 848 mg/L in the effluent samples [33].

3.1.1.9. Biological oxygen demand (BOD)

The biological oxygen demand (BOD) of the effluent samples ranged from 174.4 to 559.11 mg/L (Table 4.3), and the highest mean value was found to be 354.2 mg/L. The highest value of BOD was found in the monsoon season of 2020, and the lowest value of BOD was found in the post-monsoon period of 2021. The results showed that the BOD of effluent showed slightly seasonal variations (Figure 4) and followed the order of pre-monsoon >monsoon > post-monsoon. The dye and other chemical concentrations increased in the pre-monsoon period due to the evaporation of the effluent. On the other hand, in the monsoon season, the BOD values of collected effluent samples decreased due to an increase in water volume. For these reasons, the BOD of effluent samples becomes high in the pre-monsoon and post-monsoon periods. The study results showed that the BOD of the collected samples was six times higher than the standard. The analysis results indicate that the selected study area is not suitable for fish and other aquaculture due to the high values of BOD. Research illustrated that the BOD values of the effluent of the DEPZ industrial area at Saver were found to be 11 to 18 times higher than the DoE-BD standard [34]. Another report showed the BOD concentration of dye effluent samples collected in different industrial zones varied from 192 to 272, which supports the present results [12].

3.1.1.10. Chemical oxygen demand (COD)

The values of COD in effluent samples ranged from 257.39 mg/L to 698.63 mg/L (Table 3). The maximum COD value was found in the pre-monsoon of 2020, and the lower value of COD was found in the post-monsoon season of 2020. The study results showed a little seasonal variation (Figure 4) and followed the order of pre-monsoon >monsoon > post-monsoon. The dye and other chemical concentrations increased in the pre-monsoon period due to the evaporation of the effluent. On the other hand, COD values decreased in the monsoon period due to an increase in water volume. For these reasons, the COD of effluent samples becomes high in the pre-monsoon and post-monsoon. The present analysis results showed that effluent samples contain a three-fold higher COD value than the DoE-BD standard. A report illustrated that the explanation of samples of dye effluent collected from three different industrial zones varied from 510 to 780, which is similar to the present results [12].

Table 3. Characterization and seasonal variation of BOD, COD, and TOC of effluent samples from 2020-2021.

Parameters	Period ↓	Minimum			Maximum			Mean±SD			Standard
		Pre-monsoon	Monson	Post-monsoon	Pre-monsoon	Monson	Post-monsoon	Pre-monsoon	Monson	Post-monsoon	DoE-BD
BOD (mg/L)	2020	223.12	174.44	195.54	559.11	521.67	507.47	323.68±109.6	317.5±100.3	323.28±92.13	50
	2021	212.98	199.28	206.13	532.49	495.93	514.18	328.03±95.34	320.40±93.58	324.21±93.65	
	Biyearly (Average)	317.53			328.03			322.85±97.44			
COD (mg/L)	2020	298.12	257.39	296.19	698.63	645.37	656.76	463.26±129.5	458.69±108.76	453.20±118.87	200
	2021	315.10	298.14	312.62	665.37	651.06	658.21	470.94±113.12	455.94±112.71	463.44±112.39	
	Biyearly (Average)	453.20			470.94			460.91±115.89			
TOC (mg/L)	2020	280.94	264.08	264.58	616.45	615.74	586.42	391.67±114.01	390.90±114.21	397.10±99.0	35-40
	2021	264.41	248.22	256.43	646.57	616.95	616.24	386.24±131.72	391.35±114.31	391.40±114.29	
	Biyearly (Average	386.24			397.10			391.44±114.51			

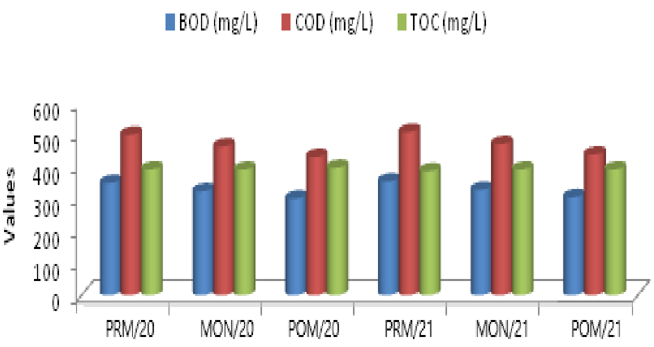

Figure 4. Seasonal variation of average BOD, COD, and TOC of effluent samples for 2020-21.

3.1.1.11. Total organic carbon (TOC)

The values of TOC in the effluent samples ranged from 248.22 mg/L to 646.57 mg/L (Table 3). The pre-monsoon period of 2021 had the lowest TOC value, while the monsoon period of 2020 had the highest value. According to the study's findings, the TOC values of the effluent samples that were analyzed showed small seasonal variations (Figure 4) and were ordered pre-monsoon < monsoon < post-monsoon. Due to the effluent's evaporation, the content of dye and other organic compounds in the pre-monsoon period increased. However, because of increased water volume and filtration during the monsoon season, the TOC values of the effluent samples were reduced. These factors cause the TOC of effluent samples to increase before and after the monsoon season compared to the monsoon season. The present analysis results showed that effluent samples contain a 5–15 times higher TOC value than the DoE-BD standard. Tareque and Mostafa (2023) illustrated that the TOC value was found to be 833 mg/L in a dye industrial effluent sample collected from the BSCIC industrial zone in Rajshahi, Bangladesh, which was slightly higher than the present study, indicating a similar TOC concentration of dyeing effluent [16].

3.2. Anionic parameters of effluent

3.2.1. Chloride (Cl^-)

The analysis results showed that the chloride (Cl^-) concentration ranged from 698.63 mg/L to 1303.41 mg/L. According to the study's findings, the effluent samples' chloride (Cl^-) contents were found to be two to four times higher than the DoE-BD standard (Table 4). The pre-monsoon season of 2020 had the highest value, while the post-monsoon period of 2021 had the lowest. The analysis results showed that the chloride (Cl^-) values of collected effluent samples showed little seasonal variation and followed the order of pre-monsoon >monsoon > post-monsoon. The dye and other chemical concentrations increased in the pre-monsoon period due to the evaporation of the effluent. In a similar research study carried out by Sultana *et al.* (2009), the concentration of chloride (Cl^-) in the effluent from the textile dying industries in Narayanganj varied from 1035 mg/L to 69494 mg/L [25].

3.2.2. Bicarbonate (HCO_3^-)

The bicarbonate (HCO_3^-) value ranged from 342.88 mg/L to 735.50 mg/L, which is found to be two times higher than the permissible limits of the DoE-BD. The maximum value was found in the pre-monsoon season of 2020, and the lowest value was found in the post-monsoon period of 2021 (Table 4). The bicarbonate (HCO_3^-) values showed slightly seasonal variations and followed the order of post-monsoon <monsoon < pre-monsoon. These findings suggest that the bicarbonate (HCO_3^-) level in the water is unsuitable for fishing. Tariq *et al.* (2006) conducted similar and supporting research, where the HCO_3^- varied from 390.56 to 912.82 mg/L in the industrial effluent of the Hayatabad industrial estate, Peshawar, Pakistan [35].

3.2.3. Sulfate (SO_4^{2-})

Sulfate (SO_4^{2-}) concentration varied from 462.58 mg/L to 866.59 mg/L. Sulfate (SO42-) levels in the effluent samples were found to be higher than the DoE-BD standard, according to the study results (Table 4). Sulfate (SO42-) was found to have the maximum value in the post-monsoon season of 2021 and the lowest value in the 2020 monsoon period. According to the study's findings, the sulfate (SO_4^{2-}) values of the effluent samples that were analyzed showed slightly seasonal variations and were ordered as follows: monsoon < pre-monsoon < post-monsoon. These higher values indicate that the sulfate (SO_4^{2-}) level in the water is unsuitable for fishing.

Table 4. Statistical analysis of Cl^-, HCO_3^-, SO_4^{2-}, NO_3^- concentration, and PO_4^{3-} in effluent samples during 2020 and 2021.

Parameters (mg/L)	Pre-monsoon	Monsoon	Post-monsoon	Standards		
	Mean ± SD	Mean ± SD	Mean ± SD	DoE-BD	WHO	FAO
Cl^-	967.3±3.4	956.1±5.3	961.9±5.2	150-600	250	1065
SO_4^{2-}	665.6±7.3	662.8±5.9	663±7.4	400	250	960
NO_3^-	148.6±0.3	144.7±0.2	147.9±0.4	10	--	<10
HCO_3^-	539.2±5	534.1±11	537.3±5.8	200	--	610
PO_4^{3-}	63.5±0.3	61.2±0.2	62.8±0.2	--	--	2.0

3.2.4. Nitrate (NO_3^-)

The concentration of nitrite (NO_3^-) ranged from 81.89 mg/L to 131.25 mg/L. According to the study findings, nitrite (NO_3^-) concentrations in the effluent samples were 10–13 times higher than the DoE-BD standard (Table 4). The post-monsoon season of 2021 had the highest value of nitrite (NO_3^-), whereas the monsoon period of 2020 had the lowest value. The study's findings showed that there was little seasonal variation in the nitrite (NO_3^-) values of the collected effluent samples, which showed post-monsoon > pre-monsoon > monsoon sequences. These high values indicate that the nitrite (NO_3^-) level in the water is unsuitable for fishing. Islam, M.R., and Mostafa (2020) supported the present findings, which showed that in the Rajshahi BSCIC industrial area in Bangladesh, the (NO_3^-) content of effluent was higher in the pre-monsoon and post-monsoon periods than it was during the monsoon [12]. The nitrite (NO3-) in the textile effluents of Bangladesh's Narsingdi Sadar industrial region ranged from 510.6 to 1230.4 mg/L, according to another study that was observed and supported by the present findings [36].

3.2.5. Phosphate (PO_4^{3-})

Phosphate (PO_4^{3-}) concentrations in water varied from 33.19 mg/L to 61.55 mg/L. According to Table 4, the pre-monsoon season of 2020 had the highest value, and the monsoon period of 2021 had the lowest. Phosphate concentrations in wastewater are significantly higher than the FAO's allowable limit (Table 4). The study's findings showed that there was little seasonal variation in the phosphate (PO_4^{3-}) values of the collected effluent samples, which followed a pre-monsoon > post-monsoon > monsoon sequence. A report showed industrial wastewater samples collected from Ghaziabad, India, where the phosphate (PO_4^{3-}) value ranged from 21.04 mg/L to 47.51 mg/L, which supports the present findings [37].

3.3. Cationic perimeters of effluent

The cationic perimeters like Na^+, K^+, Mg^{2+}, and $Ca^{2+}$of effluent samples are analyzed, which were collected in the three seasons of 2020 and 2021.

3.3.1. Sodium (Na^+)

The concentration of sodium (Na+) in the samples ranged from 594.27 mg/L to 1221.75 mg/L (Table 5). According to the study's findings, the 2020 monsoon period had the lowest value, while the post-monsoon period had the highest value. It was found that the sodium (Na+) concentration in effluent was two to six times higher than the DoE-BD's allowable limit (Table 5). According to the study's findings, there was a low seasonal change in the sodium (Na+) values of the effluent samples that were analyzed (Table 6), and the values followed the post-monsoon < pre-monsoon < monsoon sequence. A similar investigation was made by Joshi *et al.* (2015) in the Maharashtra state of India and found that the sodium (Na^+) values of the effluents varied from 417 mg/L to 1040 mg/L, and the highest value was found in the post-monsoon period of the effluent samples of the dyeing and printing industries [38].

3.3.2. Potassium (K^+)

According to the study's findings, the potassium concentration in the effluent samples varied from 49.10 mg/L to 100.09 mg/L (Table 5). The pre-monsoon period of 2021 generated the highest value, while the same period of 2021 generated the lowest. According to the study, potassium levels in the effluent samples were four to eight times higher than the DoE-BD standard. The findings showed there was little seasonal variation in the potassium (K^+) values of the collected effluent samples (Table 6) and that the values followed the pre-monsoon > post-monsoon > monsoon sequence. A similar study illustrated that the textile dyeing effluent had the highest potassium (K^+) value, which was found to be 93.08 mg/L in the BSCIC industrial estate in Rajshahi, which supported the present study results [1].

Table 5. Na_+, K_+, Mg^{2+}, and Ca^{2+} Concentration in effluent samples during 2020 and 2021.

Cations (mg/L)	Count	Minimum	Maximum	DoE-BD standard
Na^+	96	594.27	1221.75	200
K^+	96	49.10	100.09	12
Mg^{2+}	96	93.61	211.79	30-35
Ca^{2+}	96	235.99	435.78	75

Table 6. Statistical analysis of Na^+, K^+, Mg^{2+}, and Ca^{2+} concentrations in effluent samples during 2020 and 2021.

Parameters (mg/L)	Pre-monsoon	Monsoon	Post-monsoon	Standards		
	Mean ± SD	Mean ± SD	Mean ± SD	DoE-BD	WHO	FAO
Na^+	909.1±5.5	906.0±4.7	910.4±3.4	200	200	920
K^+	75.8±0.8	73.6±0.3	74.0±0.3	12	--	15
Ca^{2+}	336.3±0.7	332.4±0.8	334.5±0.2	75	--	40
Mg^{2+}	152.6±1.8	150.8±0.7	151.6±0.4	30-35	--	60

3.3.3. Magnesium (Mg^{2+})

According to the study's findings, the magnesium concentration in the effluent samples varied from 93.61 mg/L to 211.79 mg/L (Table 5). The monsoon period of 2021 had the lowest value, while the post-monsoon period had the highest value. The magnesium concentration in the effluent samples was found to be three to six times higher than the DoE-BD (2008) limit [23]. The study findings showed that the magnesium concentrations in the collected effluent samples show slightly seasonal variations (Table 6) and are sequenced as post-monsoon > pre-monsoon > monsoon. A corresponding research study showed the magnesium concentration in the effluent of Ibadan, Oyo State, Nigeria, varied from 61.08 to 198.45 mg/L in Kaduna, Oyo State, Nigeria [39].

3.3.4. Calcium (Ca^{2+})

Calcium ($Ca2+$) concentrations in water varied from 235.99 mg/L to 435.78 mg/L (Table 5). The monsoon period of 2020 had the lowest value, while the post-monsoon period of 2021 had the highest value. The calcium concentration in the effluent samples was found to be four to five times higher than the DoE-BD (2008) limit [23]. The study's findings indicated that the analyzed effluent samples' calcium ($Ca2+$) concentrations show small seasonal variations (Table 6) and follow the post-monsoon > pre-monsoon > monsoon sequence. A study conducted on effluent samples in the BSCIC industrial area of Rajshahi showed that the highest value was 372.21 mg/L, which is similar to the present study results [1].

3.4. Concentrations of the heavy metals

In this study, 10 heavy metals, namely Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, and Pb, were analyzed in the effluent samples of 2020 and 2021. The analysis results of the effluent samples are illustrated in Tables 7 and 8.

3.4.1. Chromium (Cr)

It was found that the lowest and maximum concentrations of Cr were 0.058 mg/L and 0.398 mg/L, respectively. Table 7 shows that the mean concentration of Cr was found to be 0.486 mg/L with a standard deviation of 0.111. In 2020, the post-monsoon season had the highest mean concentration of Cr in the effluent (0.328 mg/L), whereas the monsoon period had the lowest mean concentration (0.187 mg/L) (Table 7). The findings showed that the order of Cr concentration in the effluent samples was post-monsoon > pre-monsoon > monsoon. Similar findings were reported by Monica Das et al. (2011) for the textile effluent, where the Cr concentration ranged from 0.116 to 0.385 mg/L [40]. A similar report showed that the textile effluent of Bangladesh's Narsingdi district had a Cr concentration of 0.133 mg/L [1]. The DoE-BD's recommended allowable limit for the concentration of Cr in the research area was exceeded (Table 7). Ram and Sunil (2011) stated that effluent samples from textile industries in Mumbai, India's Taloja industrial estate, were found to have a biyearly mean concentration of Cr ranging from 16.9 mg/L to 35.2 mg/L [41].

Table 7. Statistical analysis of concentration of Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, and Pb in effluent samples during 2020 and 2021.

Parameters (mg/L)	Minimum	Maximum	Mean±SD	DoE-BD standard(mg/L)
Fe	0.581	5.88	2.7313±1.4	2.0
Mn	0.104	2.27	1.4869±0.04	5.0
Zn	3.15	6.011	4.9108±0.09	5.0
Cr	0.058	0.398	0.4869±0.12	0.5
Cd	0.001	0.112	0.0568±0.01	0.05
Pb	0.284	0.498	0.3616±0.16	0.1
Co	0.258	0.549	0.352± 0.04	0.2
Ni	0.179	0.462	0.221±0.07	0.1
Cu	0.194	0.310	0.251±0.11	0.1
As	0.075	0.381	0.221±0.06	0.2

3.4.2. Manganese (Mn)

Manganese is an essential trace element for our bodies in small amounts. It was found that the Mn level ranged from 0.105 mg/L at the minimum to 2.27 mg/L at the maximum. Mn was found to have a mean concentration of 1.48 mg/L and a standard deviation of 0.038 (Table 7). Table 7 shows that the maximum mean concentration of Mn in the effluent was obtained during the pre-monsoon season of 2021, at 3.59 mg/L, and the lowest during the monsoon period of 2020, at 1.67 mg/L. The findings showed that the order of Mn concentration in the effluent samples was monsoon < post-monsoon < pre-monsoon. A study illustrated a similar observation for wastewater from three different industrial areas, i.e., Narsingdi, Bangladesh Small and Cottage Industries Corporation (BSCIC) of Rajshahi, and Gazipur industrial areas of Bangladesh, where the range of the Mn was 0.2–0.4 mg/L [12]. The analysis's findings indicated that the Mn concentration was within the DoE-BD's recommended allowable range (Table 7).

3.4.3. Iron (Fe)

Iron is a chemical element. It is the most common element on Earth. Fe concentrations ranged from 0.581 mg/L at the minimum to 5.89 mg/L at the maximum. Fe concentrations were found to be 2.73 mg/L on average, with a 1.41 standard deviation (Table 7). Fe concentrations in the effluent ranged from 0.790 mg/L during the monsoon period of 2021 to 6.49 mg/L during the pre-monsoon period of 2020 (Table 8). The analysis results showed the order of monsoon < post-monsoon < pre-monsoon was followed by the concentration of Fe in the effluent samples. The present study's findings correspond with the research conducted by Islam, M.R., and Mostafa (2020) on effluent samples obtained from Rajshahi's BSCIC industrial area, where the mean concentration was found to be 3.6 mg/L [12]. The DoE-BD's recommended allowable limit for Fe concentration was found to be three times higher in the research area (Table 7). There appears to be less Fe poisoning in the area, as the study results are considerably lower than the reported values.

3.4.4. Cobalt (Co)

The minimum concentration of Co was found to be 0.258 mg/L, and the maximum was 0.549 mg/L. Table 7 shows that the average concentration of Co was found to be 0.352 mg/L with a standard deviation of 0.041. According to Table 8, the maximum average concentration of Co in the effluent was found during the post-monsoon period of 2021 at 0.648 mg/L, while the minimum was found during the monsoon period of 2020 at

0.210 mg/L. The findings indicated that the order of Co concentration in the effluent samples was post-monsoon > pre-monsoon > monsoon. Sultana et al. (2009) investigated the effluent of the textile dying industry in Narayanganj and found that similar to the present study, the average Co value was 0.531 mg/L and ranged from 0.297 to 0.765 mg/L [25]. The concentration of Co in the study area was found to be three times higher than the DoE-BD's standard allowable limit (Table 7). The study results indicate CO poisoning in the area.

3.4.5. Nickel (Ni)

Ni concentrations ranged from 0.179 mg/L at the lowest to 0.462 mg/L at the highest. Ni was found to have a mean value of 0.221 mg/L and a standard deviation of 0.075 (Table 7). Ni concentrations in the effluent ranged from 0.102 mg/L during the monsoon period of 2020 to 0.629 mg/L during the pre-monsoon period of 2021 (Table 8). The results showed that monsoon < post-monsoon < pre-monsoon was the sequence in which the concentration of Ni in the effluent samples increased. Similar investigations were carried out at Patancheru, Andhra Pradesh, India, and reported that the level of Ni in the effluent varied from 0.212 to 0.654 mg/L [32]. The concentration of Ni in the research area was found to be two to six times higher than the DoE-BD's standard allowable limit. The study results indicate Ni poisoning in the area.

3.4.6. Copper (Cu)

Cu was found to have a low value of 0.194 mg/L and a maximum concentration of 0.310 mg/L. Cu was found with a mean level of 0.251 mg/L and a standard deviation of 0.101 (Table 7). The Cu mean concentration in the effluent was found to be 0.104 mg/L during the monsoon period of 2021 and 0.366 mg/L during the pre-monsoon period (Table 8). The results showed the order of monsoon < post-monsoon < pre-monsoon was followed by the concentration of Cu in the effluent samples. According to a published report, the average concentration of Cu was found to be 1.7 mg/L in the tannery industrial area of Savar, Dhaka district, Bangladesh [30]. This value is considerably higher than the results of the present study. The concentration of Cu in the study area was found to be three times higher than the DoE-BD's standard permissible limit (Table 7). The study results indicate copper poisoning in the area.

3.4.7. Zinc (Zn)

Zn concentrations ranged from 3.16 mg/L at the lowest to 6.01 mg/L at the highest. Zn was found with a mean value of 4.91 mg/L and a standard deviation of 0.09 (Table 7). Table 8 shows that the mean concentration of zinc in the effluent varied from 2.99 mg/L during the monsoon period of 2021 to 6.21 mg/L during the pre-monsoon period. Research results showed the proportion of pre-monsoon to post-monsoon to monsoon Zn concentration in the effluent samples. The concentration of zinc in the study area was found to be within the DoE-BD's standard permissible limit (Table 7).

3.4.8. Lead (Pb)

The minimum concentration of Pb was found to be 0.284 mg/L, and the maximum was found to be 0.498 mg/L. The mean concentration of Pb was found to be 0.362 mg/L, and the standard deviation was 0.166 (Table 7). Pb concentrations in the effluent ranged from 0.208 mg/L during the monsoon period of 2021 to 0.587 mg/L during the pre-monsoon period of 2020 (Table 8). The results showed that the concentration of Pb in the effluent samples followed the order of pre-monsoon >post-monsoon > monsoon. In a similar investigation, Satyanaratana et al. (2013) reported that Pb levels in effluent in the Indian port city of Visakhapatnam, Andhra Pradesh, ranged from 0.332 to 0.523 mg/L [28]. Pb concentrations in the study area were found to be 2-4 times higher than the DoE BD's standard permissible level (Table 7). The study results indicate Pb poisoning in the area.

3.4.9. Cadmium (Cd)

The minimum concentration of cadmium (Cd) was found to be 0.0013 mg/L, and the maximum was 0.1115 mg/L. Table 7 shows that the mean concentration of Cd was found to be 0.0568 mg/L, with a standard deviation of 0.0021. The mean concentration of Cd in the effluent was 0.0009 mg/L during the monsoon period of 2020 and 0.1139 mg/L during the pre-monsoon period of 2021. Research results showed that the order of Cd concentration in the effluent samples was pre-monsoon > post-monsoon > monsoon. A similar investigation was conducted in the Maharashtra state of India and found that the Cd values of the effluents varied from 0.0012 mg/L to 0.067 mg/L in the effluent samples of the dyeing and printing industries [38]. The concentration of Cd in the study area was found to be twice as high as the DoE-BD's standard permissible limit (Table 7). The study results indicate Cd poisoning in the area.

3.4.10. Arsenic (As)

Arsenic (As) concentrations ranged from 0.075 mg/L at the lowest to 0.381 mg/L at the highest. The As was found to have a mean concentration of 0.221 mg/L and a standard deviation of 0.053 (Table 7). According to Table 7, the effluent's mean As content ranged from 0.151 mg/L during the monsoon period of 2021 to 0.442 mg/L during the pre-monsoon period of 2020. Results showed that the order of As concentration in the effluent samples was pre-monsoon > post-monsoon > monsoon. There was no arsenic poisoning in the research area since the concentration of As was found to be under the standard permissible limit of DoE-BD (Table 7).

3.5. FTIR analysis of functional groups in effluent

The study displayed the presence of some organic functional groups in the effluent sample using FTIR. In the study, a large number of functional groups were found in effluent samples, which were detected by FTIR. The frequency ranges of effluent samples were found to be 484 cm^{-1} to 3650 cm^{-1} (Table 8). In the FTIR spectra ranges of 2000 to 2640 cm^{-1}, the absorption appearance was found to be strong; in the ranges of 460 to 1980 cm^{-1}, the absorption appearance was found to be medium; and in the range of 2650 cm^{-1} to 3650 cm^{-1}, the absorption appearance was found to be weak. The absorption frequency ranges of 600 to 1610 cm^{-1} were found for C-I, C-Br, C-Cl, N-H, and C-C stretching, which indicates the presence of alkyl halides, amines, and alkines groups respectively (Table 8). The absorption frequency ranges between (1630 – 2130) cm^{-1} were found for C=O, O-H, C-H, N-H, and C=C=N stretching, which indicate the presence of acid halide, carboxylic acids, alkanes, amides, and ketenimine, and the ranges between (2140–3650) cm^{-1} for –N=N-, -N=O, =C=N-, and OH stretching, which indicate the presence of azo, nitroso, cyano, and hydroxyl groups. So, the study results confirm that the dyes and other chemicals in cottage textiles in the study areas contain alkyl halides, amines, alkenes, acid halides, carboxylic acids, alkanes, amides, ketenimine, azo, nitroso, cyano, and hydroxyl groups. Among those groups, the azo group was found to have a strong absorption appearance between 2140 and 2160 cm1, which group is very harmful to human health, aquatic life, and other microorganisms [12].

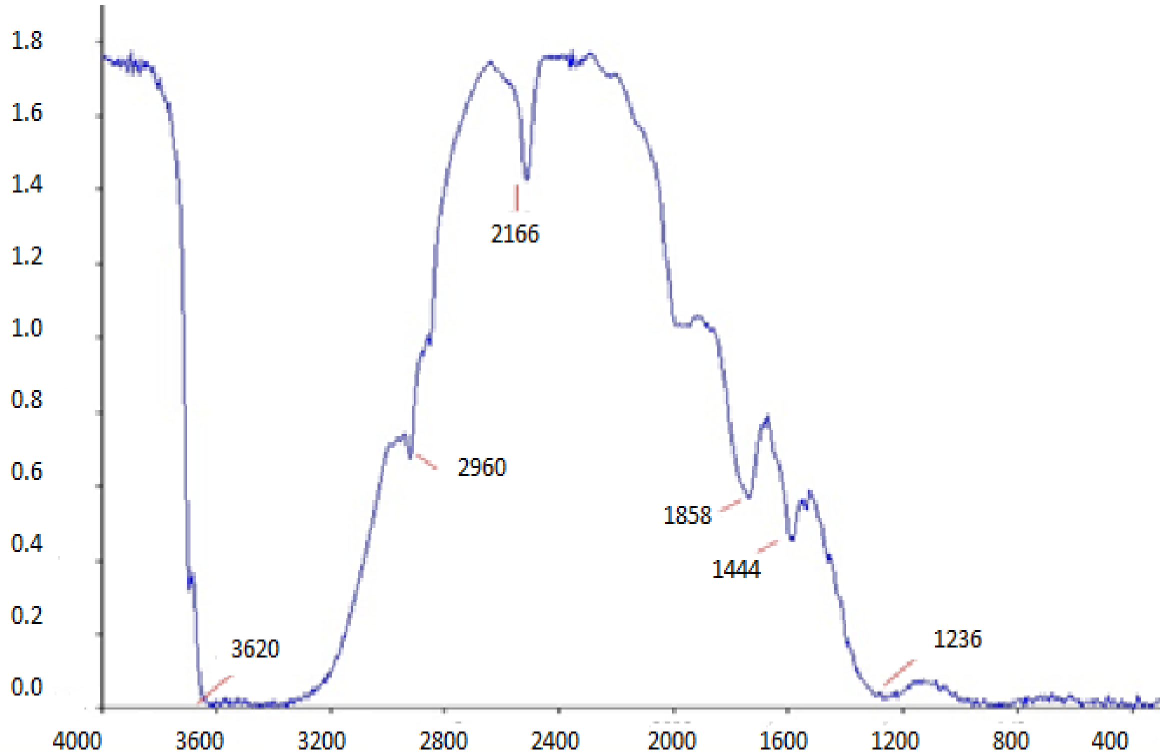

Figure 5. FTIR absorption bands of specific functional groups in effluent.

Table 8. FTIR spectra of functional groups in effluent [42]

Peak (cm^{-1})	Range (cm^{-1})	Intensity	Assignment	Functional group
1630	1640- 1500	Bend	N-H	amines
1633.5	1690- 1630	Stretch	C=C	Alkenes
1640- 1610	1640- 1610	Stretch	C=C	alkenes
1805	1810-1775	Stretch	C=C=N	ketenimine
2540	2140-2160	Stretch	-N=N-	azo
2938	3400-2400	Stretch	O-H	carboxylic acids
3200-3600	3000-2850	Stretch	C-H	alkanes
3602.5	3500-3300	Stretch	N-H	amines
3620	3700-3500	Stretch	N-H	amides
3685	~3650	Stretch	O-H	alcohols

4. Conclusions

The analysis results showed that most of the physicochemical, cationic, anionic, and trace metals in effluent samples exceeded the DoE-BD standard. The most toxic heavy metals, such as Cr, Mn, Cd, and Pb, were found to be higher than the standard permissible limit in all of the collected samples, which implied that the cottage textile industries are causing Cr, Mn, Cd, and Pb pollution in the study areas. It is a matter of concern that these metal ions can produce organometallic compounds by chemical reactions with organic functional groups found in the eluent, which cause severe damage to the environment and humans. The results showed that all parameters of effluent samples exceeded the DoE-BD, WHO, and USEPA permissible levels. In addition, the result showed that the cations found in the effluent follow the order: $Na^+ > Ca^{2+} > K^+ > Mg^{2+} > Fe^{3+} > Mn^+ > Zn^{2+} > Pb^{2+} > Cr^{3+} > Cu^{2+} > Cd^{2+}$ while the anions follow the order: $Cl^- > SO_4^{2-} > PO_4^{3-} > HCO_3^- > NO_3$ in all collected samples. The FTIR showed the presence of organic functional groups, including toxic functional groups like azo, cyano, etc., present in the effluent. During the field visit, the study observed that there was no treatment plant found in any cottage dyeing industry in the study areas. The study recommends installing an effluent treatment plant (ETP) in the study area to preserve the environment. Bangladesh is on the threshold of industrialization. In this regard, installing an effluent treatment plant (ETP) for each industry or a central effluent treatment plant (CETP) for an industrial hub is recommended for sustainable wastewater management and environmental sustainability as well. The community involvement and education aimed at cultivating a collective consciousness of environmental accountability within the populace. The people must be aware and take proper steps for a better world to survive and for the betterment of future generations.

Acknowledgments: The authors are thankful to the Institute of Environmental Science, University of Rajshahi, Bangladesh, for providing research facilities, and one of the authors is grateful to the Institute for proving him a fellowship.

Funding Statement: This work has not received any funding from any organization.

Conflicts of Interest: The authors declare no conflict of interest.

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