CME LIVE OPEN ACCESS

Journal of
Earth & Environmental Waste Management

Research Article

ISSN: 3065-8799

Assessing Pulp and Paper Industry Effluent Treatment Plant Efficiency with Multivariate Statistical Analysis and Water Quality Index

Abdullah Al Mahmud[1*] and Niger Sultana[2]

[1]*Department of Environmental Study & Research Division, Mirpur DOHS, Dhaka, Bangladesh.*

[2]*Department of Environmental Science & Disaster Management, Noakhali Science and Technology University, Noakhali, Bangladesh.*

Corresponding Author: Abdullah Al Mahmud, Department of Environmental Study & Research Division, Mirpur DOHS, Dhaka, Bangladesh.

Received: 2025 Sep 01 **Accepted:** 2025 Sep 25 **Published:** 2025 Sep 30

Abstract

To ensure compliance with the requisite standards for treated wastewater, it is imperative that the effluent treatment plant functions optimally. The present investigation employs the Wastewater Quality Index (WWQI) and multivariate statistical analysis as tools for the purpose of monitoring wastewater quality. Wastewater samples were collected from the inlet and outlet locations of an Effluent Treatment Plant (ETP) situated in the Narayanganj district of Bangladesh. The ETP has a daily capacity of approximately 5000 cubic meters. The research, spanning a duration of twelve months, was carried out during the months of January and December in the year 2022. The physicochemical characteristics of both the influent and effluent were analyzed to assess the quantity of biodegradable and non-biodegradable pollutants that were present within the wastewater. The ETP treatment process comprises two distinct treatment units. The first unit includes an equalization unit, chemical treatment, and primary sedimentation. The second unit comprises the MBBR (Moving Bed Biofilm Bioreactor) system, the ASP (Activated Sludge Process) system, and the biological sedimentation system. The physicochemical properties of the wastewater samples are evaluated through the examination of various parameters, such as pH, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS). The biochemical oxygen demand (BOD) was calculated to have a maximum monthly value of 96.59% and an average annual value of 95.70%. The efficacy of chemical oxygen demand elimination was determined to be 92.24%, with an average annual rate of 91.86%. The effluent sample was found to be within the acceptable range for pH and DO measurements. Additionally, the TSS exhibited an annual average of 96.85% and a maximum monthly average of 98.06%. WWQI utilized the ECR 2023 to scrutinize all available data pertaining to the quality of wastewater. They're existed numerous divergent forms of influent wastewater discharge, characterized by a markedly substandard quality. The Water Quality Index (WWQI) of the effluent samples was assessed to be of outstanding quality. A Pearson correlation analysis was conducted to examine the correlation among the measures of wastewater quality. The ultimate discharge exhibited superior characteristics suitable for release into the surrounding aquatic environment and demonstrated a greater efficacy in terms of pollutant elimination compared to ECR 2023. The effluent treatment plant (ETP) utilized in the pulp and paper industry is effectively managed and has the potential to be repurposed for treating other types of industrial effluent.

Keywords: ETP, BOD, COD, TSS, MBBR, ASP, Pulp and Paper, WWQI, Correlation

1. Introduction

The paper and pulp industries supply paper, fibers, and packaging materials to many industries, contributing significantly to the world economy [1]. Industrial processes in this industry generate large amounts of wastewater, which must be treated efficiently to reduce environmental concerns. The pulp and paper sector use ETPs to treat effluents and limit pollution discharge to meet regulatory limits [2]. ETP effectiveness must be assessed to manage complex wastewater streams [3]. Assessment approaches often prioritize total suspended solids, dissolved oxygen, biological oxygen demand, and chemical oxygen demand (COD) [4]. Although informative, these measures may not provide a complete picture of wastewater treatment quality and performance. Kulkarni, Kulkarni, and Waghmare suggest a more comprehensive ETP efficacy assessment for the pulp and paper industry [5].

Recently, the Water Quality Index (WQI) has become a useful instrument for assessing water bodies and discharges. Cude states that the WWQI combines physicochemical and biological variables into a single numerical number to describe water quality [6]. The USNSF-WQI, CCME-WQI, FSWQI, and OWQI are among the water quality assessment methods. Many researchers have explored these strategies, including Muir et al., Cude, Qian et al., Urbonavičiūtė et al., and Li et al., [6-10]. The Canadian Council of Ministers of the Environment's Water Quality Index (CCME WQI) is a popular and effective WWQI calculation method. The technique evaluates the aqueous medium's holistic quality using multiple characteristics. Researchers worldwide use the CCME WQI approach to evaluate industrial wastewater quality because it can analyze various waterbodies [11].

Multivariate statistical analysis is also becoming more popular in environmental monitoring and evaluation. These methods help identify important variables that affect treatment outcomes by examining their interrelationships [12,13]. In Environmental Technology and Pollution (ETP), Principal Component Analysis (PCA), Cluster Analysis, and Discriminant Analysis can help understand complex datasets, find patterns, and identify areas for improvement.

This scientific publication uses the Weighted Water Quality Index (WWQI) and multivariate statistical analysis to evaluate pulp and paper Effluent Treatment Plants. These methods allow the research to determine treatment efficacy, identify the main causes, and provide ways to improve performance and ecological viability. Industry can make informed process optimization, resource allocation, and regulatory compliance decisions with this integrated strategy.

2. Materials and Method

2.1. Untreated Wastewater of the Pulp & Paper Industry

Currently, a diverse range of industries exist, and a subset of them generate a substantial volume of wastewater during their operational processes. The pulp and paper manufacturing sector is recognized as a significant contributor to wastewater generation. On average, the production of 1 kg of paper from virgin pulp results in the release of 10 to 30 liters of wastewater into the environment, which is contingent on the manufacturing technology and machinery utilized (UNIDO) [14]. The generation of this magnitude of wastewater occurs at diverse stages of the production cycle, and the characteristics of the effluent differ contingent upon the specific product. The wastewater generated from diverse commodities is gathered within a designated area and conveyed to a pre-screening chamber. In this chamber, surplus pulp originating from the production unit is segregated and accumulated in the pulp storage facility for subsequent utilization within the system. After this stage, the wastewater is conveyed to the Effluent Treatment Plant (ETP) for processing, contingent upon its inherent characteristics. Consequently, the ETP treatment procedure is bifurcated into two distinct treatment modules, wherein one module predominantly encompasses an equalization unit, chemical treatment, and primary sedimentation. The subsequent segment encompasses the MBBR (moving bed biofilm bioreactor) system, the ASP (activated sludge process) system, and the biological sedimentation system. The block schematic presented in Figure 1 illustrates the comprehensive process of an ETP that is currently being examined in this study. The system in question is founded on a highly advanced biological treatment approach.

2.2. Sampling of Wastewater

The present investigation examines the influent and effluent waters spanning a duration of one year, from January 2022 to December 2022. Every specimen was obtained using a plastic container that underwent acidification prior to being washed with distilled water. Upon collection, the specimen was transported to the laboratory under refrigerated conditions and subsequently stored in a refrigeration unit for subsequent analysis. Samples were gathered daily throughout the study period, and a leisure book was maintained to document the observations each day. The present investigation involves the computation and evaluation of performance metrics utilizing monthly maximum, minimum, and mean values.

2.3. Physicochemical Characterization of Wastewater

Daily Upon completion of the sampling process, the pH and Dissolved Oxygen (DO) levels were promptly analyzed. The Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS) were assessed at regular intervals of five days. The laboratory utilized the HANNA HI 9146 portable dissolved oxygen meter, manufactured by Hanna, and the HQ4100 Multi/1 Channel portable meters, manufactured by Hach, to measure DO and pH. The DR1900 portable spectrophotometer and 2540D standard methods were utilized to measure BOD, COD, and TSS.

2.4. Wastewater Quality Index (WWQI)

In this study, the Wastewater Quality Index (WWQI) was employed to scrutinize the data obtained from wastewater samples and assess the quality of both the effluent (treated) and influent (raw) wastewater. The CCME approach, as outlined in CCME and Ramya et al., was employed to assess the influent and effluent measurements in compliance with the regulations stipulated in the Bangladesh Environmental Conservation Rule, 2023 (ECR 2023) for pulp and paper mills [15,16]. The stated objectives presented in Tables 1 and 2 served as the benchmark for assessing the quality of the wastewater. The study period involved the computation of WWQI for both influent and effluent samples. It was observed that all parameters were identified to be over the detection limit, indicating their significant presence in the samples. The Worldwide Quality Index (WWQI) is determined by a triad of components, namely F1, F2, and F3. Equations 1-7 are utilized to identify variables that do not meet the objectives (F2) and deviate from the intended outcomes (F3) based on their frequency. These calculations provide a comprehensive assessment of the quality of the wastewater.

Citation: Mahmud, A. A., Sultana, N. (2025). Assessing Pulp and Paper Industry Effluent Treatment Plant Efficiency with Multivariate Statistical Analysis and Water Quality Index. *J Earth Environ Waste Manag, 3*(3), 01-14.

$$F1\ (Scope) = \frac{No\ of\ failed\ variable}{Total\ no\ of\ variable}\ x\ 100 \quad (1)$$

$$F2\ (Frequency) = \frac{No\ of\ failed\ test\ value}{Total\ no\ of\ test}\ x\ 100 \quad (2)$$

The excursion was used to calculate the F3 value. The excursion is the number of times an individual's attention exceeds the aim. When the test value must not exceed the aim, use Eq. (3):

$$\text{Excursion} = \frac{Failed\ test\ value}{\text{Objective}} - 1 \quad (3)$$

In some instances, the test value cannot be less than the objective:

$$\text{Excursion} = \frac{\text{Objective}}{\text{Failed test value}} - 1 \quad (4)$$

The normalized sum of excursion is used to calculate the total amount by which each test is out of compliance:

$$\text{NSE} = \frac{\sum_{i=1}^{n} \text{Excursion}}{\text{Failed test value}} - 1 \quad (5)$$

F3 is determined as the normalized sum of deviations from the objectives, yielding a value between 0 and 100:

$$\text{F3 Amplitute} = \frac{nse}{0.01\ (\text{nse}) + 0.01} - 1 \quad (6)$$

The total of the squares of each element equals the index squared. The index value in this model is directly proportional to all three factors. The following is the CCME water quality index:

$$CCME\ WWQI = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right) \quad (7)$$

The WWQI value is calculated as a number between 0 and 100 using the above Eq. (7). The value B0 signifies poor water quality, whereas the value 100 represents no hazard and good water quality.

Month	Parameter	Maximum		Minimum		Mean		ECR 2023 Range
		In	Out	In	Out	In	Out	
January	pH	11.50	7.60	4.50	7.10	8.13	7.37	6.0-9.0
	DO	-	7.60	-	4.70	-	5.35	4.5-8
	COD	1,408.00	105.00	947.00	92.00	1,130.29	98.29	200.00
	BOD	587.00	29.00	395.00	14.00	460.57	19.29	30.00
	TSS	875.00	18.00	458.00	10.00	610.57	12.71	100.00
February	pH	11.50	7.80	4.50	7.10	8.00	7.29	6.0-9.0
	DO	-	6.00	-	4.70	-	5.31	4.5-8
	COD	1,496.00	127.00	1,008.00	84.00	1,273.33	108.33	200.00
	BOD	587.00	29.00	395.00	14.00	460.57	19.29	30.00
	TSS	875.00	18.00	458.00	10.00	610.57	12.71	100.00
March	pH	11.00	7.60	4.50	7.10	8.18	7.35	6.0-9.0
	DO	-	6.00	-	4.70	-	5.35	4.5-8
	COD	1,503.00	128.00	987.00	73.00	1,234.14	102.57	200.00
	BOD	651.00	27.00	259.00	12.00	423.43	18.71	30.00
	TSS	677.00	28.00	221.00	9.00	438.00	16.43	100.00
April	pH	12.00	7.60	4.00	7.10	8.10	7.34	6.0-9.0
	DO	-	6.00	-	4.70	-	5.37	4.5-8

Citation: Mahmud, A. A., Sultana, N. (2025). Assessing Pulp and Paper Industry Effluent Treatment Plant Efficiency with Multivariate Statistical Analysis and Water Quality Index. *J Earth Environ Waste Manag, 3*(3), 01-14.

	COD	1,427.00	112.00	1,105.00	78.00	1,257.33	97.67	200.00
	BOD	509.00	28.00	287.00	12.00	428.33	23.33	30.00
	TSS	653.00	27.00	304.00	11.00	489.83	17.50	100.00
May	pH	11.00	7.60	4.50	7.10	8.18	7.35	6.0-9.0
	DO	-	6.00	-	5.40	-	5.26	4.5-8
	COD	1,387.00	108.00	1,008.00	82.00	1,238.29	93.86	200.00
	BOD	641.00	24.00	387.00	14.00	483.29	18.71	30.00
	TSS	875.00	23.00	369.00	11.00	546.14	17.14	100.00
June	pH	11.50	7.60	4.50	7.10	8.08	7.36	6.0-9.0
	DO	-	5.80	-	5.40	-	5.05	4.5-8
	COD	1,408.00	105.00	947.00	92.00	1,132.00	98.33	200.00
	BOD	587.00	29.00	395.00	14.00	461.33	19.33	30.00
	TSS	875.00	18.00	458.00	10.00	634.33	12.33	100.00
July	pH	12.00	7.80	4.00	7.10	8.18	7.30	6.0-9.0
	DO	-	5.90	-	5.40	-	5.24	4.5-8
	COD	1,477.00	114.00	951.00	74.00	1,189.29	91.71	200.00
	BOD	578.00	23.00	228.00	10.00	390.00	17.29	30.00
	TSS	568.00	26.00	224.00	10.00	384.57	15.14	100.00
August	pH	11.00	7.60	4.50	7.10	8.18	7.35	6.0-9.0
	DO	-	6.00	-	5.40	-	5.13	4.5-8
	COD	1,456.00	112.00	998.00	85.00	1,212.29	100.43	200.00
	BOD	588.00	27.00	304.00	12.00	404.71	18.00	30.00
	TSS	602.00	27.00	322.00	10.00	470.43	18.14	100.00
September	pH	11.50	7.60	4.50	7.10	8.08	7.36	6.0-9.0
	DO	-	6.00	-	4.70	-	5.37	4.5-8
	COD	1,504.00	133.00	1,135.00	101.00	1,333.17	113.17	200.00
	BOD	608.00	34.00	384.00	14.00	472.17	20.17	30.00
	TSS	778.00	34.00	384.00	13.00	557.67	20.17	100.00
October	pH	11.00	7.60	4.50	7.10	8.18	7.37	6.0-9.0
	DO	-	6.00	-	4.70	-	5.35	4.5-8
	COD	1,501.00	127.00	1,208.00	95.00	1,371.29	107.14	200.00
	BOD	622.00	29.00	228.00	10.00	422.00	19.57	30.00
	TSS	712.00	32.00	302.00	8.00	501.71	18.14	100.00
November	pH	11.50	7.60	4.50	7.10	8.05	7.37	6.0-9.0
	DO	-	6.00	-	4.70	-	5.38	4.5-8
	COD	1,442.00	112.00	1,102.00	78.00	1,284.83	100.00	200.00
	BOD	499.00	24.00	387.00	12.00	456.17	17.50	30.00
	TSS	621.00	15.00	311.00	10.00	540.67	11.83	100.00
December	pH	11.50	7.60	4.50	7.10	8.18	7.37	6.0-9.0
	DO	-	6.00	-	4.70	-	5.33	4.5-8
	COD	1,498.00	123.00	858.00	72.00	1,222.29	98.86	200.00
	BOD	697.00	23.00	288.00	10.00	527.43	18.00	30.00
	TSS	778.00	23.00	388.00	10.00	596.29	13.57	100.00

Table 1: Characteristics of Physicochemical Parameter of Influent and Effluent Samples in 2020

2.5. Statistical Analysis

Statistical analysis is employed to examine the quantity of samples to achieve a consolidated outcome. The study utilized correlation analysis to investigate the interrelationships among the wastewater metrics. The retest of the WWQI was validated through regression analysis. Statistical analysis was conducted using the SPSS software.

2.7. Correlation Analysis

The primary objective of correlation analysis is to evaluate the strength of the relationship between two variables [17,18]. A comprehensive analysis was conducted to assess the linearity of the correlation between the influent and effluent samples. The correlation coefficient, a statistical measure that varies between -1 and +1, was employed for this purpose. Akoteyon and Soladoye as well as Daniel have indicated that a correlation coefficient ranging from 0.8 to 1 indicates a statistically significant positive linear correlation [17,18]. A moderate correlation is denoted by a numerical value ranging from 0.5 to 0.8. According to Akoteyon and Soladoye and Daniel, a correlation coefficient ranging from 0 to 0.5 indicates a weak association between the variables [17,18].

2.8. Principle Component Analysis

The Principal Component Analysis (PCA) statistical technique is commonly employed to identify underlying patterns and examine interrelationships among data sets, as noted by Alberto et al., [19]. According to Alberto et al., a considerable proportion of the initially correlated variables can be transformed using PCA into a more controllable set of uncorrelated variables [19]. The loading plot is a commonly employed tool to aid in the interpretation of principal component analysis (PCA) outcomes, as it illustrates the correlation between water quality metrics and the principal component extracted [20]. The present study specifically selected the influent and effluent variables for principal component analysis, as noted by Platikanov et al., [20].

3. Result and Discussion

3.1. Analysis of Physicochemical Characteristics of Influent & Effluent from ETP

Wastewater samples were collected from two distinct locations within the effluent treatment plant (ETP) during the period spanning January 2022 to December 2022. Throughout the sampling period, the input wastewater sourced directly from the industrial facility is denoted as influent, while the residual waters that are discharged from the effluent treatment plant are referred to as effluents. The pulp and paper industry typically produce a significant volume of wastewater that contains various pollutants, including chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), pH imbalances, and reduced dissolved oxygen (DO) levels. All the physicochemical characteristics, except for TDS, were analyzed in this study. The ETP employs two distinct treatment methods to address these factors, and these methods are mutually interconnected.

3.2. Primary or Physicochemical Treatment of Influent

The influent wastewater analyzed in each sample contained varying amounts of TSS, COD, and BOD, along with undesirable debris, pulp, and paper. The team responsible for designing and operating the Effluent Treatment Plant (ETP) employs a mechanical screening process during the physicochemical treatment stage to eliminate any unwanted physical substances that may hinder the optimal treatment procedure. Table 2 presents a notable variation in the Total Suspended Solids (TSS) ranging from 221 to 875, Chemical Oxygen Demand (COD) ranging from 858 to 1504, and pH levels ranging from 4.0 to 12.0 among the incoming tributaries. The upstream processes exhibit temporal variability, resulting in the inflow of diverse, superior quality effluent to the Effluent Treatment Plant (ETP). Following the screening process, it is necessary to achieve effluent equalization to establish a proximate parameter for the subsequent treatment procedures. The effluent was subjected to a broad pH range; however, prior to any chemical treatment, such as coagulation, neutralization is required. The technique involves the utilization of NaOH for the purpose of neutralizing acidic effluent, while doses of HCl acid are employed to neutralize basic effluent. The pH level of the incoming effluent is continuously monitored through the utilization of a pH sensor, which is an integral component of the system's comprehensive automation. After the neutralization phase, it is necessary to manage the wastewater by eliminating suspended organic, inorganic, and colloidal particles using coagulants and flocculants to control COD or TSS. Polyacrylamide and polyalanine chloride were identified as the coagulants and flocculants utilized in the effluent treatment plant under investigation. Following the mechanical agitation of chemicals with the wastewater, the resultant mixture was subjected to a physical settling process, commonly referred to as the primary clarifier. In this context, the gravitational force facilitated the sedimentation of the denser flocs, while the buoyant slag was subsequently eliminated along with the amassed slag. By adhering to this methodology, the operational team can attain a 50-70% decrease in TSS and COD efficacy. Subsequently, the influent water undergoes a secondary or biological treatment process, wherein a biological system eliminates the biochemical oxygen demand (BOD), and bacterial activity removes certain amounts of chemical oxygen demand (COD) and total suspended solids (TSS) from the system. This phenomenon occurs after the comprehensive treatment process.

3.3. Secondary treatment or Biological Treatment

The biological system observed in the examined ETP was found to consist of three discrete segments, with the MBBR (Moving Bed Bio-film Bioreactor) system exhibiting the highest efficiency owing to its advanced technology. It has been determined that mutag biochips have been employed as a biological carrier in this Effluent Treatment Plant (ETP) due to their extensive surface area, which enhances the efficacy of wastewater treatment. The maximum surface area provided by biocarriers is currently 5500 square meters, achievable through the utilization of one cubic meter volume of biochips. The MBBR treatment system has the capability to effectively handle diverse levels of BOD and COD. It was also observed that the activation of the system and live bacteria is regulated by adjusting the mixed liquor suspended solid (MLSS) through the utilization of return activated sludge from the biological clarifier. The MBBR system employed multiple diffusers to evenly disperse the air, which was consistently supplied by a blower. To enhance the efficacy of BOD and COD removal after MBBR, the conventional ASP (Activated Sludge Process) is also maintained. Furthermore, it has been observed that the biological component of the effluent treatment plant (ETP) comprises a degassing unit which facilitates the elimination of undesirable nitrogenous gases. After the degassing of a portion of the ETP, the wastewater is transferred to a biological clarifier. The system remains connected to a secure power supply through the force of gravity. The treated water in the biological clarifier underwent sludge removal, with a portion of the bio sludge being transferred to the MBBR tank via a sludge transfer pump, referred to as RAS. The remaining bio sludge was conveyed to the sludge digesting system. The term "WAS" referring to waste sludge, which can be described as a type of sediment. After its passage through the biological clarifier, the processed water was conveyed to the DO augmentation tank, where a steady supply of air was introduced to elevate the dissolved oxygen levels and ensure compliance with the ECR regulations. As per the results of the inquiry, the wastewater has undergone biological treatment resulting in the elimination of 70 to 90% of BOD and 50 to 95% of COD and TSS. The diagram depicted in Figure 1 portrays the complete ETP treatment system that is currently being examined.

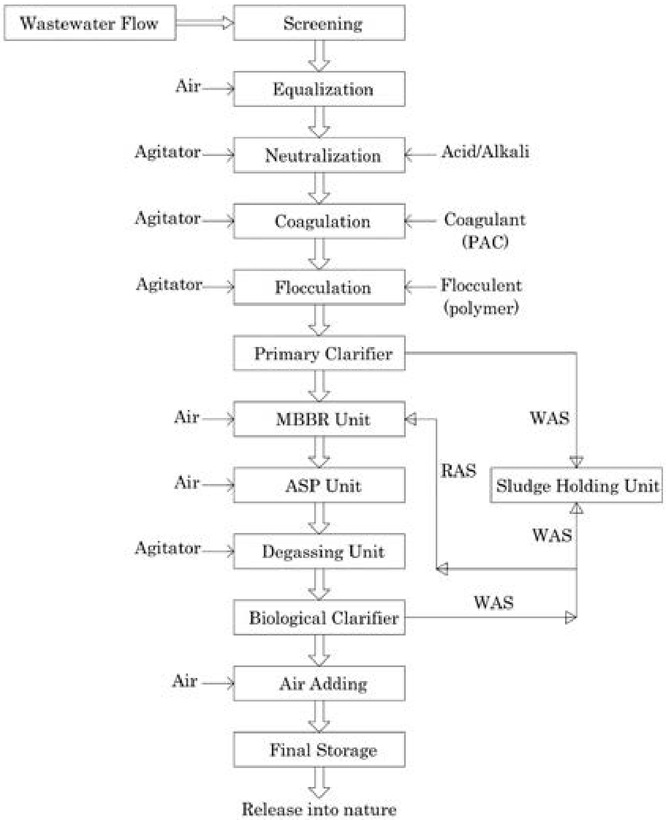

Figure 1: Process Block Diagram of Pulp and Paper Mill ETP

3.4. Removal Efficiency of COD

The chemical oxygen demand (COD) of the incoming wastewater exhibited a range of 1504 to 858 milligrams per liter (mg/L). The month of October recorded the highest average value of 1371 mg/L, while the lowest average value was determined to be 1130 mg/L. The ETP plan's removal efficiency was determined to be 91.86% on average over the course of the previous year. The month of May had the highest recorded monthly average value of 92.42%, while January had the lowest recorded monthly average value of 91.30%. The mean value of the output parameter's chemical oxygen demand (COD) is 100.86 mg/L. The month of September recorded the highest average value of 113.17 mg/L, while the month of July recorded the lowest average value of 91.71 mg/L. The COD values of the outflow water, both in terms of average and minimum, remain within the prescribed limits as outlined in Table 2.

SN	Parameter	Data Range in 2022		ECR 2023 Limits	Sample Count
		Influent	Effluent		
1	pH	4.0-12.0	7.6-7.1	6.0-9.0	350
2	Dissolve Oxygen (DO) (mg/L)	0	4.7-6.0	4.5-8	350
3	Chemical Oxygen Demand (COD) (mg/L)	858-1504	72-133	<200	79
4	Biological Oxygen Demand (BOD) (mg/L)	228-697	10.0-34.0	< 30	79
5	Total Suspended Solids (TSS) (mg/L)	221-875	8.0-34.0	< 100	79

Table 2: Summary of Physicochemical Characteristics of Influent and Effluent Sample in 2022

SN	Water Quality	Range	Description of threat	WWQI (Influent)				
				pH	DO	BOD	COD	TSS
1.	Excellent	95-100	No threat	100	100	99.72	100	100
2.	Good	80-94	Minor					
3.	Fair	65-79	Occasionally					
4.	Marginal	45-64	Frequently					
5.	Poor	0-44	Threatened					
SN	**Water Quality**	**Range**	**Description of threat**	**WWQI (Influent)**				
				pH	**DO**	**BOD**	**COD**	**TSS**
1.	Excellent	95-100	No threat					
2.	Good	80-94	Minor					
3.	Fair	65-79	Occasionally					
4.	Marginal	45-64	Frequently					
5.	Poor	0-44	Threatened	0	0	0	0	0

Table 3: Classification of WWQI Using the CCME Method

	Influent				Effluent			
	Pearson Correlation		P-value		Pearson Correlation		P-value	
	COD	BOD	COD	BOD	COD	BOD	COD	BOD
BOD	-0.049	-	0.874	-	0.265	-	0.382	-
TSS	-0.246	0.795	0.418	0.001	0.568	0.402	0.043	0.173

Table 4: Pearson Correlation Coefficients Relationship Between Influent and Effluent Quality Parameter

3.5. Removal Efficiency of BOD

The biochemical oxygen demand (BOD) of the influent wastewater exhibited a range of 697 to 228 mg/L. The month of December recorded the highest average BOD value of 527.43 mg/L, while the lowest average value was determined to be 390 mg/L. The ETP plant's average removal efficiency over the course of the previous year was calculated to be 95.70%. The month of May had the highest average monthly value at 96.59%, while January had the lowest average monthly value at 94.55%. The average value of the output parameter BOD is 19.13 mg/l. September exhibits the highest average value of 23.33 mg/l, while July displays the lowest average value of 17.29 mg/l. The established limits for the average and minimum BOD readings of the effluent are not exceeded by the system.

3.6. Removal Efficiency of TSS

The total suspended solids (TSS) of the wastewater influent exhibited a range of 221 to 875 mg/L. The average TSS value for June was observed to be highest at 634.33 mg/L and lowest at 384.57 mg/L. The study determined that the ETP plan exhibited an average removal efficiency of 96.85% over the previous year. Notably, the month of June demonstrated the highest average monthly value at 98.06%, while the month of July exhibited the lowest average monthly value at 96.06%. The average TSS output parameter is commonly observed to have a value of 16 mg/l. Notably, the month of September has the highest average value of 20.17 mg/l, while November has the lowest average value of 11.83 mg/l. The mean and minimum Total Suspended Solids (TSS) measurements of the discharged water do not exceed the prescribed limits as specified in Table 2.

The monthly average values of COD, BOD, and TSS are compared in Figure 2. The average removal efficiency rate of TSS is significantly greater than that of COD and BOD. When compared to biochemical oxygen demand (BOD) and total suspended solids (TSS), chemical oxygen demand (COD) exhibits a comparatively lower efficacy in terms of removal.

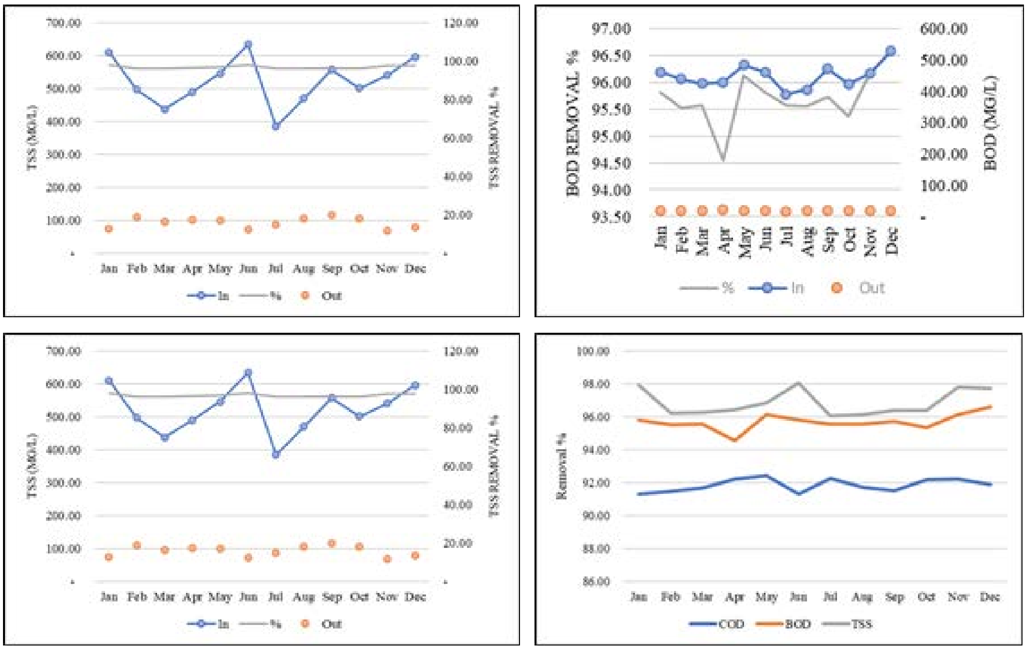

Figure 2: Removal Efficiency of COD, BOD & TSS of the ETP with maximum and minumum montly average and coparatively analysis of removal efficiency among COD, BOD & TSS

3.7. Wastewater Quality Index (WWQI)

The determination of the wastewater quality index (WWQI) is based on the analysis of various physicochemical parameters of both influent and effluent samples, as per the methodology proposed by CCME and Ebrahimi et al., [15,21]. The present index has the potential to evaluate the overall quality of water for prospective utilization. The optimal WWQI value, indicative of optimal wastewater quality and congruent with the intended design objectives, may serve as a metric for assessing the efficacy of an Effluent Treatment Plant's (ETP) operations. Conversely, the WWQI score that is the least in magnitude indicates the existence of wastewater that is highly hazardous or polluted. The reduction in the wastewater quality index (WWQI) of the influent can be attributed to various factors, including but not limited to dissolved oxygen (DO), total suspended solids (TSS), pH, chemical oxygen demand (COD), and biochemical oxygen demand (BOD). Ebrahimi et al., assert that the aforementioned factors exert a significant influence on the WWQI score, resulting in a decline in the quality of influent wastewater [21].

As per ECR 2023, the direct release of influent water or raw water with a high WWQI value into the environment poses a significant threat to the ecosystem. Stated differently, ETP is currently operating optimally with all equipment and software functioning at an optimal level. In its initial condition, the ETP's performance exhibited the highest score based on the WWQI metric. All effluent parameters exhibit a maximum value of 100, apart from BOD. According to the Biological Oxygen Demand (BOD) analysis, the Water Quality Index (WQI) has been determined to be 99.72, indicating a level of exceptional quality. According to the ECR 2023 standard, the Pulp and Paper ETP has demonstrated excellent quality performance as indicated by the WWQI outcome.

3.8. Correlation Analysis

Table 5 displays the Pearson correlation coefficients and p-values pertaining to COD, BOD, and TSS in influent and effluent samples. The tributary exhibited a negative correlation between BOD and COD, as indicated by a value of -0.049. The tributary's TSS and COD ratio exhibited a negative trend, albeit marginally higher at -0.246. In relation to the effluent, a noteworthy positive correlation of 0.874 was observed between COD and BOD. This observation indicates a positive correlation between the levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in wastewater.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Feb	1.000										
Mar	0.999	0.999									
Apr	0.998	0.997	0.998								
May	0.998	0.998	1.000	0.999							
Jun	1.000	1.000	0.999	0.998	0.998						
Jul	0.999	0.999	1.000	0.998	1.000	0.999					
Aug	0.998	0.998	1.000	0.998	1.000	0.998	1.000				
Sep	0.998	0.998	1.000	0.998	1.000	0.998	1.000	1.000			
Oct	0.999	0.999	1.000	0.998	1.000	0.998	1.000	1.000	1.000		
Nov	1.000	1.000	0.999	0.997	0.998	1.000	0.999	0.998	0.998	0.998	
Dec	1.000	1.000	1.000	0.998	0.999	1.000	1.000	0.999	0.999	0.999	1.000

Table 5: Pearson Correlation Coefficients Relationship Among the Monthly Value of Effluent Value

Table 6 illustrates the interrelation between the monthly effluent parameters. The table displays the correlation coefficient between the effluent levels of the respective pair of months in each cell. The diagonal entries in the table are consistently valued at 1000, as they effectively depict the correlation between a given month and itself. The table displays a consistent trend of robust positive associations among the monthly effluent measurements. The effluent values of February and March exhibit a strong positive correlation of 0.999, indicating a significant association between the two months. Several other pairs of months exhibit robust positive correlations, with coefficients ranging from 0.997 to 1000. This suggests the presence of a dependable and noteworthy correlation among effluent measurements taken during different months [22].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Feb	0.985										
Mar	0.978	0.999									
Apr	0.985	1.000	0.999								
May	0.993	0.998	0.995	0.998							
Jun	1.000	0.981	0.973	0.981	0.990						
Jul	0.970	0.997	0.999	0.997	0.991	0.964					
Aug	0.985	1.000	0.999	1.000	0.997	0.980	0.997				
Sep	0.990	0.999	0.997	0.999	0.999	0.987	0.994	0.999			
Oct	0.979	0.999	0.999	0.999	0.994	0.975	0.998	0.999	0.998		
Nov	0.991	0.999	0.997	0.999	0.999	0.987	0.994	0.999	1.000	0.998	
Dec	0.997	0.992	0.987	0.991	0.998	0.995	0.981	0.991	0.995	0.986	0.995

Table 6: Pearson Correlation Coefficients Relationship Among the Monthly Value of Influent Value

The investigation utilized Pearson's correlation coefficients to analyze the correlation between the monthly influent values presented in Table 7. The correlation coefficient between the influential values of each pair of months is denoted by the value in the respective cell of the table. The findings suggest a robust affirmative association among the tributary values of distinct months, exhibiting coefficients that span from 0.973 to 1.000. The analysis reveals a strong correlation coefficient of 0.999 between the months of February and March, indicating a significant association between their respective influential factors. Several other pairs of months display noteworthy positive correlations, which vary from 0.973 to 1.000. It is noteworthy to mention that the correlation coefficient between the months of June and July exhibits a slightly lower value of 0.964 in comparison to the remaining coefficients presented in the table. The results of this study offer significant insights into the robust and consistent correlation between monthly tributary values. This underscores the significance of incorporating temporal patterns in tributary characteristics when devising effective wastewater management and treatment approaches.

Eigenvalue	1.9043	1.1294	0.8155	0.1508
Proportion	0.476	0.282	0.204	0.038
Cumulative	0.476	0.758	0.962	1.000
Eigenvectors				
Variable	PC1	PC2	PC3	PC4
pH	-0.249	-0.670	-0.673	0.190
COD	-0.188	0.741	-0.613	0.200
BOD	0.647	-0.005	-0.414	-0.640
TSS	0.695	-0.034	-0.021	0.718

Table 7: Eigenanalysis of the Correlation Matrix

3.9. Principal Component Analysis: pH, COD, BOD, TSS

The table presented herein furnishes data pertaining to eigenvalues and their corresponding proportions. Eigenvalues are numeric quantities that signify the significance of a specific factor within a given dataset. The present scenario entails the existence of four distinct eigenvalues, namely 1.9043, 1.1294, 0.8155, and 0.1508. The column labeled "Proportion" denotes the proportion of the overall variability that is accounted for by each respective eigenvalue. The statement denotes the proportional significance of individual factors in relation to the entirety of the dataset. The initial eigenvalue accounts for an estimated 47.6% of the overall variability, followed by the second eigenvalue at approximately 28.2%, the third eigenvalue at around 20.4%, and the fourth eigenvalue at roughly 3.8%. The column labeled as "Cumulative" presents the proportion of variability explained by the eigenvalues in a cumulative manner. The table displays the progressive impact of individual factors in a cumulative manner from the leftmost to the rightmost column. The first eigenvalue exhibits a cumulative proportion of 47.6%, whereas the second eigenvalue demonstrates a cumulative proportion of 75.8%. The third eigenvalue, on the other hand, displays a cumulative proportion of 96.2%. Ultimately, the cumulative proportion for all four eigenvalues is 100%. To summarize, the table presents the significance and impact of individual factors, as measured by their respective eigenvalues, within a given data set. The level of influence of a given factor is directly proportional to the magnitude of its corresponding eigenvalue. The inclusion of proportion and cumulative proportion columns facilitates comprehension of the comparative importance of individual factors and the collective influence of multiple factors in elucidating the overall variability of the dataset [23].

The table provided illustrates the loadings or coefficients of four distinct variables, specifically pH, COD, BOD, and TSS, on four principal components, denoted as PC1, PC2, PC3, and PC4. The loadings serve to demonstrate the magnitude and orientation of the correlation that exists between each variable and its corresponding principal component. After conducting an analysis of the table, several patterns become apparent. The data indicates a significant positive correlation (0.647) between PC1 and BOD, implying that BOD exerts the greatest impact on PC1. Conversely, it can be observed that pH (-0.249) and COD (-0.188) demonstrate negative loadings, thereby suggesting a negative correlation with PC1. Upon transitioning to PC2, it becomes apparent that COD (0.741) and pH (-0.670) exhibit noteworthy influences. The high loadings of both variables suggest a significant correlation with PC2. The presence of a negative sign in association with pH implies an inverse correlation, whereas the presence of a positive sign in relation to COD implies a positive correlation. Upon examining PC3, it is evident that pH (-0.673) exhibits the most substantial loading, thereby signifying a strong negative correlation. Furthermore, the Biochemical Oxygen Demand (BOD) exhibits a moderate negative loading of -0.414, indicating a comparatively weaker inverse correlation with the third principal component (PC3). Finally, it can be observed that PC4 exhibits a significant and positive correlation with TSS, with a correlation coefficient of 0.718. The positive loading indicates a positive correlation between Total Suspended Solids (TSS) and Principal Component 4 (PC4). Through the interpretation of these loadings, it is possible to obtain insights into the contribution of each variable to the principal components and comprehend the fundamental patterns present in the dataset.

4. Discussion

The physicochemical properties of both the influent and effluent samples of the effluent treatment plant (ETP) were analyzed, yielding valuable insights into the efficacy and efficiency of the treatment protocols employed. The main focus of the discussion will be on the primary or physicochemical treatment of influent, secondary or biological treatment, the effectiveness of COD, BOD, and TSS removal, the wastewater quality index (WWQI), as well as correlation analysis and principal component analysis (PCA). The influent wastewater collected from the pulp and paper industry displayed significant fluctuations in its TSS, COD, and pH levels. The physicochemical treatment employed in the ETP involved several processes, including the removal of physical impurities, neutralization of pH, coagulation, flocculation, and settling in the primary clarifier. These processes were utilized to eliminate suspended organic and inorganic particles. After the initial treatment, the incoming water was subjected to a secondary treatment process utilizing both the Moving Bed Biofilm Reactor (MBBR) system and the Activated Sludge Process (ASP) in order to achieve biological removal of both Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The study determined that the ETP exhibited a removal efficiency of 91.86%, 95.70%, and 96.85% for COD, BOD, and TSS, respectively, indicating the effectiveness of the treatment methodologies employed [24].

The wastewater quality index (WWQI) was obtained by analyzing the physicochemical properties of both the influent and effluent samples. The measurements of both influent and effluent WWQI indicated exceptional water quality, surpassing the ECR 2023 guidelines. This observation suggests that the ETP is functioning optimally and efficiently in its treatment of wastewater to meet the requisite quality standards. The correlation analysis revealed intriguing associations among the influent and effluent parameters. A negative correlation has been observed between BOD and COD in the influent, indicating that higher levels of COD are linked to lower levels of BOD. The analysis revealed a significant correlation between COD and BOD in the effluent, suggesting that elevated levels of COD are positively associated with increased levels of BOD. The findings indicate a significant association between the quantity of organic matter and the corresponding levels of contaminants present in wastewater. As part of the correlation analysis, a comparison was made between the monthly influent and effluent data. The study revealed robust and affirmative associations among the effluent measurements of multiple months, indicating the enduring patterns in the characteristics of the processed wastewater throughout the duration of the research. Comparable positive associations among the input values of other months were also detected, underscoring the temporal patterns in the characteristics of the untreated sewage. The principal component analysis (PCA) was utilized to uncover the significance and inputs of pH, COD, BOD, and TSS in the dataset. Based on the eigenvalues and their corresponding proportions, it can be inferred that the primary eigenvalue, accounting for 47.6% of the variability, was succeeded by the second, third, and fourth eigenvalues in terms of their explanatory power. The findings indicate that the primary principal component (PC1) was significantly influenced by the first principal component of biochemical oxygen demand (BOD) in PC1, the second principal component of chemical oxygen demand (COD) in PC2, and the pH in PC3. A significant positive correlation was observed between TSS and PC4, while a robust negative correlation was noted between PC4 and TSS. The loadings facilitate the comprehension of interrelationships and patterns within the dataset.

The findings and deductions indicate that the ETP is a proficient method for treating incoming wastewater from the pulp and paper sector. The physicochemical and biological treatment processes were successful in achieving high removal efficiencies due to the effective elimination of a significant amount of COD, BOD, and TSS. The wastewater quality index indicated that the water quality followed the ECR 2023 standards, demonstrating a high level of excellence. The correlation analysis and principal component analysis (PCA) unveiled the associations among different parameters and the fundamental patterns in the dataset. The findings of this study enhance our comprehension of the ETP's efficacy and have the potential to inform the development of more efficient strategies for wastewater treatment and management in subsequent endeavors [25].

5. Conclusion

In order to mitigate its negative impact on the environment, the pulp and paper industry generates a significant quantity of wastewater that requires appropriate treatment. The wastewater generated by this enterprise undergoes treatment at Effluent Treatment Plants (ETPs). The standard evaluation techniques primarily focus on parameters such as total suspended solids, dissolved oxygen, biological oxygen demand, and chemical oxygen demand. The study employs a combination of the Weighted Quality Index (WWQI) and multivariate statistical analysis techniques to evaluate the efficacy of Environmental Technology Providers (ETPs) in the pulp and paper sector. The utilization of this integrated approach facilitates a comprehensive assessment of the effectiveness of treatment, the recognition of noteworthy factors that impact outcomes, and recommendations for augmenting operational efficiency and ecological viability. The present investigation scrutinized the physicochemical characteristics of both influent and effluent wastewater derived from the effluent treatment plant (ETP) of the pulp and paper industry. During the initial stage of physicochemical treatment, undesirable physical substances were eliminated through processes such as screening, pH neutralization, and chemical treatment aimed at removing suspended particles. The integration of the Moving Bed Biofilm Reactor (MBBR) and the Activated Sludge Process (ASP) during the secondary or biological treatment phase was implemented to facilitate the removal of organic contaminants via bacterial activity. The treatment system exhibited a range of 70% to 90% efficiency in removing COD, and 50% to 95% efficiency in removing BOD. The reliability of the WWQI was established through the utilization of regression analysis, in conjunction with statistical analytic techniques such as correlation analysis, to examine the associations between wastewater indicators. These investigations facilitate comprehension of the comprehensive functionality of the ETP by illuminating the interrelationships among diverse variables. In summary, the research highlights the importance of employing a comprehensive approach that incorporates multivariate statistical analysis methods and the WWQI for evaluating ETP efficacy within the pulp and paper sector. The outcomes and recommendations derived from these assessments possess the potential to assist decision-makers in making informed decisions, enhance the efficacy of treatment, and foster sustainable business practices. This, in turn, can lead to a reduction in the ecological ramifications of wastewater discharge.

Declaration

Funding

The present study received funding from Water Technology BD Limited which is the parents' organization of Environmental Research and Study Division.

Conflicting Interests

The authors do not possess any pertinent competing interests to disclose with respect to the substance of this article.

Author Contributions

The authors of this work are Abdullah al Mahmud and Niger Sultana, who have engaged in the process of conceptualization. The methodology employed in this study involved the participation of Abdullah al Mahmud, Niger Sultana in formal analysis and investigation. Additionally, the writing of the original draft was carried out by Abdullah al Mahmud and Niger Sultana, while the review and editing were performed by Niger Sultana. Finally, the supervision of this study was carried out by Niger Sultana.

The accessibility of data

As per the authors' assertion, the primary data substantiating the outcomes of the research are presented in the article and supplementary materials. Upon a justifiable request, the author who is responsible for correspondence may furnish additional data.

Acknowledgments

The authors wish to express their sincere appreciation and indebtedness to the Environmental Study & Research Division, A sister Concern of Water Technology BD Limited, Mirpur DOHS, Dhaka-1216 for generously providing laboratory facilities that enabled the conduct of data analysis.

References

1. Mishra, S., Behera, R. K., & Tewari, P. K. (2019). Pulp and Paper Industry. In Green Chemistry for Environmental Sustainability (pp. 205-217). Springer, Singapore.
2. Tang, W., Zhou, S., & Li, Y. (2020). Environmental Performance Evaluation of Pulp and Paper Industrial ETPs Using Grey Relational Analysis. In 2020 5th International Conference on Energy, Environment and Sustainable Development (EESD) (pp. 1-5). IEEE.
3. Kasmi, M., Abidli, S., Elabed, S., Moussa, M., & Khalfaoui, M. (2019). Performance evaluation of wastewater treatment plant: A case study. International Journal of Sustainable Engineering, 12(1), 3-9.
4. Agnihotri, S., Tyagi, V. K., & Zhang, Y. (2021). Industrial wastewater treatment using electrocoagulation: A comprehensive review. Journal of Environmental Management, 278, 111546.
5. Kulkarni, S., Kulkarni, M., & Waghmare, S. (2019). Performance evaluation of effluent treatment plant (ETP) for treatment of pulp and paper mill wastewater. International Journal of Civil Engineering and Technology (IJCIET), 10(3), 306-314.
6. Cude, C. G. (2001). Oregon Water Quality Index: A tool for evaluating water quality management effectiveness. Journal of the American Water Resources Association, 37(1), 125-137.
7. Muir, D., Chen, L., & Reiner, E. (2004). A multiple-approach assessment of the health of the near-shore marine environment in the Strait of Georgia (B.C., Canada). Marine Pollution Bulletin, 48(9-10), 900-915.
8. Qian, X., Guo, L., Chen, S., & Xu, S. (2017). Assessing water quality in the upper Min River, China, using the water quality index method. Water Science and Technology, 76(10), 2582-2594.
9. Urbonavičiūtė, A., Sakalauskaitė, J., Vaiciulytė, V., & Nizač, V. (2020). Evaluation of water quality indices for river water quality assessment: A case study of the Neris River (Lithuania). Water, 12(3), 842
10. Li, X., Shao, X., Su, Y., Chen, J., & Wu, Q. (2020). Water quality evaluation based on the fuzzy comprehensive evaluation method in the Chaohu Lake, China. Water Science and Technology: Water Supply, 20(6), 2427-2435.
11. Abhishek, A., & Khambete, A. (2013). Water Quality Index of Industrial Wastewater. International Journal of Science, Engineering and Technology Research (IJSETR), 2(7), 1465-1468.
12. Debels, P., Figueroa, R., Urrutia, R., Barra, R., & Niell, X. (2005). Biomonitoring of heavy metals and organic pollutants in the Liucura River watershed in southern Chile. Environmental Monitoring and Assessment, 110(1-3), 299-322.
13. Li, J., Feng, C., Wang, C., & Wu, J. (2017). Multivariate statistical analysis of water quality in the mainstream, tributary, and sub-tributary of the Three Gorges Reservoir before and after impoundment. Environmental Monitoring and Assessment, 189(3), 110.
14. UNIDO. (2010). Assessment of environmental emissions from the pulp and paper industry. United Nations Industrial Development Organization.
15. CCME. (2001). Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0 Technical Report. Canadian Council of Ministers of the Environment.
16. Ramya et al. (2019). Ramya, K., Kaliamoorthi, P., & Vasudevan, N. (2019). Performance evaluation of ETP from pesticide manufacturing industry by using WWQI and multivariate statistical analysis. Environmental Science and Pollution Research, 26.
17. Akoteyon, I. S., & Soladoye, O. (2011). Correlation and regression analysis of pollutant fluxes from anthropogenic activities. Journal of Environmental Science and Technology, 4(4), 439-448.
18. Daniel, W. W. (2013). Biostatistics: A Foundation for Analysis in the Health Sciences (10th ed.). Wiley.
19. Alberto, S., Giovanni, D. D., & Marta, D. (2001). Principal component analysis on correlated data: a methodological review. Statistical Analysis and Data Mining, 31(1), 463-486.
20. Platikanov, S., Atena, M., & Mariana, L. (2014). Multivariate statistical analysis for water quality assessment of river Danube. Procedia Technology, 12, 33-39.
21. Ebrahimi, A., Haghollahi, A., Mesdaghinia, A., Nasseri, S., Mahvi, A. H., & Nabizadeh, R. (2017). Development of wastewater quality indices using principal component and factor analysis for an urban river. Environmental Monitoring and Assessment, 189(6), 1-11.
22. Abdullah, M. S., Samdin, Z., Abdullah, N. H., & Zainudin, N. H. (2018). Application of principal component

analysis (PCA) on heavy metals contamination in water and sediment of Port Klang coastal area. Journal of Sustainability Science and Management, 13(2), 115-126.
23. APHA, AWWA, WPCF. Standard Methods for the Examination of Water and Wastewater. 20th edition, American Public Health Association, Washington, DC, New York, USA, 1998.
24. Bhatia, N., Kumar, A., & Kumar, A. (2021). Assessment of water quality and suitability of river Yamuna using cluster analysis: A case study. Journal of Environmental Management and Tourism, 12(9), 2834-2849.
25. Farzadkia, M., Mehrdadi, N., Moradnia, M., & Ahmadi, E. (2022). Application of principal component analysis (PCA) and hierarchical cluster analysis (HCA) for assessing groundwater quality in a contaminated area. Journal of Water Supply: Research and Technology-Aqua, 71(2), 222-236.