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Characterization of Paper Mill Effluent and Its Impacts on the Environment

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Abstract

The study aimed to characterize paper mill effluents and determine the quality of surface water in the vicinity of the paper mills using a water quality index to understand the pollution level due to the discharge of untreated effluents. Physicochemical parameters and CCME (Canadian Council of Ministersof the Environment) Water Quality Index (WQI) were used to estimate the degree of pollution in the selected paper mills area in Bogura District of Bangladesh. Moreover, a public perception survey was conducted in the study area to illustrate the present scenario regarding paper mill effluent discharge. The analytical results revealed that the concentrations of TSS, EC, COD, BOD_5, phenols, K, and $NO_3 - N$ were higher than the permissible limit, and the DO level was below the ECR 1997 standard. However, there was no concentrations of heavy metals exceeded the permissible level. The FTIR analysis showed the presence of several toxic pollutants, including lignin, phenol, and halo compound. The CCME WQI showed that sites S-1 and S-2 were ranked as marginal, while site S-3 was ranked as fair. The study observed that the discharge of untreated paper mill effluent has the potential to cause harm to aquatic life and the environment.

Keywords: Heavy metals, indexing, physicochemical parameters, pollutant, water quality

1. Introduction

There are 110 paper mills in Bangladesh with annually more than 1.5 million tons of paper productioncapacity [1]. As the country's demand is around 0.9 - 1.0 million metric tons, paper mills can use half of their production capacity. Therefore, nearly a decade ago, paper and paper product exporting was started, and the opportunity has become a boon for the industry. Industrial wateruse and effluent generation are global concerns. Most of the industries directly discharge poorly treated or untreated effluents into the nearby water body, which results in deterioration of water quality [2-6]. Among the major effluent-generating industries, the paper industry is among the most notorious industries around the globe [7-8]. The process of making paper uses a lot of freshwater. [8-10]. One ton of paper requires 273 - 455 m^3 of freshwater. Therefore, it discharges approximately 300 m^3 of effluent to produce one ton of paper [11]. The main steps of paper production are raw material preparation, digestion, pulping, bleaching, etc. [12]. Almost all steps generate different types of environmental pollutants like air emissions, solid waste, and toxic effluent [13]. The volume and physicochemical characteristics of the paper mill effluent depend on the different production methods and raw materials. Different types of chemicals are used as additives, fillers, dyes, whiteners, strengtheners, surfactants, and biocides in the paper manufacturing process. As a result, the effluent from paper mills comprises BOD, COD, TSS, TDS, different inorganic ions, and organic compounds at high level [14-19]. More than 250 chemicals are found in pulp and paper mill effluent [20]. Discharge of untreated or insufficiently treated effluent from pulp and paper mills or other industrial processes into nearby surface water destroys the aquatic ecosystem [16, 21-23]. Usually, nontechnical politicians, policymakers, government officers, or the general public have no idea or scope to understand the water quality physicochemical data. In this case, the water quality index (WQI) plays an important role as a communication tool to transfer water quality data [24-26]. To reveal water quality data in an easily understood format, several water quality indices have been developed [27, 28]. The CCME (Canadian Council of Ministers of the Environment) summarizes data of water quality conventionally to design a water quality index. The CCME WQI, considering all water quality data, generates a single number between zero and 100 that indicates the water quality level [29-32]. The objective of this study was to characterize the paper mill effluents and assess the impacts of the untreated effluents on the environment around the mills' area.

2. Materials and Methods

2.1 Study Area

The study area is located at Kahaloo Upazila in Bogura district, Bangladesh (Figure 1). It lies between 24° 52′ 0″ north and 89° 11′ 0″ east. More than three private sector paper mills are located in this Upazila, which relies on imported pulp and recycles waste paper. Among those, a paper mill was selected for the study based on production capacity and location. The effluent of the paper mill discharges through a canal connected to the Nagar River at the location point S1 (Figure 1). In the rainy season, the water source of the canal was the Nagar River, but it becomes dry in the winter, and the water quality severely deteriorates and cannot be used for any purposes.

2.2 Questionnaire survey

A structured questionnaire survey was conducted to get the public's perception of the present scenario of the discharge of paper mill effluent into the surface water body in the study area. It was conducted based on different categories of questions, including personal and socioeconomic data, environmental impact data, health impact data, etc. A total of fifty (50) villagers were selected using the random sampling technique. The data were analyzed using statistical methods.

2.3 Sample Collection

Effluent samples were collected from the outlet of a paper mill, before mixing with the surface water body, in the years 2019 to 2020. In the same time, surface water samples were collected around the effluent discharging point, canal, and the Nagar River. All samples were collected at three times (Pre-monsoon, Monsoon, and Post-monsoon) in a calendar year during two years from the outlet, effluent discharge point(S-1), middle of the discharge point, and the river, which is 350 meters downstream of the canal (S-2), and 700 meters downstream where the canal falls into the river (S-3). All samples were collected in clean plastic pots and were preserved in refrigerator to avoid any chemical change before analysis.

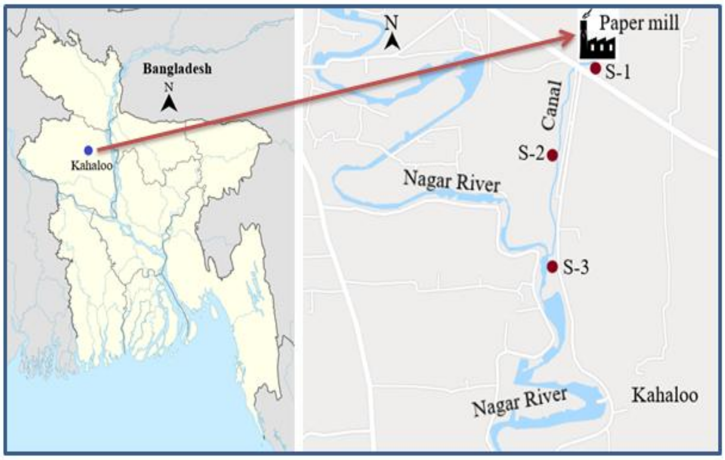

Figure 1: Location Map of the study area.

2.4 Physicochemical Analysis

This study considered a total of 28 physicochemical parameters (i.e., Temperature, pH, EC, DO, turbidity, TDS, TSS, BOD_5, COD, TOC (Total Organic Carbon), Phenolic compounds, Total Hardness (TH), Cl^-, SO_4^{2-}, PO_4^{3-}, NO_3^--N, HCO_3^-, Na, K, Ca, Mg, Cu, Fe, Mn, Zn, Pb, Cd, and Cr. Digital meters were used in the sites to monitor the temperature, pH, EC, DO, and turbidity directly. Using the standard methods other parameters were measured in laboratory [33, 34]. Moreover, an FTIR analysis of the paper mill effluent was conducted to identify functional groups of organic pollutants.

Table 1: Description of The Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI).

Score	Ranking	Description
95-100	Excellent	Water quality is protected with a virtual absence of threat, or impairment; conditions very close to natural, or pristine levels
80-94	Good	Water quality is protected with only a minor degree of threat, or impairment; conditions rarely depart from natural, or desirable levels
65-79	Fair	Water quality is usually protected but occasionally threatened, or impaired; conditions sometimes depart from natural, or desirable levels
45-64	Marginal	Water quality is frequently threatened, or impaired; conditions often depart from natural, or desirable levels
0-44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural, or desirable levels

The calculated WQI score was then ranked into one of the following five categories (Excellent, good, fair, marginal, and poor) mentioned in Table 1.

Equtions:

$$\text{Scope, F1} = \left(\frac{Number\ of\ Failed\ Variables}{Total\ Number\ of\ Variables}\right) \times 100 \quad \text{(i)}$$

$$\text{Frequency, F2} = \left(\frac{Number\ of\ Failed\ Tests}{Total\ Number\ of\ Tests}\right) \times 100 \quad \text{(ii)}$$

Amplitude, F_3: Amplitude is calculated based on the excursion of each failed test relative to its objective.

If failed test is greater than the objective:

$$\text{Excursion} = \left(\frac{\text{Failed Test value}}{\text{Objective}}\right) - 1 \quad \text{(iii)}$$

If failed test is less than the objective:

$$\text{Excursion} = \left(\frac{Objective}{Failed\ Test\ value}\right) - 1 \quad \text{(iv)}$$

$$\text{Normalized Sum of Excursions (NSE)} = \left(\frac{\sum \text{Excursion}}{\text{Total Number of Test}}\right) \quad \text{(v)}$$

$$\text{Amplitude, } F_3 = \left(\frac{NSE}{0.01NSE + 0.01}\right) \quad \text{(vi)}$$

CCME WQI calculation:

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

2.5 Water Quality Index (WQI)

This study used the CCME (Canadian Council of Ministers of the Environment) Water Quality Index (WQI) to assess the water quality status in the study area. A total of 22 The WQI score was determined by taking into account the following water quality parameters: temperature, pH, DO, EC, TSS, TDS, BOD_5, COD, Phenol, Cl^-, SO_4^{2-}, NO_3^--N, PO_4^{3-}, HCO_3^-, Na, K, Ca, Cu, Mn, Zn, Cr, Pb, Cd and Fe (Eq. vii). The three (3) elements that make up the CCME WQI are scope (F1), frequency (F2), and amplitude (F3). F_1 denotes the percentage of parameters which don't settle their objectives at least once (failed parameters) by the period (Eq. i). F_2 denotes the percentage of isolate tests which don't settle their objectives (failed tests) (Eq. ii), and F_3 denotes the degree by which failed tests don't settle their objectives (Eq. vi) [30-32, 35]. The equations are mentioned above.

3. Results and Discussion

3.1. Public perception survey

The social survey report showed that most respondents had a negative attitude regarding the discharge of paper mill effluent into surface water. Before, the paper mill started the respondents perception towards functional water usage was 68, 62, 88, 70, and 12 % for washing, bathing, fishing, irrigation, and no use, respectively, and after the paper mill started, the perception was 0, 0, 16, 12 and 82 % for washing, bathing, fishing, irrigation, and no use, respectively (Figure 2).

Figure 3 illustrates that according to the public perception, crop production, and fishery decreased, livestock diseases, and skin diseases problems were very severe in the study area, whereas soil fertility decreased and other human health effects were marginal.

3.2 Physicochemical characterization of effluent

Table 2 lists the physicochemical parameters of the effluents from paper mills. It shows that the range of electrical conductivity (EC), total suspended solids (TSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), Phenolic compounds, nitrate-nitrogen (NO_3^--N), and potassium ion (K^+) were 2053 to 2070 µS/cm, 592 to 600 mg/L, 280 to 288 mg/L, 843 to 850 mg/L, 2.95 to 3.0 mg/L, 28.40 to 29.00 mg/L, and 78.9 to 81.4 mg/L, respectively, in the paper mill effluents which exceeded the standard limit, whereas the DO (dissolved oxygen) level ranged 1.0 to 1.2 mg/L was below the prescribed value. In Bangladesh, there is no permissible value of turbidity, TOC, TH, phosphate (PO_4^{3-}), bicarbonate (HCO_3^-), and magnesium ion (Mg^{2+}). However, the turbidity ranged from 270 to 276 mg/L, and TOC ranged from 106 to 110 mg/L in the effluent was very high.

The temperature, pH, TDS, Cl^-, SO_4^{2-}, Na, Ca, Cu, Fe, Mn, Zn, Pb, Cd, and Cr values were within the permissible limit.

3.3 Physicochemical characterization of surface water

Tables 3 and 4 list the physicochemical parameters of the surface water near the places where paper mill effluents are discharged. The research showed that the average temperatures at sites S-1, S-2, and S-3 were33.8, 29.5, and 27.0 ^{o}C, respectively, within the standard level of surface water of Bangladesh (BD-SW standard). The average values of pH at the sites S-1, S-2, and S-3 were 8.15, 7.53, and 7.30, respectively, within the prescribed level. The DO level varied from 1.3 to 4.5 mg/L, which was less than required level. Several reports illustrated that the surface water near the paper mill discharge point was highly polluted and dangerous for aquatic life [36, 37].

The lowest electrical conductivity (EC) value was 665 µS/cm at S-3 in the monsoon of 2019, whereas the highest value was 2050 µS/cm at S-1 in the pre-monsoon of (2020). It exceeded the permissible limit at most sites and seasons. According to Devi et al. [14], who made a similar observation, the presence of inorganic ions is indicated by a high EC value [13]. The range of turbidity was 44.0 to 270.0 NTU.

Though there is no surface water standard for turbidity in Bangladesh, the turbidity values in the three sampling sites showed much higher values, and the values decreased with the distance from the effluent discharge point. The results indicated that the paper mills discharge untreated effluent that might influence the turbidity of the surface water bodies in the areas (Table 3).

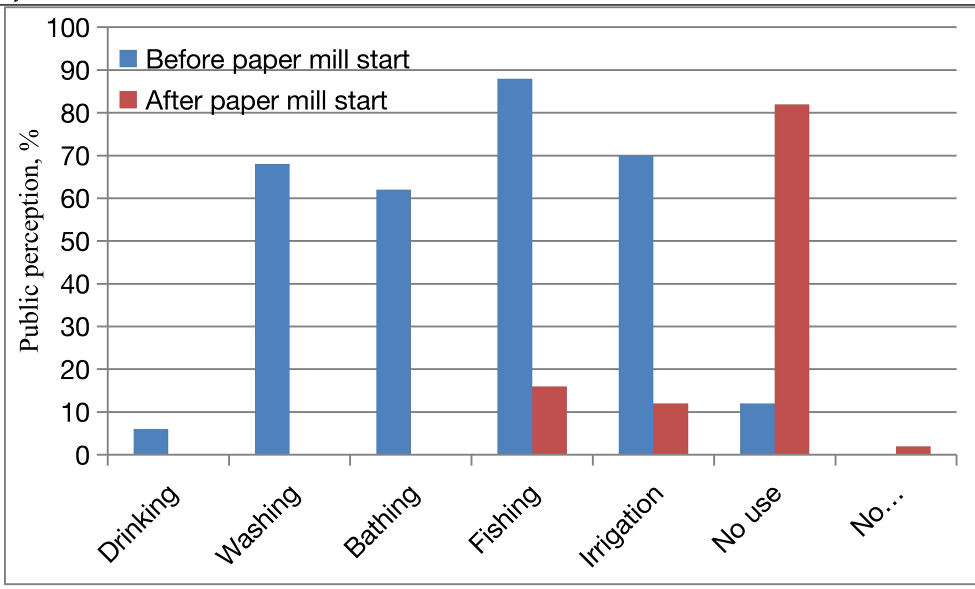

Figure 2 Functional water usage of canal and river around paper mill effluents discharge areas.

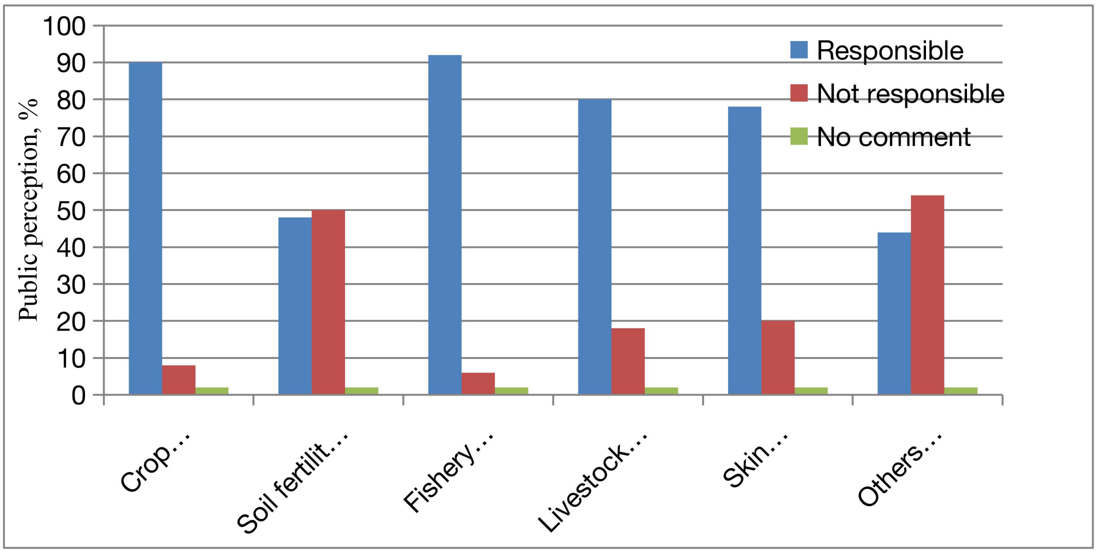

Figure 3 Impacts of paper mill effluents around the discharge areas.

The TSS (total suspended solids) ranged from 157.0 to 592.0 mg/L, above the acceptable level, as shown in Table 4. The values decreased with distance from the effluent discharge point indicating that the paper mill effluent might influence the TSS value of the surface water body in the area. Mishra et al. [36] reported a comparable outcome. High TSS value imports high COD and BOD_5. The TSS (Total suspended solids) may shift the soil texture, porosity, soil fertility and water-holding capacity [37]. The TDS (total dissolved solids) varied from 394.0 to 1499.0 mg/L, which was within the permissible limit. The BOD_5 and COD varied from 134.0 to 278.0 mg/L and 177.0 to 843.0 mg/L respectively, and were higher than the permissible limits. Similar observations were reported by Giri et al. [17] and Devi et al. [14]. High BOD_5 and COD values indicate the presence of organic and inorganic pollutants in high volumes [38].

The TOC and TH ranged from 50.6 to 105 mg/L, and 140 to 604 mg/L, respectively (Table 4). There is no surface water standard for TOC and TH in Bangladesh. However, the TOC and TH values decreased with the distance from the effluent discharge point indicating that the paper mill effluent might influence the TOC and TH levels of the surface water bodies in the area. Ahmed et al. [39] showed a maximum TOC of 46 mg/L in the surface water bodies in the Dhaka export processing zone (DEPZ) area [39]. Compared to that, the TOC level of the surface water bodies is very high in the effluent discharge area. The drinking water standard for TH is 200–500 mg/L [40], and the TH was found within the tolerance level. The phenolic compound varied from 0.925 to 2.946 mg/L, exceeded the permissible limit. Toczyłowska-Mamińska, (2017) reported a similar observation [41].

The chloride ion (Cl^-) and sulfate ion (SO_4^{2-}) ranged from 57.90 to 238.0 mg/L and 32.0 to 123.0 mg/L respectively (Table 4), were found within the standard level. At most of the sampling sites, The concentration of nitrate-nitrogen (NO_3^--N) varied from 8.80 to 28.90 mg/L, which higher than the prescribed limit. Chandra et al. [42] observed a similar observation. Due to the discharging of effluents in the surface water bodies the concentration of nitrate-nitrogen was at higher level [42]. The bicarbonate (HCO_3^-) and phosphate (PO_4^{3-}) varied from 20.89 to 99.52 mg/L, and 1.11 to 7.93 mg/L respectively. Due to the discharging of effluents in the surface water bodies, the PO_4^{3-} concentration was found to be higher in the study area. The sodium ion (Na^+) and potassium ion (K^+) varied from 12.56 to 45.98 mg/L, and 13.67 to 78.94 mg/L respectively. The potassium ion concentration exceeded the limit whereas, the concentration of the sodium ion was within the prescribed limit. Kumar et al. [18] reported a similar result, that the concentration of magnesium ion (Mg^{2+}) and calcium ion (Ca^{2+}) ranged from 2.08 to 7.31, and 6.08 to 26.30, respectively. The concentration of calcium ion was within the prescribed level. The utmost concentrations of heavy metals Fe, Cu, Zn, Mn, Pb, Cr, and Cd ions were 1.67, 0.853, 0.0593, 0.987, 0.0867, 0.0120, and 0.0189, respectively. Hence, heavy metal contamination was not found in the study.

3.4 Organic pollutants

Several organic functional groups were identified by the FTIR analysis of the effluent (Figure 4). Peak 3435 cm-1 in the range 3500-3200 cm-1 denoted H-bonded OH groups of alcohols and phenols. Peak 1640 cm-1 in the range 1650-1640 correspondents to C=C and C=O bonds. Peak 1542 indicated lignin compounds. Peak 1431 at the range 1460-1380 represented the O-H bond of phenolic compounds. Peak 619 at the range 850-550 denoted chloro-organic compounds presented in the paper mill effluent. Several reports showed a similar observation [19, 43-45]. These detected pollutants may have hepatotoxic, carcinogenic, and endocrine-disrupting effects.

Due to a high concentration of toxic organic pollutants in the paper mill effluent, it inhibits the germination of seeds and plant growth. Moreover, cytotoxic and genotoxic effects were reported by Yadav & Chandra [43].

Several reports showed the presence of organic pollutants i.e., chlorophenols, ethers, amines, lignins, carboxylic acids, dioxin derivatives, furan derivatives, etc. in paper mill effluents [43, 46-49]. Lignin compounds presented in paper mill wastewater can break down into phenolic compounds. Whereas, chlorine is used as a bleaching agent, continuously mixing with the wastewater. As a result, phenolic compounds and chlorine may yield chlorophenols in wastewater, which were reported as estrogenic and mutagenic compounds [12, 50-51]. Other reports showed that chlorophenols produce dioxins and furans, which are well-known toxic compounds and persistent (Figure 5) [48-49].

Organic pollutants presented in the paper mill effluent may induce pathogenic bacteria. The organic pollutants in the paper mill effluent, including recalcitrant chloro-organic compounds and the toxic heavy metals, are getting into the ecosystem and accumulating in the fatty tissues of the

Table 2: Physicochemical parameters of paper mill effluents.

Parameters	Minimum	Maximum	Mean±SD	Permissible limit (ECR 1997)
Temperature	37	39	38.3±0.8	40
pH	8.4	8.6	8.5±0.07	6.0-9.0
DO	1	1.2	1.12±0.07	4.5-8.0
EC	2053	2070	2060±6	1200
Turbidity	270	276	273.5±2	-
TSS	592	600	595.5±3	150
TDS	1502	1513	1507±4	2100
BOD_5	280	288	284.8±3.2	50
COD	843	850	846.2±2.6	200
TOC	106	110	108.3±1.6	-
TH	605	609	607±1.4	-
Phenols	2.95	3	2.97±0.02	1
Cl^-	240	245	242.8±2.1	600
SO_4^{2-}	125	127	126±0.89	400
NO_3^-- N	28.4	29	28.7±0.2	10
PO_4^{3-}	7.94	8	7.96±0.02	-
HCO_3^-	99.55	105	100.9±2	-
Na^+	45.99	48.8	46.78±1.2	200
K^+	78.95	81.4	79.75±0.98	12
Ca^{2+}	26.24	28.21	27.1±0.94	75
Mg^{2+}	7.33	7.89	7.49±0.21	-
Fe	1.67	1.77	1.72±0.04	2
Cu	0.76	0.82	0.78±0.02	0.5
Zn	0.0594	0.065	0.06±0.00	5
Mn	0.786	0.805	0.80±0.00	5
Pb	0.0869	0.0885	0.087±0.00	0.1
Cr	0.012	0.015	0.014±0.00	0.5
Cd	0.019	0.0198	0.019±0.00	0.05

(The temperature, EC and Turbidity are in ^{0}C, µS/cm and NTU respectively and the others are in mg/L except the pH)

Table 3 Physical parameters of surface water body in paper mill effluents discharge areas.

Parameter	Sample spot	Period						Mean±SD	BD SW Standard (ECR 1997)
		Pre-mon. 2019	Mon. 2019	Post-mon. 2019	Pre-mon. 2020	Mon. 2020	Post-mon. 2020		
Tempe-rature	S-1	35	37	30	35	36	30	33.8±3.06	40
	S-2	34	33	22	33	34	21	29.5±6.22	
	S-3	31	32	18	32	32	17	27±7.38	
pH	S-1	8.2	8	8.1	8.3	8.1	8.2	8.15±0.1	6.0-9.0
	S-2	7.6	7.4	7.5	7.7	7.5	7.5	7.53±0.1	
	S-3	7.4	7.2	7.3	7.4	7.2	7.3	7.3±0.09	
DO	S-1	1.4	1.7	1.6	1.3	1.6	1.5	1.52±0.15	4.5-8.0
	S-2	1.3	2.1	1.9	1.3	2	1.7	1.72±0.35	
	S-3	2	4.5	3.2	1.9	4.3	3	3.15±1.1	
EC	S-1	2043	1890	1944	2050	1898	1955	1963±69	1200
	S-2	1566	1267	1298	1570	1265	1303	1378±147	
	S-3	1208	665	1045	1208	789	1067	997±223	
Turbidity	S-1	267	253	269	266	256	270	263±7	-
	S-2	170	172	198	177	173	209	183±16	
	S-3	99	45	66	102	44	87	74±26	

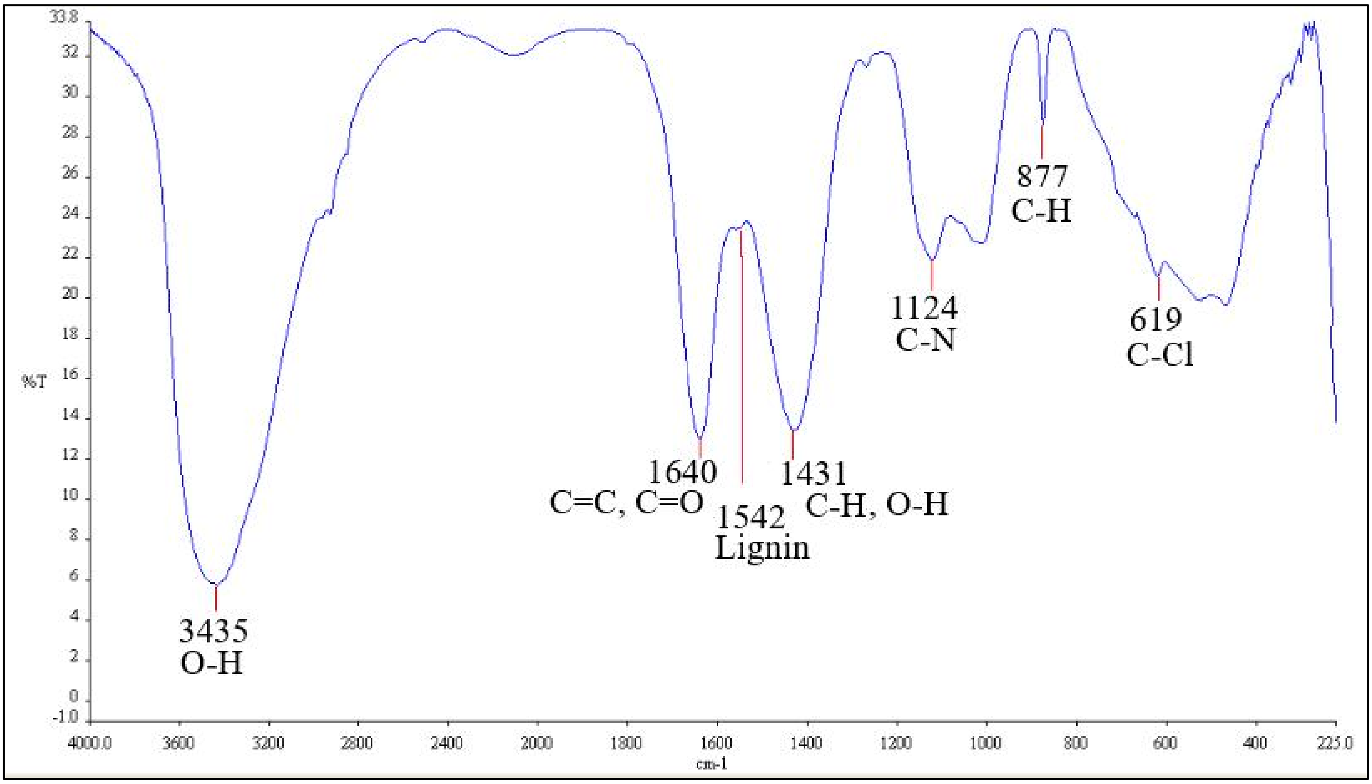

Figure 4: FTIR spectra of pulp and paper mill effluents.

Table 4: Physicochemical parameters, anions, cations and heavy metals of surface water body around paper mill effluents discharge areas.

Parameter	Minimum	Maximum	Mean±SD			BD SW standard (ECR 1997)
			S-1	S-2	S-3	
TSS	157	592	579±14	310±51	180±16	150
TDS	394	1499	1406±100	1071±258	589±154	2100
BOD_5	134	278	250±30	192±18	158±33	50
COD	177	843	726±95	528±147	313±110	200
TOC	50.6	105	100±2.8	77.6±8.3	57.3±7.6	-
TH	140	604	536±61	290±71	162±19	-
Phenols	0.925	2.946	2.2±0.8	1.6±0.38	1.1±0.25	1
Cl^-	57.9	238	207±26	135±58	90±23	600
SO_4^{2-}	32	123	110±7.6	71±18	45±7	400
NO_3^- N	8.8	28.9	25.7±2.7	17±6	10.6±2.7	10
PO_4^{3-}	1.11	7.93	7.2±0.77	2.95±0.57	2.38±0.89	-
HCO_3^-	20.89	99.52	95.7±3.8	53.1±18.8	36.4±7.9	-
Na^+	12.56	45.98	37.7±5.5	24.7±4.2	17.9±3.8	200
K^+	13.67	78.94	69.1±12.9	42.6±11.7	30.4±12.4	12
Ca^{2+}	6.08	26.3	24.3±2.2	20.0±5.2	13.8±4	75
Mg^{2+}	2.08	7.31	7±0.16	5.5±1.07	3.6±1.2	-
Fe	0.425	1.67	1.5±0.11	0.94±0.15	0.62±0.18	2
Cu	0.02	0.853	0.197±0.28	0.199±0.32	0.039±0.01	0.5
Zn	0.0126	0.0593	0.057±0.00	0.039±0.00	0.029±0.01	5
Mn	0.189	0.987	0.65±0.09	0.42±0.14	0.46±0.28	5
Pb	0.0229	0.0867	0.074±0.00	0.052±0.00	0.032±0.00	0.1
Cr	0.0020	0.0120	0.009±0.00	0.006±0.00	0.004±0.00	0.5
Cd	0.0021	0.0189	0.014±0.00	0.006±0.00	0.004±0.00	0.05

Table 6 The calculated terms of the CCME WQI for the surface water body in paper mill effluents discharge areas.

Sample location	Scope, F_1	Frequency,F_2	∑ Excursion	NSE	Amplitude, F_3	WQI score	Ranking
S-1	36.36	36.36	117.97	0.89	47.19	59.70	Marginal
S-2	36.36	36.36	68.07	0.52	34.02	64.39	Marginal
S-3	36.36	25.76	32.01	0.24	19.52	71.91	Fair

human body through the food chain.

3.5. Water Quality Index

At three sampling locations (i.e., S-1, S-2, S-3), the surface water quality was evaluated using the CCME (Canadian Council of Ministers of the Environment) water quality index (WQI). Some parameters (TOC, Turbidity, TH, Mg^{2+}, PO_4^{3-} and HCO_3^-) have no permissible limit for surface water quality. Hence, a total of 22 parameters (i.e., pH, temperature, EC, DO, TDS, TSS, COD, BOD_5, phenol, Cl^-, NO_3^--N, SO_4^{2-}, K, Na, Ca, Fe, Zn, Cu, Pb, Mn, Cd and Cr) were considered to evaluate the WQI score. The calculated terms of the index are mentioned in Table 5. In the present study, the CCME WQI scored 59.70, 64.39, and 71.91 at the three different locations S-1, S-2, and S-3, respectively (Table 5). The WQI ratings of 59.70 and 64.39 show that the surface water quality at sites S-1 and S-2 was only marginal, indicating that the area's water quality was in danger and frequently deviated from the natural or desirable levels found at both sites. Whereas the score of 71.91 represents that the ranking was fair at site S-3, which means the water quality was often preserved but occasionally threatened and deviated from ideal or expected values. [32].

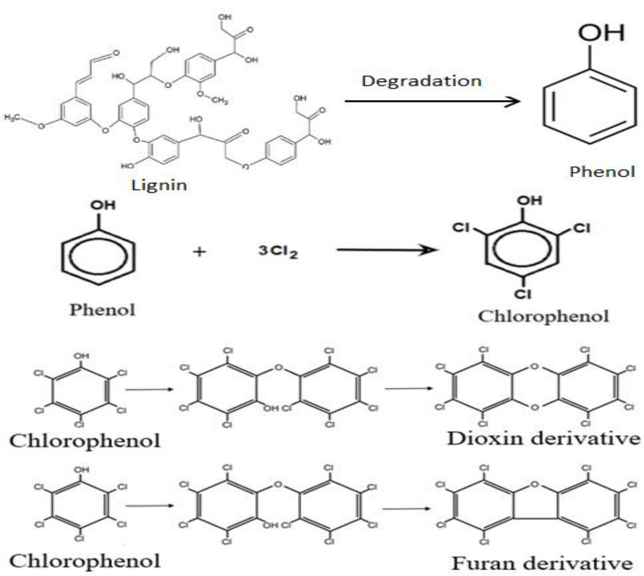

Figure 5: Possible reactions to produce dioxins and furans in paper mill effluents.

From site S-1 to site S-2 to site S-3, the WQI ratings revealed a tendency in favor of improvement. This pattern shows that the surface water quality at the discharge site (S-1) was worsened by the discharge of paper mill effluent, and that the water quality gradually improved as discharge distance increased. Similar observations were made by Dinu et al. [52] and Al-Janabi et al. [53].

4. Conclusions

The survey results regarding the public perception of the crop, fish, livestock, and skin diseases showed negative impacts in the study area because of the discharging untreated paper mill effluent. It revealed that 82 percent of the respondents did not use the canal or the river water for domestic purposes due to the paper mill effluent discharge. The analytical results for both the effluents and the surface water samples showedthe concentrations of TSS, EC, COD, BOD_5, phenolic compounds, K^+ and NO_3^--N higher than the permissible limits. Moreover, the DO levels were below the standard level. However, there was no evidence that the heavy metal concentrations exceeded the permissible standard limits. The FTIR analysis results showed the presence of several toxic pollutants, including lignin, phenol, and halo- compounds, in the effluent samples. The CCME water quality index revealed that the water quality of the nearby surface water bodies in the paper mill effluent discharge area was marginal from the discharge point to the middle of the canal (about 350 meters downstream) and fair at 700 meters downstream before falling into the river. Concerning the analysis results of the study, the surface water quality of the area was deteriorating and causing harm to the aquatic environment. Therefore, immediate measures should be taken to stop the discharge of untreated effluent from the paper mills to the surface water bodies, and thus help the restoration of the ecosystem.

The study carefully analyzed the findings extracted from the social survey and experimental results and finally, made some recommendations that would be helpful to reduce environmental degradation regarding paper mill effluents discharge.

The recommendations are as follows:

a) Advanced manufacturing technologies with less water used in the production processes should be installed in the paper manufacturing industry.

b) Modern and effective ETP comprises of combined treatment (i.e., coagulation, flocculation, adsorption, membrane filtration, advanced oxidation, and biological) facilities should be accommodated in paper mills.

c) Wastewater recycling systems or reusing effluent water from processing should be introduced to ensure sustainable water resource management.

d) Paper mills should not be set up on agricultural land. It should be established in industrial zones with advanced effluent treatment technology.

e) Proper monitoring should be ensured to maintain the surface water quality standards for effluent discharge.

Authors Contribution

M.S.Z.S., and M.G.M., have the main idea of the manuscript. MSZS wrote the the manuscript. M.G.M revised the manuscript and provide suggestions.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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Data Availability statement

The data presented in this study are available on request from the corresponding author.

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