Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 3, Pages 09-25, July-September 2024

Evaluation of the Irrigation Water Quality of a Canal Contaminated with Textile Dyeing Industry Effluent

Tawfeequa Rahman[1] & M.G. Mostafa[2*]

[1,2]Water Research Laboratory, Institute of Environmental Science, University of Rajshahi, Rajshahi 6205, Bangladesh.
Corresponding Author (M.G. Mostafa) Email: mgmostafa@ru.ac.bd[*]

DOI: https://doi.org/10.38177/ajast.2024.8302

Article Received: 05 May 2024 Article Accepted: 17 July 2024 Article Published: 24 July 2024

ABSTRACT

The textile dyeing industries discharge untreated effluent into nearby surface water bodies and introduce large numbers of inorganic, organic toxic compounds containing suspended solids, color, etc., which pose a threat to use for irrigated agricultural lands and human health. The study aimed to assess the irrigation water quality of textile dyeing industry effluent-contaminated canal water. The canal water samples were collected from several locations, analyzed for various physicochemical parameters, and assessed for water quality using multivariate statistical analysis and several water quality indices. The analysis results illustrated that the high levels of electrical conductivity (EC), total suspended solids (TSS), turbidity, Na+, NO3-, PO43-, HCO3-, BOD, and COD in the wastewater samples exceeded the DoE-BD standard limits, indicating a higher level of pollution of the canal water. Concerning heavy metal concentrations, Pb was found to be at a higher level in the water. Moreover, irrigation water quality indices such as permeability index (*PI*), Kelly's ratio (*KR)*, sodium adsorption ratio (*SAR*), and magnesium adsorption ratio (*MAR*) were found to be higher than the standard limits. The multivariate cluster analysis showed that the two clusters were found among the eighteen sampling sites that included heavily contaminated sites. The discharge of industrial effluent into canal water has a detrimental effect on agricultural products. The study observed that the canal water is not suitable for irrigation purposes, and thus the textile dyeing industrial effluent must be treated by installing an environmentally friendly effluent treatment plant (ETP) before being dumped into surface water bodies, which will help reduce environmental pollution as well as develop sustainable surface water resource management.

Keywords: Effluent; BOD; COD; Water quality indices; Physicochemical parameters; Statistical analysis.

1. Introduction

The textile industry has made a significant contribution to uplifting Bangladesh's economic status. When processing and finishing raw materials, these industries employ a range of chemicals and azo dyes (direct, reactive, fast, mordant, premetallized, etc.). The textile industry typically utilizes enormous amounts of water throughout the production process, and after the process is complete, contaminated liquids are discharged into sewers or drains without any kind of pretreatment (Kant, 2012; Chindah et al., 2004; Islam, M.R., and Mostafa, 2018). Moreover, a significant amount of wastewater containing untreated textile dyes is discharged into surface water bodies. Undoubtedly, the direct release of contaminated water reduces soil productivity and negatively affects crop yield in the surrounding agricultural areas (Islam et al., 2006; Islam, M.R., and Mostafa, 2020). Industrial wastewater, or sewage water, is discharged into surface water bodies and used as irrigation water in some areas of Siddhirganj Upazila in Narayanganj district. This irrigation water may pose a risk to human health and other applications if it is not treated before being discharged into the environment. Untreated or insufficiently treated textile effluent can have long-term adverse health effects and negatively impact the natural ecosystem, endangering aquatic and terrestrial species (APHA, 2002). High levels of BOD, COD, color, toxicity, surfactants, turbidity, and possibly heavy metals are all taken into consideration in the dye baths (Wynne et al., 2001; Shakil and Mostafa, 2021b). Several inorganic and organic compounds, suspended particles, dissolved solids, etc., are present in the discharge effluent. The canal water around the industrial zone is severely polluted and poses a huge threat to human health, crop production, soil fertility, and the environment (Monira and Mostafa, 2023; Yusuf et al., 2004; AEPA, 1998). Some of these may contain heavy metals, including chromium, copper, zinc, and mercury, while others may contaminate water with oils, greases, and waxes (EPA, 1974; Monira et al., 2023). Gazipur and Narayanganj's

Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 3, Pages 09-25, July-September 2024

textile dyeing industry regularly produces a significant volume of effluent sewage sludge. They eventually find their way into the Turag and Shitalakkhya Rivers after being dumped directly into the nearby channel, agricultural fields, irrigation canals, and surface water (Sultana et. al., 2009; Islam and Mostafa, 2021a; Islam and Mostafa, 2022a & b). This study aimed to evaluate the textile dyeing industry effluent-contaminated canal water for irrigation purposes. The study considered the characterization of the canal water and assessed the degree of pollution using several indices.

2. Materials and Methods

2.1. Study area

Narayanganj, the most well-known administrative district in Bangladesh, has been the center of industrialization. Situated on the banks of the Shitalakkhya River. The study area is Siddhirganj, an administrative area called Upazila in Narayanganj district, mostly recognized as an epicenter for the textile industry. The sampling area is approximately located at 23^{o}.66'424 North latitude and 90^{o}.49'183 East longitude.

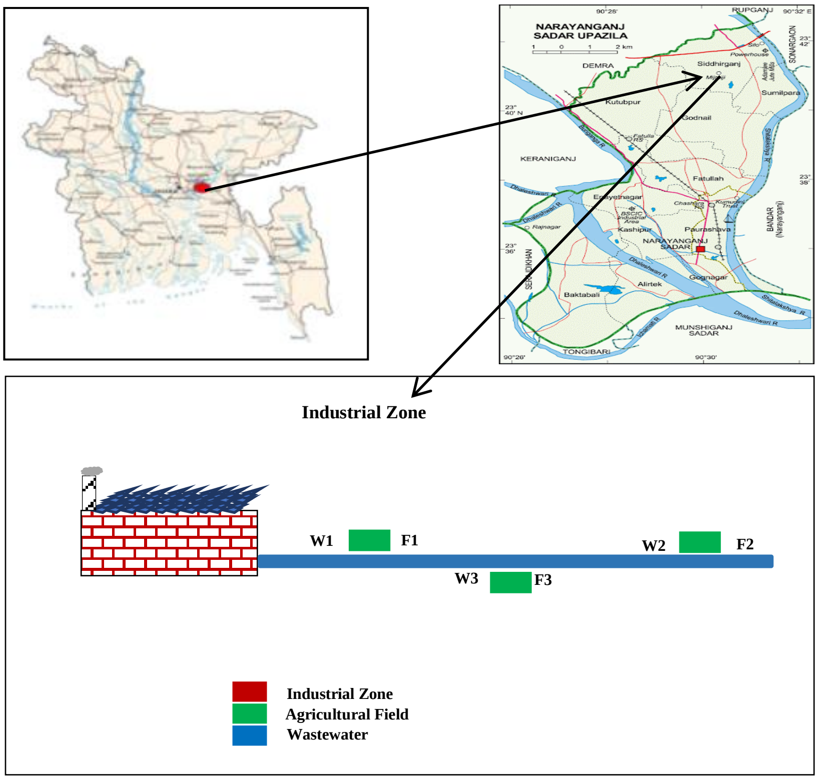

Figure 1. Sampling Location map of the Study Area

2.2. Sample collection and preparation

The industrial wastewater effluents were collected from textile dyeing units in Narayanganj, Bangladesh, from pre-monsoon 2022 to post-monsoon 2023. The samples were collected for analyzing the following parameters (Tables 1 and 2). Special care was taken to reduce air, glassware, and reagent contamination during the overall process of sample preparation and analysis. The methods and procedures used for data collection, preservation, analysis, and interpretation are in accordance with APHA (2012) guidelines. The turbidity was measured with a turbidimeter, and the pH, EC, and DO were measured with a portable multi-meter. Total dissolved solids (TDS) and

Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 3, Pages 09-25, July-September 2024

total suspended solids (TSS) were measured using the gravimetric methods of analysis. The biological oxygen demand (BOD) was assessed using the BOD_5 method. Each sample was analyzed three times to ensure the precision and accuracy of the measurements obtained.

2.3. Statistical analysis

By applying suitable data dimension reduction (Li et al., 2011), the data sets were statistically evaluated using principal component analysis (PCA), Pearson's correlation, and hierarchical Cluster analysis (CA) to investigate the quality of effluents and potential sources of different pollutants in the study area (Islam et al., 2023; Rahman et al., 2017; Xiao et al., 2014). To show their average behaviors and dispersions, descriptive statistics were also produced, such as the parameters' mean and standard deviation. SPSS software (version 20) was used for all statistical analyses of the data.

2.4. Irrigation Water Quality Indices

The four most commonly used parameters for assessing irrigation water quality are sodium adsorption ratio (*SAR*), EC or TDS, residual sodium carbonate (*RSC*), and concentration of certain ions such as Na^+, HCO_3^-, and Cl^- (Michael 1992; Raghunath, 1987; Islam and Mostafa, 2021b). The following techniques were taken into consideration for the current irrigation water quality assessment, with the exception of the other physicochemical parameters (Islam and Mostafa, 2022; Monira et al., 2024):

Gupta (1983) expressed residual sodium bio-carbonate (*RSBC*) as:

$$RSBC = \mathrm{HCO_3^-} - \mathrm{Ca^{2+}} \qquad (1)$$

Sodium adsorption ratio (*SAR*) value of irrigation water calculates the relative proportion of Na^+ to Ca^{2+} and Mg^{2+} (Alrajhi et. al., 2017) and according to Richards (1954), *SAR* is expressed as:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad (2)$$

Donen (1964) defined permeability index (*PI*) as:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{(Na^+ + Ca^{2+} + Mg^{2+})} \times 100 \qquad (3)$$

Kelley's ratio (*KR*) (Kelley, 1963) is described as:

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})} \qquad (4)$$

Magnesium adsorption ratio (*MAR*) also recognized as a magnesium hazard was calculated (Raghunath 1987) as:

$$MAR = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \qquad (5)$$

The *Na%* is calculated as the following Eq. (Todd 1980):

$$Na\% = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \qquad (6)$$

To assess the sodium risk in irrigation water, soluble sodium percentage, or SSP, was utilized.

Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 3, Pages 09-25, July-September 2024

Todd (1980) established *SSP* as:

$$SSP = \frac{(Na^{+}+K^{+})}{(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})} \times 100 \qquad (7)$$

The concentrations in each equation are expressed as milli-equivalents per liter, or mEq/L, and are computed by dividing the relevant ion's equivalent weight in milligrams per liter (mEq/L) by its aqueous concentration, which is given in milligrams per liter.

3. Results and Discussion

3.1. Effluent Characterization

A description of the physicochemical characteristics and heavy metal content of textile dyeing industry effluent in Siddhirganj Upazila, Narayanganj, Bangladesh, is shown in Tables 1 and 2.

Table 1. Physicochemical parameters of t the contaminated canal water samples in Narayanganj, Bangladesh

Parameter	Pre-Monsoon 2022-2023	Monsoon 2022-2023	Post Monsoon 2022-2023	Mean±STD	DoE standard limit
Temp. (°C)	34.02	30.35	27.70	30.69±3.17	40°C
pH	7.00	7.20	7.72	7.30±0.37	6.5-8.5
EC (µS/cm)	1511.67	1079.67	1951.67	1514.33±436.01	2250.00
TSS (mg/L)	778.00	564.00	990.83	777.61±213.42	100.00
TDS (mg/L)	1328.33	1631.17	2032.50	1664.00±353.23	2100.00
Turbidity (NTU)	44.69	24.89	16.16	28.58±14.62	10.00
TH (mg/L)	345.67	349.34	261.17	318.72±49.88	200-500
Ca^{2+} Hardness	148.97	135.19	146.67	143.61±7.38	
Mg^{2+} Hardness	196.70	214.17	114.50	175.12±53.22	
DO (mg/L)	1.57	1.65	2.69	1.97±0.62	6.00
BOD_5 (mg/L)	187.68	454.45	150.65	264.26±165.75	30.00
COD (mg/L)	294.49	573.02	263.11	376.87±170.59	200.00

The temperature of the samples varies from 27.70°C to 34.02°C, as shown in Table 1, within the standard limit. Whereas the pH values in this study varied between 7.00 and 7.72, which were within the standard limit for discharge wastewater (DoE, 2023). At various sampling intervals, EC values ranging from 1079.67 to 1951.67 mS/cm were recorded; these values were often less than DoE standards (Table 1). In the study, total suspended solids (TSS) were found to be significantly greater than the DoE (2023) standard, ranging from 564 to 990.83 mg/L. The high TSS reported might be the cause of various dyeing compounds being used in the textile mills as well as textile fibers released during dyeing processes (Islam, M.R., and Mostafa, 2022; Kambole 2003). The average value found in this study was less than the average value found in Nigerian textile effluent (Ohioma et al., 2009).

In this study, the amounts of TDS in the effluent were between 1328.33 and 2032.50 mg/L, which was within the permissible limit. Various turbidity concentrations were observed in this characterization study. The samples showed a high turbidity level of 16.16 to 44.69 NTU, which was higher than the DoE standard (2023). In numerous cases, turbidity can have a detrimental impact on the quality of water. For example, it can reduce the amount of light that plants receive and harm fish and other aquatic species' delicate gill structures. Since the samples include a large number of total solids, the water becomes less clear due to a rise in turbidity, and photosynthesis rates also drop. Total hardness (TH) is the sum of the magnesium (114.50-214.17 mg/L) and calcium (135.17-98.97 mg/L) hardness values found in the samples. TH ranges from 261.17 to 349.34 mg/L. The harder the water, the more likely it is to react with soap. The average TH values were less than those that Ntuli et al. (2009) and Hussain et al. (2004) had reported.

In this research, the values for DO were between 1.57 and 2.69 mg/L, which were lower than the DoE standard (2023). An excessive organic load entering the water and causing oxygen depletion could be the cause of the reduced DO level (Mohabansi et al., 2011). Kale (2016) states that the temperature of the water, the time of day, the season, depth, altitude, and flow rate are some of the variables that affect DO levels. As a result of the high levels of BOD and COD in the waste water sample, the DO content was extremely low. Low DO readings in the current study could be the result of increased microbial activity. Since organic material decomposes more quickly in warm temperatures, this process may have a significant role in the consumption of DO. Additionally, flow is decreased during dry spells, which lessens the quantity of oxygen agitated into the water. Ahmed (2007) reported DO values in textile effluent near the DEPZ area higher than the present study area.

Notably, in Narayanganj, Bangladesh, textile effluent was found to have BOD values ranging from 150.65 to 454.45 mg/L. This is three to ten times higher than the BOD limit that is permitted for wastewater to be released into inland surface water. Multiple studies have demonstrated that the composite textile mill generates a significant amount of waste that requires oxygen for biochemistry. BOD is the rate at which, throughout the course of an aerobic five-day disintegration process, bacteria in water extract oxygen from dissolved organic matter. The large discharge of industrial wastewater effluent, which contains a significant amount of organic matter, may be the cause of an increase in BOD. Patel and Vashi (2015) claim that the untreated textile effluent is the reason for the high BOD value, which quickly depletes the surface water source of DO. As a result, there is less DO in water when BOD is high.

The measured COD value ranged from 263.11 mg/L to 573.02 mg/L, above the standard limit set by the DoE. Increases in COD may be caused by a large volume of industrial waste, which includes softeners, detergents, formaldehyde-based dye fixing agents, non-biodegradable dyeing chemicals, and more. Significant amounts of toxicants, such as heavy metals, may be present in the wastewater, as indicated by the notable rise in COD levels relative to BOD (Uwidia and Ejeomo, 2013). Similar COD values were found in the textile effluent near Savar Upazila (Roy et al., 2010) and in the Bangladeshi DEPZ area (Ahmed, 2007) in a small number of additional studies. According to the study, a higher COD indicates that there are more compounds in the water body with a higher EC.

Table 2. Major cations, anions, and heavy metals of the effluent samples of textile dyeing industry in Narayanganj, Bangladesh

Parameter	**Pre-Monsoon 2022-2023**	**Monsoon 2022-2023**	**Post Monsoon 2022-2023**	**Mean±STD**	**DoE standard limit**
K	11.87	3.92	7.85	7.88±3.98	12.00
Ca^{2+}	59.59	54.00	57.07	56.89±2.80	75.00
Mg^{2+}	48.00	52.26	23.06	41.10±15.77	25-50
Na	289.77	425.10	871.83	528.90±304.60	200.00
NO_3^-	50.34	41.90	55.64	49.29±6.93	5.00
PO_4^{3-}	6.25	7.16	7.16	6.86±0.53	2.00
SO_4^{2-}	125.07	89.14	155.93	123.38±33.43	400.00
HCO_3^-(mg/L)	440.83	495.30	561.34	499.15±60.35	
Cl^-(mg/L)	229.53	275.29	229.67	244.83±26.38	150-600
Cr	0.11	0.03	0.08	0.07±0.04	0.50
Mn	0.51	0.49	0.51	0.50±0.01	2.00
Fe	0.74	0.73	0.73	0.73±0.00	3.00
Ni	0.06	0.05	0.05	0.05±0.00	1.00
Cu	0.07	0.07	0.07	0.07±0.00	3.00
Zn	0.18	0.20	0.20	0.19±0.01	5.00
Cd	0.02	0.02	0.01	0.02±0.00	2.00
Pb	0.14	0.14	0.11	0.13±0.02	0.10

In this study, the range of potassium was 3.92 to 11.98 mg/L, which was below the standard limit, while the range of calcium was 54.00 to 59.59 mg/L, which was also below the standard limit. Moreover, the range of magnesium was 23.06 to 52.26 mg/L, which was below the standard limit (DoE, 2023). Na^+ concentrations in textile dyeing effluent ranged from 289.77 to 871.83 mg/L, exceeding DoE's permissible limit (2023). The sodium compounds, which are utilized in practically every stage of wet processes, are the cause of the wastewater's increased Na^+ concentration. Sodium chloride is one of the sodium compounds that is widely used in the textile industry to soften water (Hussain et al., 2004).

In this study, the range of nitrate was observed from 41.90 to 55.64, which was higher than the standard limit (DoE, 2023), while the range of phosphate was found to be 6.25 to 7.16, which was also higher than the DoE standard (2023). Higher values of nitrate in industrial effluent can occur due to fertilizer runoff, leakage from septic tanks, erosion of animal manure, and also due to the effluent from wastewater treatment plants (ETP). Moreover, higher levels of phosphate might be found while using industrial chemicals and detergents, agricultural runoff, and stormwater that carries pollutants into local waterways. The bicarbonate ion remains as Na, Mg, and Ca bicarbonate, and these are the most common and abundant minerals in the aquifer system (Islam and Mostafa, 2024). Bicarbonate is correlated with the overall hardness of the water and has no recognized national or international standard levels. The average concentration of bicarbonate in the textile dyeing effluent was found to be 440.83 to 561.34 mg/L in different sampling periods of the study area (Table 3). The concentration of sulfate varied from 89.14 to 155.93 mg/L, and that of chloride varied from 229.53 to 275.29 mg/L, which was within the permissible limit (DoE, 2023).

The mean concentrations of Cr, Mn, Fe, Ni, Cu, Zn, and Cd in textile dyeing effluents were found to be within the DoE (2023) permitted limit (except for Pb), as shown in Table 2. The prolonged build-up of lead from motor vehicle emissions may be one of the main causes of the elevated lead content in the water. Based on these findings, it can be said that the water is too polluted to be used for irrigation because of the effluent levels from textile dyeing.

Table 3. Irrigation Water Quality Indices of the effluent samples of textile dyeing industry in Narayanganj, Bangladesh

Parameter	**Pre-monsoon 2022-2023**	**Monsoon 2022-2023**	**Post Monsoon 2022-23**	**Mean±Std**	**Standard limit**
RSBC	6.48	7.44	8.49	7.47±1.00	<5-safe, 5-10= marginal, >10=unsatisfactory
SAR	59.97	63.57	76.99	66.84±8.97	between 3 to 9
PI	56.85	59.31	68.33	61.50±6.04	<1
KR	31.77	35.41	35.85	34.35±2.24	>1
MAR	72.05	73.89	68.32	71.42±2.84	50.00
% of Na	87.97	90.34	96.95	91.75±4.65	<40 recommended
SSP	87.98	90.35	96.96	91.76±4.65	>60

In the present study, the *RSBC* value was found to be marginal. The excess concentration of HCO_3^- over Ca^{2+} is shown by *RSBC* (Hussain and Hussain, 2004). The post-monsoon period in the study area had the highest *SAR* value and the highest concentration of Na^+ of any other sample period (Table 3). There is a substantial correlation between the *SAR* values of irrigation water and the amount of Na^+ absorbed by the soil (Raihan and Alam, 2008).

The cation change complex could become saturated with Na^+ if the irrigation water has a high Na^+ content and a low Ca^+ content. Due to the clay particles' dispersion, this may completely damage the soil's structure (Todd, 1980). Higher Na^+ levels lead to the formation of alkaline soil, whereas irrigation water containing Na^+ reacts with the soil to decrease permeability. The soil becomes impervious when the water is used repeatedly. High Na^+ saturation is another direct cause of Ca^{2+} deficiency. When the soil is repeatedly irrigated for a prolonged length of time with high Na^+ water, under wet conditions it becomes plastic and sticky, and in dry conditions it forms crusts and clouds. However, the addition of Ca^{2+} or Mg^{2+} salts in irrigation water reduces the adverse effects of sodium by increasing the soil's permeability (Punmia and Lal, 1981; Asaduzzaman, 1985).

The amount of water that is suitable for irrigation depends on several aspects, but in general, the higher the *SAR*, the less suitable the water is. Soil additives may be necessary for irrigation utilizing water with a high *SAR* in order to prevent long-term soil damage. Years of application of irrigation water with a high *SAR* can cause the sodium in the water to replace the calcium and magnesium in the soil. This will result in a loss of soil structure and tilth, as well as a reduction in the soil's capacity to create stable aggregates. Moreover, this will result in less soil permeability and infiltration, which will negatively impact crop productivity. If *SAR* is higher than 9, fine-textured soils will have severe issues, while sandy soils will experience fewer problems. There won't be an issue if *SAR* is less than 3. Given that all *SAR* values in this study region exceeded the standard limit, we can conclude that there is a serious issue there.

Nevertheless, it was insufficient for irrigation, despite taking the study area's permeability index (*PI*) into account. Donen's chart (Raghunath 1987) indicates that the *PI* should be less than 1, but the study area's *PI* value was 100 times higher (Table 3). The equilibrium between the ions Na^+, Ca^{2+}, and Mg^{2+} in water is shown by Kelley's ratio (*KR*). An excessive amount of Na is present in the water when the *KR* is greater than 1. According to Kelley's (1963) recommendation, the ratio of irrigation water should not be greater than 1, even though the study area's ratio was five to thirty times higher (Table 3).

When the magnesium adsorption ratio (*MAR*) is higher than 50, it is detrimental to the soil (Gupta and Gupta 1987). The pre-monsoon and post-monsoon months had the highest *MAR* recorded in the study area. Such elevated *SSP* in irrigation water may decrease soil permeability and hinder plant growth (Joshi et al., 2009). Moreover, *SSP* is employed to assess salt risks. Water containing more than 60% *SSP* might lead to sodium buildup, which can deteriorate the physical characteristics of the soil. The percentage of *SSP* > 60 in this study suggests that the study area's soil quality was extremely low and unfit for irrigation. Sodicity, permeability, and shifting soil structure are the three hazard areas that are most affected by the values of *Na%*, saturated sodium percentage (*SSP)*, sodium adsorption ratio (*SAR*), and permeability index (*PI*). These parameter values show the total Na-hazard in the soil, which hardens the soil, lowers the rate of infiltration, decreases plant water adsorption capacity in the root zone, and produces an alkaline (with HCO_3^-/CO_3^-) and saline (with Cl^-) environment in the soil.

The study observed that the contaminated soil of these textile industrial locations is insufficient for farming based on a variety of indices of textile dyeing effluent. As was said before, as textile dyeing effluents damage the environment, they must be appropriately treated before being disposed of.

Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 3, Pages 09-25, July-September 2024

4. Multivariate statistical analysis

4.1. Pearson Correlations

Table 4 displays the results of an analysis using Pearson's correlation coefficient between the chemical parameters of irrigation water samples. In Table 4, pH showed significant positive correlations with K, Na, and DO. Similarly, a close relationship was noted between EC- K, EC-Ca^+, EC- NO_3, EC- SO_4^{2-} and EC- HCO_3^- ($p<0.01$), suggesting a common source of these ions. A good correlation between TSS-TDS, TSS-Na, TSS-NO_3^- and TSS- DO ($p<0.01$) was also observed in water samples. TDS showed a high positive connection ($p<0.01$) with K-Na-DO, and a strong positive correlation ($p<0.01$) with the other parameters (K, N, SO4, and DO), according to the matrix data for this study. A strong positive correlation was found between Na, DO ($p<0.01$), and C-Mg-HCO_3^-. At a significant level of 0.01, a strong correlation was also found between Pb and the other parameters that were studied. It was evident that BOD and COD had a considerable correlation significant at the 0.01 level with other metrics. In Table 4, correlation coefficients between the physicochemical characteristics and heavy metal content in effluent samples, Pb concentration was substantially and positively related to COD and BOD. The concentrations of pH, TDS, K, Na^+, NO_3^- and DO were significantly and negatively correlated with Pb.

Table 4. Pearson correlation among the physicochemical parameters of the effluent samples from textile dyeing industry in Narayanganj, Bangladesh

	pH	EC	TSS	TDS	K	Na	Ca^{2+}	Mg^{2+}	NO_3^-	PO_4^{3-}	SO_4^{2-}	HCO_3^-	Cl^-	DO	BOD_5	COD	Pb
pH	1																
EC	0.131	1															
TSS	0.305	0.347	1														
TDS	0.292	0.462	0.559	1													
K	0.805	0.511	0.492	0.772	1												
Na	0.786	0.444	0.672	0.785	0.963	1											
Ca^{2+}	-0.291	0.551	-0.322	-0.074	-0.068	-0.273	1										
Mg^{2+}	-0.549	0.010	-0.889	-0.476	-0.539	-0.723	0.609	1									
NO_3^-	0.426	0.516	0.822	0.247	0.444	0.598	-0.257	-0.686	1								
PO_4^{3-}	0.235	0.389	-0.612	-0.192	0.169	-0.037	0.477	0.637	-0.185	1							
SO_4^{2-}	-0.186	0.877	0.467	0.624	0.355	0.357	0.402	-0.060	0.431	0.033	1						
HCO_3^-	-0.138	0.749	-0.247	0.391	0.290	0.113	0.678	0.529	-0.139	0.647	0.690	1					
Cl^-	-0.571	0.059	-0.329	0.400	-0.126	-0.197	0.199	0.463	-0.579	0.044	0.369	0.580	1				
DO	0.790	0.136	0.790	0.514	0.748	0.879	-0.561	-0.933	0.725	-0.320	0.067	-0.354	-0.516	1			
BOD_5	-0.268	-0.690	-0.695	-0.119	-0.331	-0.410	-0.169	0.441	-0.900	0.044	-0.539	-0.051	0.578	-0.470	1		
COD	-0.243	-0.715	-0.661	-0.103	-0.313	-0.383	-0.209	0.392	-0.883	0.004	-0.557	-0.093	0.557	-0.428	0.998	1	
Pb	-0.862	-0.600	-0.456	-0.537	-0.936	-0.883	-0.064	0.472	-0.568	-0.318	-0.311	-0.265	0.388	-0.718	0.538	0.527	1

4.2. Cluster analysis

Using a dendrogram with Ward's method and hierarchical Cluster analysis, the research area's sampling points are classified (Figure 2). Sample sites within the same cluster have characteristics related to the parameters under study.

It is possible that the parameters that are part of the same cluster were extracted from the same source (Islam and Mostafa, 2022c). Cluster analysis for data sets depending on the parameters of the water samples that were examined resulted in two separate clusters (Figure 2). The only four variables that make up Cluster 1 are pH, Na, DO, and TSS, which showed positive loading on PC2, where, only TSS showed a negative loading on PC6 (Table 5). Temperature, turbidity, BOD, COD, NO_3^-, and PO_4^{3-}, as well as Mg hardness, Mg, TH, HCO_3^-, Cl^-, and TDS, were used to create Cluster 2. Hence, the same cluster contained the parameters from sources of the same kind.

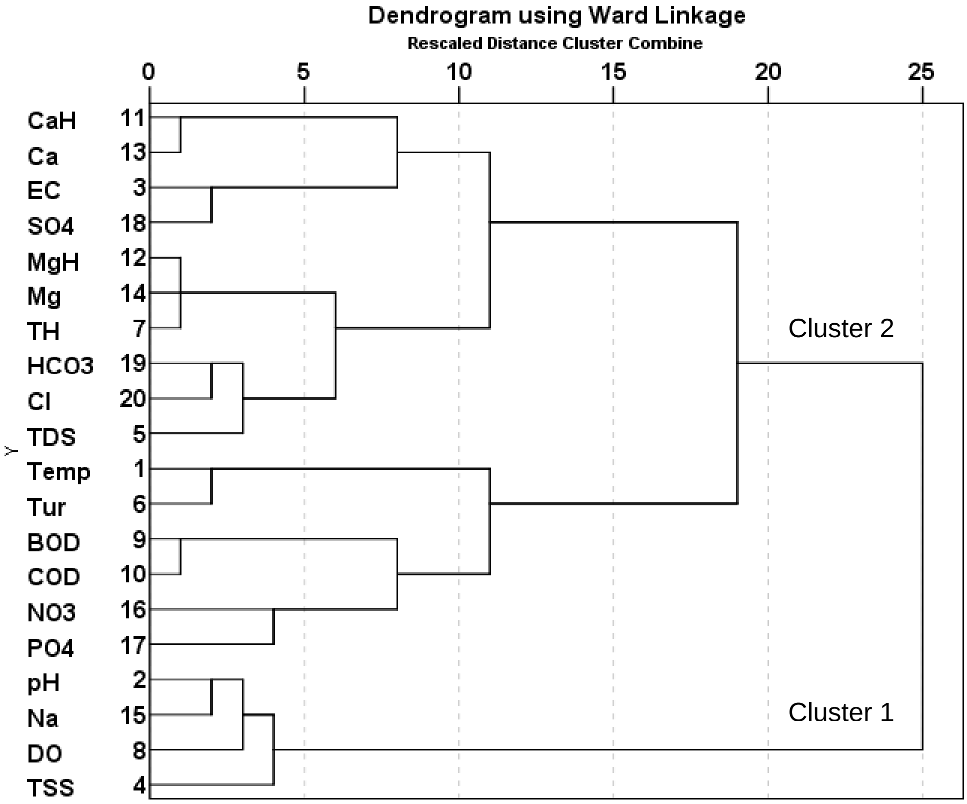

Figure 2. Hierarchical cluster analysis based on the physicochemical parameters in contaminated canal water

4.3. Principal component analysis

Principal Component Analysis (PCA) is mostly employed when most of the variables have a higher correlation with each other, and it is preferable to minimize their number to an independent set. The association seen in the clustered variables could be explained via PCA. In Table 5, the total 90.64% of the variance in the study area explores six controlling factors that were identified from the data sets with Eigenvalues greater than one (Liu et al., 2003). The structure of the underlying parameters, a scree plot (Figure 3) was used to determine the number of PCs to be kept for analysis. In Figure 3, the number of principal components is shown along the x-axis, which is 20 in this case. Whereas, the percentage of the variance per PC (eigenvalues) is presented along the y-axis. Here, the curve appears at the 10th PC, which is COD. Table 5 displays the factor loadings that have been determined, the cumulative percentage of variation, and the percentages of total variance that each component accounts for. The loading factors with loaded absolute values of >0.75, 0.75-0.50, and 0.50-0.30, respectively, were classified as "strong," "moderate," or "weak" (Islam and Mostafa, 2022c Gao et.al., 2016). The variance explanations of the PCs, PC1,

Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 3, Pages 09-25, July-September 2024

PC2, PC3, PC4, PC5, and PC6 were 31.222%, 24.592%, 10.901%, 10.409%, 7.660%, and 5.860%, respectively (Table 5).

In addition, the study found that PC1, PC2, PC3, PC4, PC5, and PC6 for the data set strongly loaded on TH, Mg hardness, Mg^+, Cl^-, pH, Na^+, SO_4^{2-}, BOD, COD, Ca hardness, Ca^+, and PO_4^{3-}suggesting that the contaminated water samples included more ionic compounds (Islam and Mostafa, 2022c; Ahmed et.al., 2016). In PC1, PC2, PC3, and PC6, HCO_3^-, DO, EC, and NO_3^- have substantial factor values, indicating a moderate degree of association between them. The source of variables on which PC1, PC2, PC4, and PC5 are loaded on might be geogenic, whereas, PC3 and PC6 loading variables might be discharged from anthropogenic sources, especially from industrial effluents and agricultural activities in the study area. Another potential source of wastewater contamination could come from natural processes, such as the oxidation of iron (Rahman and Gagnon 2014). All six PCs were weakly and negatively loaded on temperature TDS, TH, and TSS (Table 5). Furthermore, the PCA results with positive and negative values suggested whether the extracted loads on a certain component had an impact on the water samples or not.

Table 5. Varimax rotated principal component analysis of the analyzed parameters of the effluent samples from textile dyeing industry in Narayanganj, Bangladesh

Rotated Component Matrix[a]						
	Component					
	PC1	PC2	PC3	PC4	PC5	PC6
Temp	.125	-.770	-.554	-.044	.235	-.022
pH	-.010	.925	-.092	-.130	.048	.062
EC	.064	.094	.687	-.584	.219	.128
TSS	-.237	.323	.274	-.411	-.094	-.720
TDS	.476	.387	.506	.017	.078	-.435
Tur	-.075	-.351	-.773	.068	.183	-.321
TH	.893	-.001	-.100	.116	.307	.142
DO	-.317	.743	-.009	-.217	-.134	-.324
BOD	.166	-.154	-.126	.943	.059	.080
COD	.120	-.087	-.149	.954	.083	.099
CaH	.262	-.050	.072	.061	.949	.074
MgH	.936	-.252	-.031	.037	.108	.139
Ca	.262	-.050	.072	.061	.949	.074

Mg	.936	-.252	-.031	.037	.108	.139
Na	-.206	.773	.476	-.127	.036	-.170
NO3	-.051	-.218	.090	.428	.077	.679
PO4	.115	.098	.141	-.160	.060	.837
SO4	.073	-.130	.757	-.309	.397	-.233
HCO3	.731	.014	.540	-.057	.354	.142
Cl	.835	-.001	.220	.225	.099	-.247
Eigenvalues	6.244	4.918	2.180	2.082	1.532	1.172
% of Variance	31.222	24.592	10.901	10.409	7.660	5.860
Cumulative %	31.222	55.815	66.716	77.125	84.785	90.644
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.						
a. Rotation converged in 9 iterations.						

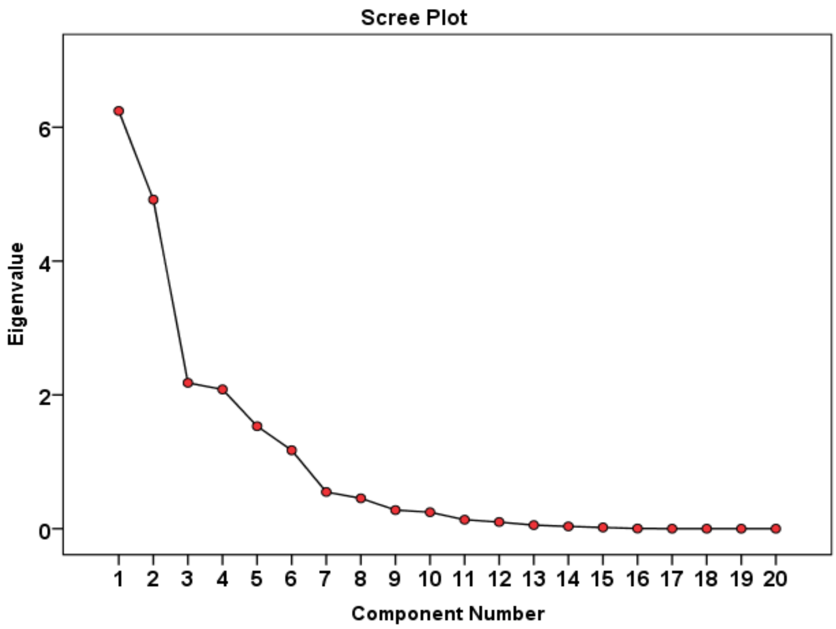

Figure 3. Scree Plot based on the physicochemical parameters in contaminated canal water

5. Conclusion

The textile dyeing industry plays an important role in the economic growth of Bangladesh. The textile dye industry discharges huge volumes of effluent, which is one of the biggest issues that generate pollutants in the environment.

The mean physicochemical parameters such as temperature, pH, DO, EC, TDS, TH, and Cl- were found to be 30.69°C, 7.30, 1.97 mg/L, 1514.33 S/cm, 1664 mg/L, 318.72 mg/L, and 244.83 mg/L, respectively, which are within the DoE standard (except TSS, BOD, and COD). The concentrations of major cations and anions, including heavy metals found in the textile effluents, were in the order of Na > Ca>Mg>K >Fe>Mn>Zn>Pb>Cr >Cu >Ni >Cd, respectively. Moreover, irrigation water quality indices such as permeability index (*PI*), Kelly's ratio (*KR)*, sodium adsorption ratio (*SAR*), and magnesium adsorption ratio (*MAR*) were found to be higher than the standard limits. Through multivariate cluster analysis, two clusters were found among the eighteen sampling sites, which included heavily contaminated sites. The study observed that the canal water is not suitable for irrigation purposes, and thus the textile dyeing industrial effluent must be treated by installing an environmentally friendly effluent treatment plant (ETP) before being dumped into surface water bodies.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare having no competing interest with any party concerned during this publication.

Consent for Publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors made full contribution starting from proposal writing, visualization, methodology, data analysis, first draft writing, review and editing.

References

AEPA (Australian Environmental Protection Authority) (1998). Environmental Guidelines for the Textile dyeing and Finishing Industry, State Government of Victoria, Melbourne, Victoria, Australia.

Ahmed, T. (2007). Characterization of textile effluent from selected industries in DEPZ and their treatment by adsorption-filtration process. M.Sc. Dissertation, Jahangirnagar University, Savar, Dhaka.

Ahmed, F., Bodrud-Doza, M., & Islam, A.R.M.T. (2016). Characterization of groundwater quality using water evaluation indices, multivariate statistics and geostatistics in central Bangladesh. Water Science, 30: 19–40.

Ahmed, N., Bodrud-Doza, M., & Didar, S.M. (2018). Hydrogeochemical evaluation and statistical analysis of groundwater of Sylhet, north-eastern, Bangladesh. Acta Geochimica, 38: 440–455.

Alrajhi, A., Beecham, S., & Ali, H. (2017). Effects of partial root-zone drying irrigation and water quality on soil physical and chemical properties. Agricultural Water Management, 182: 117–125. doi: 10.1016/j.agwat.2016.12.011.

APHA (American Public Health Association) (2002). Standard method for examination of water and wastewater.

APHA (American Public Health Association) (2012). Standard Methods for the Examination of Water and Wastewater, 21th ed. American Public Health Association, Washington DC, USA.

Asaduzzaman, M. (1985). Handbook of groundwater and wells. BRAC Prokashana, Dhaka.

Chindah, A.C., Braide, A.S., & Sibeudu, O.C. (2004). Distribution of hydrocarbons and heavy metals in sediment and a crustacean (shrimps- Penaeusnotialis) from the bonny/new Calabar river estuary, Niger Delta. Ajeam-Ragee, 9: 1–14.

DoE (2023). The General Overview of Pollution Status of Rivers of Bangladesh. Department of Environment, Dhaka, Bangladesh.

Donen, L.D. (1964). Water Quality for agriculture. Department of Irrigation, University of California, Davis.

EPA (1974). Wastewater- Treatment Systems: Upgrading Textile Operations to Reduce Pollution, United States. Environmental Protection Agency, Washington DC, USA.

Ghaly, A.E., Ananthashankar, R., Alhattab, M., & Rama Krishnan, V.V. (2014). Production, Characterization and Treatment of Textile Effluents: A critical Review. J. Chem. Eng. Process Technol., 5(1): 1–9.

Gupta, S.K. (1983). Variations of water table in Yamuna drainage basin of Haryana-implications and management strategies. Paper presented at the Seminar on Strategies for Irrigation Water Management, Patna.

Gupta, S.K., & Gupta, I.C. (1987). Management of saline soils and waters. Oxford and IBH Publishing Company, New Delhi.

Hannan, M.A., Rahman, M.A., & Haque, M.F. (2011). An investigation on the effects of bleaching powder with dyeing industries effluents. Research Journal of Environmental Protection, 4: 301–308.

Hannan, M.A., Rahman, M.A., & Haque, M.F. (2011). An investigation on Quality Characterization and Magnitude of Pollution Implications with Textile Dyeing Industries Effluent using Bleaching Powder. DUET Journal, 1(2): 49–59.

Hossen, M.A., & Mostafa, M.G. (2023). Assessment of heavy metal pollution in surface water of Bangladesh. Environmental Challenges, 13: 100783. https://doi.org/10.1016/j.envc.2023.100783.

Hussain, I., & Hussain, J. (2004). Evaluation of irrigation water quality of the village situated near river Kothari, Rajasthan (India). Pollut. Res., 23: 561–564.

Hussain, J., Hussain, I., & Arif, M. (2004). Characterization of textile wastewater. J. Ind. Pollut. Contr., 20(1): 137–144.

Islam, F., Rumi, S., & Juhaina, J. (2006). Industrial pollution in Bangladesh. www.worldbankgroup.org.

Islam, M.R., & Mostafa, M.G. (2020). Characterization of textile dyeing effluent and its treatment using poly aluminum chloride. Applied Water Science, 10(5): 1–10.

Islam, M.R., & Mostafa, M.G. (2018). Textile dyeing effluents and environment concerns- a review. J Env. Sci. Nat. Resour., 11(1&2): 131–144.

Islam, M.R., & Mostafa, M.G. (2022). Adsorption kinetics, isotherms and thermodynamic studies of methyl blue in textile dye effluent on natural clay adsorbent. Sustainable Water Resources Management, 8(2): 1–12.

Islam, M.S., & Mostafa, M.G. (2021a). Groundwater quality and risk assessment of heavy metal pollution in middle-west part of Bangladesh. Journal of Earth and Environmental Science Research, 3: 143.

Islam, M.S., & Mostafa, M.G. (2022a). Comparison of classical and developed indexing methods for assessing the groundwater suitability for irrigation. J. of Sust. Agriculture and Environment, 1: 2. doi: 10.1002/sae2.12027.

Islam, M.S., & Mostafa M.G. (2021b). Development of an integrated irrigation water quality index (IIWQIndex) model. J of Water Supply, 22(2): 2322–2337. https://doi.org/10.2166/ws.2021.378.

Islam, M.S., & Mostafa M.G. (2022b). Suitability of water quality index methods for assessing groundwater quality in the Ganges River basin area. H2Open Journal, 5(2): 198–220. https://doi.org/10.2166/h2oj.2022.145.

Islam, M.S., & Mostafa M.G. (2022c). Evaluation of Hydrogeochemical Processes in Groundwater Using Geochemical and Geostatistical Approaches in the Upper Bengal Basin. Geofluids, Article ID 9591717. https://doi. org /10.1155/2022/9591717.

Islam, M.S., Mostafa, M.G., & Muhammad, T. (2023). Identification of Sources and Mobilization of Trace Elements in Shallow Groundwater of the Upper Ganges River Basin. J. of Chem and Environment, 1(2): 14–29.

Islam, M.Z., & Mostafa, M.G. (2024). Seasonal Variation of Fe, Mn, and Pb in Groundwater of Northwestern Bangladesh. Journal of Chemistry and Environment, 3(1): 77–97.

Joshi, D.M., Kuman, A., & Agarwal, N. (2009). Assessment of the irrigation water quality of River Ganga in Haridwar district. Indian J Chem., 2(2): 285–292.

Kale, V.S. (2016). Consequence of temperature, pH, turbidity, and dissolved oxygen water quality parameters. International Advanced Research Journal in Science, Engineering and Technology, 3(8): 186–190.

Kalley, W.P. (1963). Use of saline irrigation water. Soil Science, 95: 355–391.

Kamal, A.K.I., Ahmed, F., Hasan M., Uddin, M.K., & Hossain S.M. (2016). Characterization of Textile Effluents from Dhaka Export Processing Zone (DEPZ) Area in Dhaka, Bangladesh. Pollution, 2(2): 153–161.

Kambole, M.S. (2003). Managing the Water Quality of the Kafue River. In Physics and chemistry of the Earth, Parts A/B/C, 28(20–27): 1105–1109.

Kant, R. (2012). Textile dyeing industry an environment hazard. Natural Sciences, 4(10): 22–26.

Kumar, M., Ramanathan, A.L., Tripathi, R., Farswan, S., Kumar, D., & Bhattacharya, P. (2017). A study of trace element contamination using multivariate statistical techniques and health risk assessment in groundwater of Chhaprola Industrial Area, Gautam Buddah Nagar, Uttar Pradesh, India. Chemosphere, 166: 135–145.

Li, C., Kang, S., Zhang, Q., Gao, S., & Sharma, C.M. (2011). Heavy metals in sediments of the Yarlung Tsangpo and its connection with the arsenic problem in the Ganges-Brahmaputra Basin. Env Geochem Health, 33(1): 23–32.

Liu, C.W., Lin, K.H., & Kuo, Y.M. (2003). Application of factor analysis in the assessment of groundwater quality in a black foot disease area in Taiwan. Science of the Total Environment, 313: 77–89.

Metcalf, E. (2003). Wastewater Engineering treatment and Reuse, Fourth Edition. New York, USA: McGraw Hill.

Michael, A.M. (1992). Irrigation theory and practices. Vikash Publishing House Pvt. Ltd., New Delhi.

Mohabansi, N.P., Tekade, P.V., & Bawankar, S.V. (2011). Physico-chemical Parameters of Textile Mill Effluent, Hinganghat, Dist. Wardha (M.S.). Current World Environ., 6(1): 165–168.

Monira, M.S., & Mostafa, M.G. (2023). Heavy Metals in Agricultural Soil and Their Impacts on Rice Production and Human Health: A Review. Asian Journal of Applied Science and Technology, 7(2): 204–216. https://doi.org/10.38177/ajast.2023.7222.

Monira, U., Sattar, G.S., & Mostafa, M.G. (2023). Characterization and Removal Efficiency of Central Effluent Treatment Plant (CETP). J. of Sustainability and Environmental Management, 2(1): 42–50. https://doi.org/10.3126/josem.v2i1.53116.

Monira, U., Sattar, G.S., & Mostafa, M.G. (2024). Assessment of surface water quality using the Water Quality Index (WQI) and multivariate statistical analysis (MSA), around tannery industry effluent discharge areas. H2Open Journal, 7(2): 130–148.

Ntuli, F., Ikhu-Omoregbe, D., Kuipa, P.K., Muzenda, E., & Belaid, M. (2009). Characterization of Effluent from Textile Wet Finishing Operations. In Proceedings of the World Congress on Engineering and Computer Science 2009, San Francisco, USA.

Ohioma, A.I., Luke, N.O., & Amraibure, O. (2009). Studies on the pollution potential of wastewater from textile processing factories in Kaduna, Nigeria. J. Toxicol. Environ. Health Sci., 1(2): 034–037.

Patel, H., & Vashi, R.T. (2015). Characterization and column adsorptive treatment for cod and color removal using activated neem leaf powder from textile wastewater. Jour of Urban and Environmental Engineering, 9(1): 45–53.

Punmia, B.C., & Lal, P.B.B. (1981). Irrigation and Water Power Engineering. Standard Publishers Distributors, New Delhi.

Raghunath, H.M. (1987). Groundwater. Wiley Eastern Limited, New Delhi.

Rahman, M.A.T.M.T., Saadat, A.H.M. Islam, M.S., Al-Mansur, M.A., & Ahmed, S. (2017). Groundwater characterization and selection of suitable water type for irrigation in the western region of Bangladesh. Applied water Science, 7(1): 233–243. http://doi.org/10.1007/s13201-014-0239-x.

Rahman, M.S., & Gagnon, G.A. (2014). Bench-scale evaluation of drinking water treatment parameters on iron particles and water quality. Water Research, 48: 137–147.

Richards, L.A. (Ed.) (1954). Diagnosis and improvement of saline and alkali soils. USDA Hand book, No. 60.

Roy, R., Fakruddin, A.N.M., Khatun, R., Ialam, M.S., Ahsan, M.A., & Neger, A.J.M.T. (2010). Characterization of Textile Industrial Effluents and its Effects on Aquatic Macrophytes and Algae. Bangladesh J. Sci.. Ind. Res., 45(1): 79–84.

Sayed, M.A., & Mostafa, M.G. (2021). Efficiency assessment of $FeSO_4$ coagulant on yarn dyeing industrial effluent. BAUET Journal, 3(1): 50–58.

Sultana, M.S., Islam, R., Sahaa & Mansur, M.A.A. (2009). Impact of the Effluents of Textile Dyeing Industries on the Surface Water Quality inside D.N.D Embankment, Narayanganj. Bangladesh J. Sci. Indus. Res., 44(1): 66.

Sultana, Z., Ali, M.E., Uddin M.S., & Haque M.M. (2013). Study on implementation of effluent treatment plants for safe environment from textile waste. Journal of Research in Environmental Science and Toxicology, 2(1): 9–16.

Sultana, Z., Ali, M.E., Uddin, M.S., & Haque, M.M. (2013). Implementation of Effluent Treatment Plants for Waste Water Treatment. Journal of Environmental Protection, 4(3): 301–308. doi: 10.4236/jep.2013.43035.

Todd, D.K. (1980). Groundwater hydrology. Wiley, New York.

Uwidia, I.E., & Ejeomo, C. (2013). Characterization of textile wastewater discharges in Nigeria and its pollution implications. Global Journal of Researches in Engineering General Engineering, 13(4): 0–4.

Wynee, G., Maharaj, D., & Buckley, C. (2001). Cleaner Production in the Textile Industry-Lessons from the Danish Experience. School of Chemical Engineering, University of Natal, Durban, South Africa.

Xiao, J., Jin, Z., & Wang, J. (2014). Geochemistry of trace elements and water quality assessment of natural water within the Tarim River Basin in the extreme arid region, NW China. Journal of Geochemical Exploration, 136(1): 118–126.

Yusuff, R.O., & Sonaibare, J.A. (2004). Characterization of textile industries' effluents in Kaduna, Nigeria and pollution implications. Global Nest: The Int. J., 6(3): 212–221.