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Physico-Chemical Analysis of Textile Effluents from Bagru, Jaipur (Rajasthan, India): Implications for Environmental Impact and Treatment Needs

Malvika Singh [a*], Seema Bhadauria [a] and Sumit Meena [a]

[a] *Medical Mycology and Biochemistry Lab, Department of Botany, University of Rajasthan, Jaipur – 302004, Rajasthan, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The textile industry is one of the largest water polluters worldwide. The coloured and bad odour effluent discharged from such industries pollutes not only the water bodies but also affects groundwater quality. In the present study, thirty-five water samples were collected from different dyeing units of the Bagru textile area (Rajasthan, India) famous for using natural dyes for textile processing. The physico-chemical analysis of these water samples shows that all parameters exceeded the permitted range recommended by the Central Pollution Control Board (CPCB) and World Health Organization (WHO). The analysis revealed the use of synthetic dyes in Bagru's

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**Corresponding author: E-mail: singhmalvika07@gmail.com;*

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textile industry for dyeing and printing. Based on the estimated characteristics, these textile effluents must be properly treated before releasing into the environment as the discharge of untreated effluents into local water bodies leads to significant water pollution, adversely affecting aquatic ecosystems and biodiversity. Additionally, contaminants can permeate the soil, compromising agricultural productivity and food safety. The air quality is also compromised due to the release of volatile organic compounds (VOCs) during the dyeing process, posing respiratory risks to nearby communities. This research underscores the urgent need for improved waste management practices and regulatory measures to mitigate the adverse environmental effects associated with synthetic dyes in Bagru's textile industry.

Keywords: Textile industry; water polluter; contamination; physico-chemical analysis; groundwater quality; ecosystem.

1. INTRODUCTION

The environmental pollution caused by the discharge of poorly treated effluents from the textile industry has gained increased attention over the past few decades. The textile industry is a major contributor to water pollution, consuming large quantities of water in the dyeing and finishing processes. It is estimated that every year worldwide, 280,000 tons of textile dyes are discharged in industrial effluents (Jin et al., 2007). Most of the textile dyestuffs (more than 3000 different varieties) are produced by using synthetic dyes. Synthetic dyes are stable and cost-effective to synthesise. They are also available in a variety of colours (Chang et al., 2004). In the paper, textile, food, cosmetics, leather and pharmaceutical industries, these dyes are used to a great extent (Telke et al., 2008).

Most of the textile dyes are carcinogenic, which, when accumulated in the body, leads to alteration in several physiological and biological functions (Rawat et al., 2016). The types of synthetic dyes used in dyeing processes significantly impact water quality parameters, including dissolved oxygen, pH, and organic and inorganic content (Banat et al., 1996).

The disposal of textile industry waste in open landfills or water bodies leads to severe environmental consequences. These include reduced sunlight penetration, decreased oxygen levels, and accumulation of toxic pollutants, which can harm both aquatic and terrestrial ecosystems (Vandevivere et al., 1998; Stolz, 2001).

Due to the steady rise in population and urbanization, wastewater discharge into the environment has dramatically increased in many developing nations, including India (Pirsaheb et al., 2014; Preisner, 2020). The Indian textile industry is one of the largest in the world and Rajasthan, one of the states of India, has a longstanding legacy in the textile industries. The capital of the Rajasthan state, Jaipur, has a distinct niche in the corporate and tourism worlds for the resources and business markets. Jaipur is primarily recognized globally as the "Pink City" due to its rich heritage in traditional art and craft, handicrafts, history, and historical themes. The study area of this investigation is Bagru, which is the well-known global hub for block printing, indigo dyeing, and natural dyeing. In terms of resources for the textile industry, Bagru is noteworthy. Bagru is located 30 kilometres away from Jaipur on National Highway No. 8 (the Delhi-Jaipur-Mumbai GVK Expressway), in a geographic location of 26°49' 0 North, 75°33' 0 East of Jaipur (Fig. 1). Bagru printing has an approximately 450-year history. Raiger and Chippa communities make up the majority of Bagru's population. These people moved to Bagru from Jaipur because the Sanjaria River provided water and chikkni mitti, which are needed for the dyeing process. Despite the river drying up 20 years ago, many printing families still live in the region. Dabu printing is the town's most famous export. Due to their dual toxicity, Bagru's coloured effluents from several cluster units (printing and dyeing) have received a lot of attention. Additionally, the effluent from these units and companies was dumped into open spaces and agricultural land, negatively impacting the native plants and animals as well as the general health of the communities and their surrounding people (Sharma et al., 2014).

This study's foundation is the investigation of the physico-chemical characteristics of the water in the Bagru textile region, which may assist in determining the detrimental effects of the disposal of textile wastewater on groundwater quality as well as on the environment and subsequent use of this wastewater for irrigation purposes.

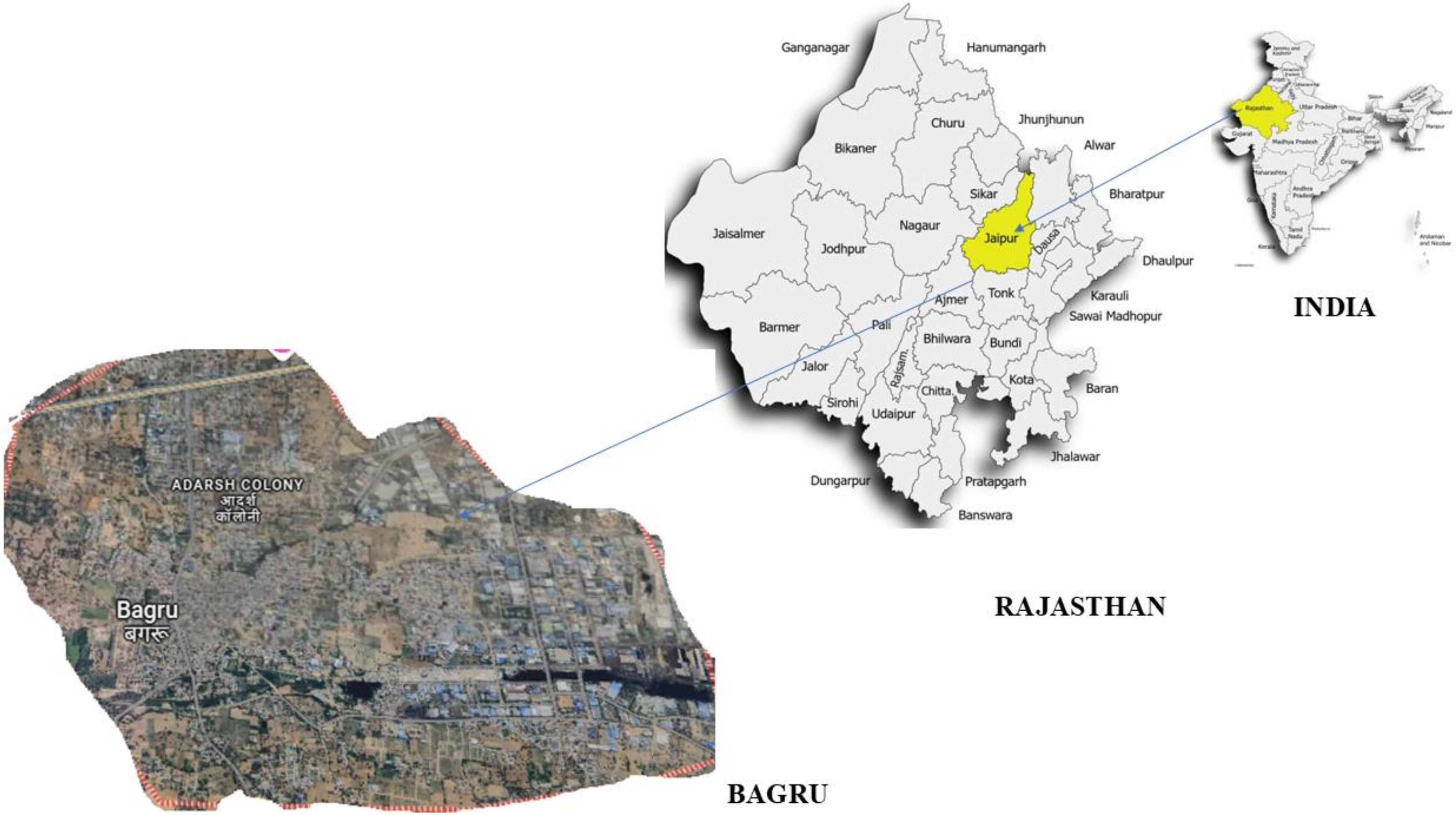

Fig. 1. Map of the study area and sampling site in Bagru

2. MATERIALS AND METHODS

2.1 Collection of Water Samples

Thirty-five wastewater samples were collected from different textile and printing units in the Bagru region. These samples were collected in sterilised polyethylene bottles and labelled as BTEF1 to BTEF35. The bottles were sterilised by chemical sterilisation method using hydrogen peroxide. Before sterilisation, bottles were often thoroughly washed with detergents to remove residues. Following this, they were rinsed with a chemical solution to eliminate any remaining contaminants. The temperature and pH were noted while collecting the samples. The pH was measured with a digital pH meter and the temperature was measured using a laboratory thermometer. After being transferred to the lab, the effluent samples were kept in the refrigerator at 4℃ for additional examination.

2.2 Physico-chemical Analysis of Collected Textile Effluent Sample

The standard procedures were followed in the physico-chemical evaluation of effluent samples (American Public Health Association, 1998). In this study, physico-chemical parameters including total dissolved solids (TDS), temperature, pH, electrical conductivity (EC), chloride, chemical oxygen demand (COD) and biological oxygen demand (BOD) were examined.

2.2.1 Determination of the temperature of collected water samples

The temperature was recorded when the samples were being collected. 25 ml effluent sample was taken in the Erlenmeyer flask and thoroughly mixed. Following this, a standardised thermometer was submerged in it and allowed enough time for the temperature to stabilise. After the temperature was noted down, the thermometer was removed from the flask, wiped clean and then recapped for further use (Agarwal et al., 2022).

2.2.2 Determination of the pH of collected effluent samples

The pH was also measured while collecting the wastewater samples. Before use, the electrode of the pH meter (Konvio Neer Digital pH Meter) was rinsed with distilled water. Subsequently, the pH electrode was immersed in standard pH solutions, specifically pH 4 and pH 7, for the calibration of the pH meter. After that, 25 ml of the effluent sample was taken in the beaker to determine its pH (Agarwal et al., 2022).

2.2.3 Determination of the electrical conductivity (EC) of collected water samples

Standard KCl (0.01 M) solution was used to standardize the conductivity meter (Labsphere Laboratory LS601 Conductivity Meter) in order to analyse the conductivity of the effluent sample. After standardising the conductivity meter, the electrode was immersed into a 25 ml aliquot of the wastewater sample (Agarwal et al., 2022).

$$\text{EC (mS/cm)} = \frac{\text{Specific conductance of N / 100KCl solution in μmhos/cm}}{\text{Measured conductance of N / 100KCl solution in μmhos/cm}} \times 0.001$$

2.2.4 Determination of the chloride content in collected water samples

In a 100 ml Erlenmeyer conical flask, 25 ml effluent sample was taken and 1 ml of 5% K_2CrO_4 was added to it. Then this solution was titrated against $AgNO_3$ until the yellow colour changed to brick red, signifying that the chloride ions were saturated. To determine the concentration of chloride ions, the burette reading was noted. Distilled water was used as a blank to estimate chloride (Agarwal et al., 2022).

The following formula was used to calculate chloride ions concentration.

$$\text{Chloride (mg/L)} = \frac{\text{Va-Vb} \times \text{Normality} \times 35.45 \times 1000}{\text{Volume of Sample taken}}$$

Here,

Va= volume of $AgNO_3$ used for effluent sample
Vb = volume of $AgNO_3$ used for blank sample
Normality = normality of AgNO3 (0.0141N)

2.2.5 Determination of the chemical oxygen demand (COD) of collected water samples

A 10 ml aliquot of water sample was diluted to 50 ml with distilled water in a round-bottom. 1 ml of Mercuric sulfate ($HgSO_4$) solution was then added to the flask and mixed thoroughly. After that 5 ml of Potassium dichromate ($K_2Cr_2O_7$) solution was added, followed by 15 ml Silver sulfate - Sulfuric acid solution that was added slowly and carefully. Then the reflux condenser was connected and the content was digested at 150℃ for 2 hours. After digestion, the flask was cooled down in a water bath. 2-4 drops of ferroin indicator were then added to the flask and then titrate against 0.025 M Ferrous ammonium sulfate (FAS) solution. The blank was also prepared in the same way using distilled water.

The chemical oxygen demand (COD) was determined by using the following formula.

$$\text{COD (mg/L)} = \frac{8 \times 1000 \times DF \times M \times (V_B - V_S)}{\text{Volume of sample (in ml)}}$$

Here,

DF – Dilution Factor
M – Molarity of standardized Ferrous Ammonium Sulfate (FAS) solution
VB – Volume of titrant used in titration with blank preparation
VS – Volume of titrant used in titration with sample preparation

2.2.6 Determination of the biological oxygen demand (BOD) of collected water samples

First the dilution water was prepared by adding 5 ml each of 27.5% w/v solution of Calcium carbonate, 22.5% of w/v solution of Magnesium sulfate, 0.15% w/v solution of Ferric chloride and Phosphate buffer solution in 5 litres of double distilled water. After that four 300 ml BOD bottles were taken and then the required quantity of sample was added to two of them and was diluted up to the mark with diluted water. The remaining two BOD bottles were also filled with dilution water and used as blank. All four bottles were closed immediately to avoid any air bubbles. One sample and one blank were incubated at 27℃ for three days. The initial dissolved oxygen (DO) of the remaining sample and blank bottles was measured using a Winkler titration method. The remaining sample and blank were analysed immediately to determine dissolved oxygen (DO). The final DO was determined after incubation of three days to calculate BOD (Agarwal et al., 2022).

The biological oxygen demand (BOD) was determined by using the following formula.

$$\text{BOD mg/l} = (\text{B.R. for sample at } D_0 - D_3) \times \text{dilution factor}$$

$$\text{Dilution factor} = \frac{\text{Bottle volume (300 ml)}}{\text{Sample volume}}$$

Here,

B.R. = Burette reading of titrant
D_0 = Initial dissolved oxygen of the sample (mg/l)
D_3 = Dissolved oxygen of the sample after 3 days incubation (mg/l)

2.2.7 Determination of the total dissolved solids (TDS) of collected water samples-

The weight of clean and dry beakers was taken and noted as initial weight W1. Then the 100 ml water sample was filtered through the Whatman filter paper (0.45µm) and filtrate was collected into that beaker. After that, the beaker was kept in the oven at 103℃ for 24 hours to dry the water filtrate. After drying, the beaker was allowed to cool down and then weighed again, recorded as W2.
The total dissolved solids (TDS) were determined using the following formula.

$$\text{TDS (mg/L)} = \frac{W2 - W1}{V} \times 1000$$

Here,

W2 = Final Weight of the beaker after evaporation of the sample (mg)
W1= Initial weight of the beaker (mg)
V = Volume of sample taken (ml)

2.3 Statistical Analysis

All the water quality parameters were analysed in triplicates to reduce the degree of error. For Statistical analysis of data, Microsoft Excel (version 2019) was used. A study of correlation and a test of significance were performed.

3. RESULT

The current investigation aimed to study the physico-chemical characteristics of textile wastewater by analysing various water quality parameters (Table 1). This study may also help to identify the negative impacts of disposing of textile wastewater on the soil environment, groundwater quality and the use of this wastewater for irrigation purposes. This study suggests that appropriate treatment techniques are needed before releasing textile effluents into the sewage because all the physico-chemical parameters were higher in terms of pollution levels.

3.1 Statistical Analysis

The "t" test has been used to calculate the degree of significance in the observed correlation coefficient. The Correlation matrix (Table 2) suggests that temperature has minimal influence on the other parameters, electrical conductivity (EC) is strongly correlated with total dissolved solids (TDS), and chemical oxygen demand (COD) and biological oxygen demand (BOD) are moderately correlated, which indicates higher levels of organic matter in water, reflecting their roles in assessing water quality.

3.2 Colour and Odour

In this investigation, the colour of the collected textile wastewater samples was recorded from grey to black depending on the type of dye used. The odour was strong and unpleasant which may be due to volatile compounds (such as benzene). The colour of the effluent is one of the most significant markers of water contamination.

Table 1. Physico-chemical analysis of collected textile wastewater

S.No.	Sample Code	Temp. (℃)	pH	EC (mS/cm)	Chloride (mg/L)	COD (mg/L)	BOD (mg/L)	TDS (mg/L)
1	BTEF1	30	8.25	5.1	446	1709	330	3261
2	BTEF2	33.2	7.7	4.53	NA	2061	545	2898
3	BTEF3	26.5	7.82	4.12	NA	2002	723	2626
4	BTEF4	30	8.13	6.02	400	1147	278	3149
5	BTEF5	32.8	6.5	2.56	NA	1843	813	1638
6	BTEF6	31.5	8.52	3.67	363	1833	958	2349
7	BTEF7	33	6.74	4.64	NA	2151	569	2966
8	BTEF8	29.5	10.28	6.74	428	2347	1034	6014
9	BTEF9	27.5	6.62	4.9	537	2158	930	3138
10	BTEF10	32.5	11.2	2.45	475	2082	484	1567
11	BTEF11	36.5	9.83	4.28	582	1976	480	2738
12	BTEF12	32.9	10.8	2.86	NA	2033	921	1832
13	BTEF13	32.7	8.67	2.75	643	1821	833	1760
14	BTEF14	34.6	6.41	5.19	288	2161	347	3319
15	BTEF15	28.5	7.68	1.18	489	2183	530	756
16	BTEF16	31.5	8.42	2.94	NA	2013	758	1883
17	BTEF17	33.5	6.25	4.47	524	1903	530	2857
18	BTEF18	28.5	6.53	5.5	NA	1801	664	352
19	BTEF19	37	9.76	5.68	421	2321	418	3631
20	BTEF20	29	10.26	4.51	373	2197	500	2885
21	BTEF21	28.5	5.63	3.84	467	2068	708	2460
22	BTEF22	31.7	11.71	4.16	345	1822	715	2664
23	BTEF23	33	5.49	2.01	483	1970	424	1285
24	BTEF24	32.8	10.46	1.09	NA	1851	743	695
25	BTEF25	32	6.77	3.53	247	2077	651	2258
26	BTEF26	31.2	7.2	2.81	NA	2137	796	1796
27	BTEF27	35.5	5.85	2.23	NA	1644	806	1426
28	BTEF28	33.2	6.23	1.37	667	1941	703	878
29	BTEF29	31.5	8.28	1.38	313	2223	962	882
30	BTEF30	29.5	9.86	4.63	514	2228	938	2963
31	BTEF31	28	6.27	0.872	225	1906	711	558
32	BTEF32	33.5	10.16	3.57	NA	1947	477	286
33	BTEF33	35	5.86	4.44	529	1771	670	2838
34	BTEF34	31	8.46	5.08	NA	2351	1033	8289
35	BTEF35	33.7	8.73	6.34	NA	2233	859	8416
Mean		31.75	8.09	3.76	443.59	1997.45	681.17	2551.8
SD		2.57	1.78	1.57	118.11	235.46	207.90	1848.96

**NA – could not be calculated due to high colour strength*
**SD – Standard deviation*

Table 2. Correlation among all water quality parameters

Parameter	Correlation coefficient						
	Temperature (℃)	**pH**	**EC (mS/cm)**	**Chloride (mg/L)**	**COD (mg/L)**	**BOD (mg/L)**	**TDS (mg/L)**
Temperature (℃)	1.000						
pH	0.064788177	1.000					
EC (mS/cm)	-0.01187878	0.142261633	1.000				
Chloride (mg/L)	0.216097921	-0.045409101	-0.027054226	1.000			
COD (mg/L)	-0.03693691	0.182829717	0.094391441	-0.069627737	1.000		
BOD (mg/L)	-0.236272441	0.089322962	-0.106576036	0.056564645	0.337216899	1.000	
TDS (mg/L)	0.049007129	0.159246361	0.708530513	-0.021944874	0.370478296	0.240293276	1.000

The release of highly coloured effluents is visually unpleasant and could make it difficult for light to get through. This significantly affects the metabolic processes of aquatic vegetation in the impacted water bodies (Khehra et al., 2006).

3.3 Temperature (℃)

Chemical and biological interactions in water are impacted by temperature. Fig. 2 shows temperature variations of different effluents collected from textile industries and dyeing units. The standard temperature limit for discharged effluent is 30 °C. The temperature of collected samples was found in the range of 26.5℃ to 37℃. The temperature of effluent samples which was noted as 37° C, was considerably higher than the typical discharge values. When these effluents are dumped into water bodies, they cause direct harm to the aquatic environment. These effluents have the potential to alter aquatic plant communities in a variety of ways such as changes in species composition, growing crops, and a decline in diversity of flora and fauna (Grace and Tilly, 1976).

3.4 pH

The Fig. 3 shows the pH variations of collected water samples. When it comes to effluent discharge into water bodies, the *Central Pollution Control Board* (CPCB) advises keeping the pH level between 6 and 9. In this study, The pH of the collected wastewater sample was found in the range of 5.49 to 11.71. Excessive or insufficient pH levels can harm aquatic life, humans, and disrupt biological processes. The pH of effluent samples increases as a result of the overuse of carbonate, bicarbonate, hydrogen peroxide, and sodium hydroxide during the bleaching process. The effluent's high pH is also a sign of overuse of dyes. Although the pH of wastewater has little effect on health, it does affect several chemical reactions. pH typically limits biological activity and several chemical treatment procedures (Verma and Dalela, 1975).

3.5 Electrical Conductivity (mS/cm)

The potential of a solution to conduct a flow of electric current is measured by its electric conductivity (EC), which is dependent on the temperature, presence and total concentration of ions in the water as well as their mobility. It is a useful indicator of the overall salt content of wastewater. One of the key factors used to assess whether water is suitable for irrigation is its conductivity (Sultana et al., 2009). The standard EC limit for textile effluents is 2-3 mS/cm. Fig. 4 shows the variable range of EC for investigated textile effluents which was found between 0.872 mS/cm to 6.34 mS/cm. The samples which showed the exceeded values of EC are not suitable for irrigation and need further treatment.

3.6 Chloride (mg/L)

According to WHO, the standard value of Chloride content for textile wastewater is 250 mg/L. Fig. 5 shows that the chloride content of collected water samples was found in the range of 225 mg/L to 667 mg/L which is much higher than the permissible value. The chloride content of some water samples (BTEF2, BTEF3, BTEF5, BTEF7, BTEF12, BTEF16, BTEF18, BTEF24, BTEF26, BTEF27, BTEF32, BTEF34 and BTEF35) could not be calculated due to their strong colours. Wastewater containing chloride could be due to the water softening process

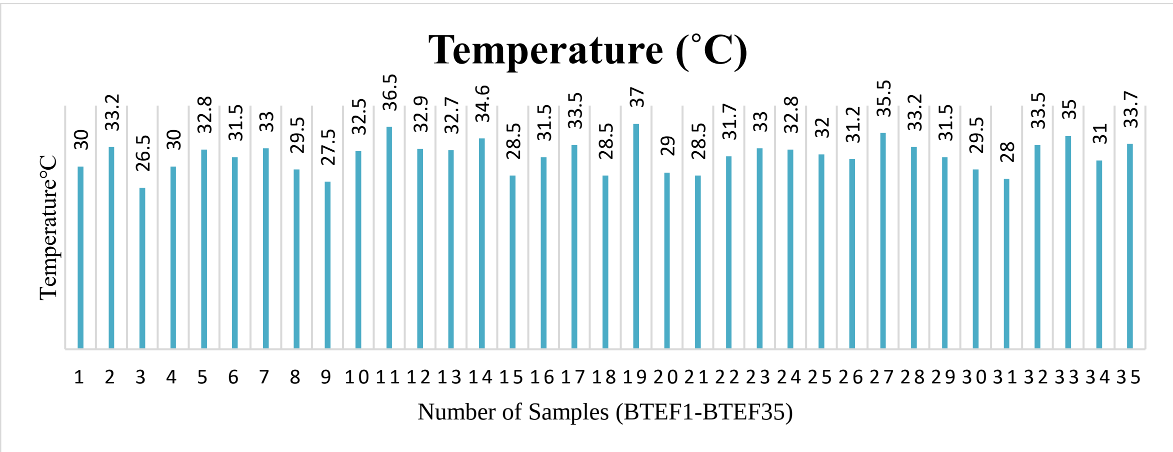

Fig. 2. Temperature of collected water samples

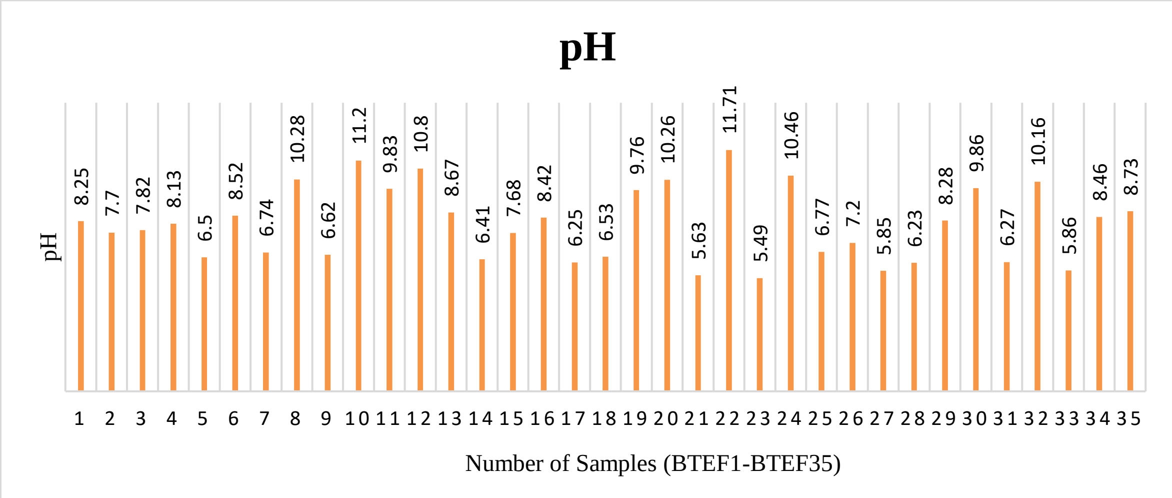

Fig. 3. pH analysis of collected water samples

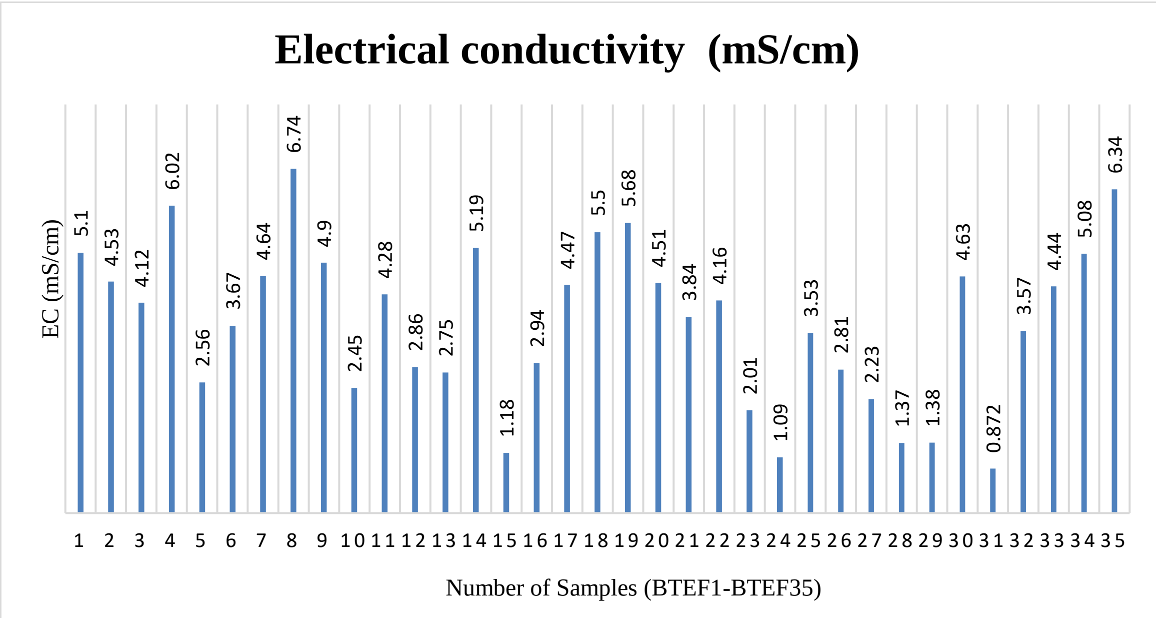

Fig. 4. Electrical conductivity (mS/cm) of collected water samples

or from recharging softeners such as sodium chloride. The majority of the chloride found in wastewater is derived from raw water used in dyeing processes. Some dyes need additional chlorine added as a fixing agent. The high chloride content of wastewater released into the environment causes scorching of the leaf margins, tiny and thicker leaves, and can decrease plant growth overall (Palani et al., 2015).

3.7 Chemical Oxygen Demand (mg/L)

A high COD signifies the presence of organic materials in wastewater that are resistant to biological processes and potentially harmful. It analyses the concentration of chemically oxidizing materials in water as well as the amount of oxygen needed for the chemical oxidation of organic matter (Sawyer and McCarty, 1978). Fig. 6 shows that the COD value of investigated water samples was found between 1147 mg/L to 2347 mg/L in the current study which is higher side than the standard value of COD which is 250 mg/L according to CPCB.

3.8 Biological Oxygen Demand (mg/L)

All aquatic life, including the microorganisms that carry out the purification processes of water bodies, depends on dissolved oxygen. Fish and other aquatic organisms require oxygen to survive, just like land animals do. An oxygen-rich water sources are considered healthy, whereas oxygen-depleted water bodies indicate severe pollution. Biological oxygen demand (BOD) measures how much oxygen is needed by aquatic organisms to break down the biodegradable organic matter present in water into simpler compounds (Sultana et al., 2009). The standard value of BOD for textile effluent is 30 mg/L. The BOD of analysed water samples was found in the range of 278 mg/L to 1034 mg/L as shown in Fig. 7. The higher the value of BOD, the higher the presence of pollutants in water bodies is indicated. A high BOD suggests that the waste water may not have enough oxygen for living organisms to survive which would result in the eradication of aquatic life.

3.9 Total Dissolved Solids (mg/L)

Total dissolved solids (TDS) measure the total amount of inorganic salts and other dissolved materials in water. If wastewater with a high TDS value is used as irrigation water, it could result in salinity issues. According to CPCB, the standard value of TDS is 2000 mg/L. Fig. 8 shows that the TDS of investigated samples were found in the range of 286 mg/L to 8416 mg/L which were far above the permissible value.

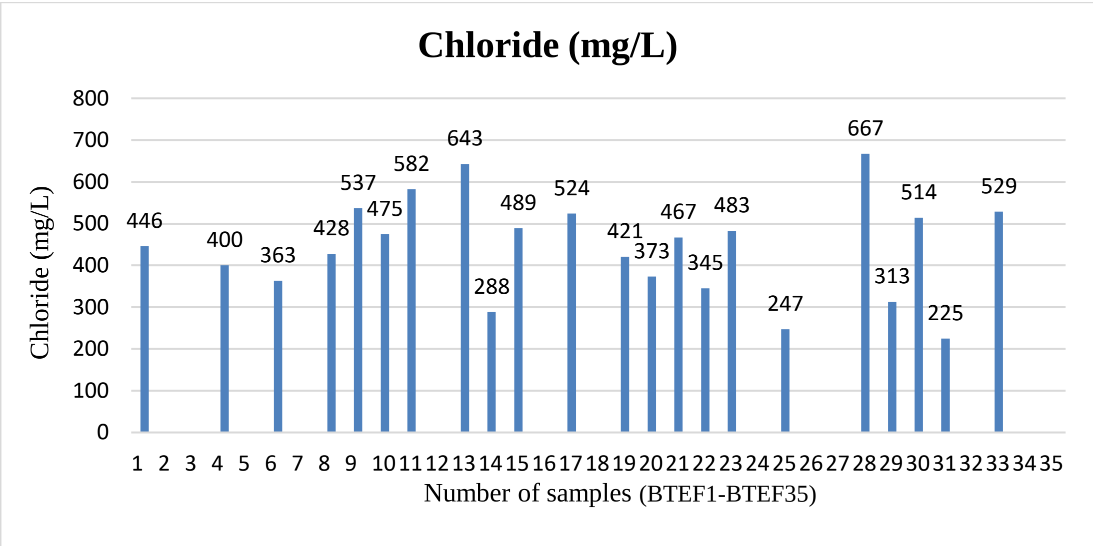

Fig. 5. Chloride (mg/L) content of water sample

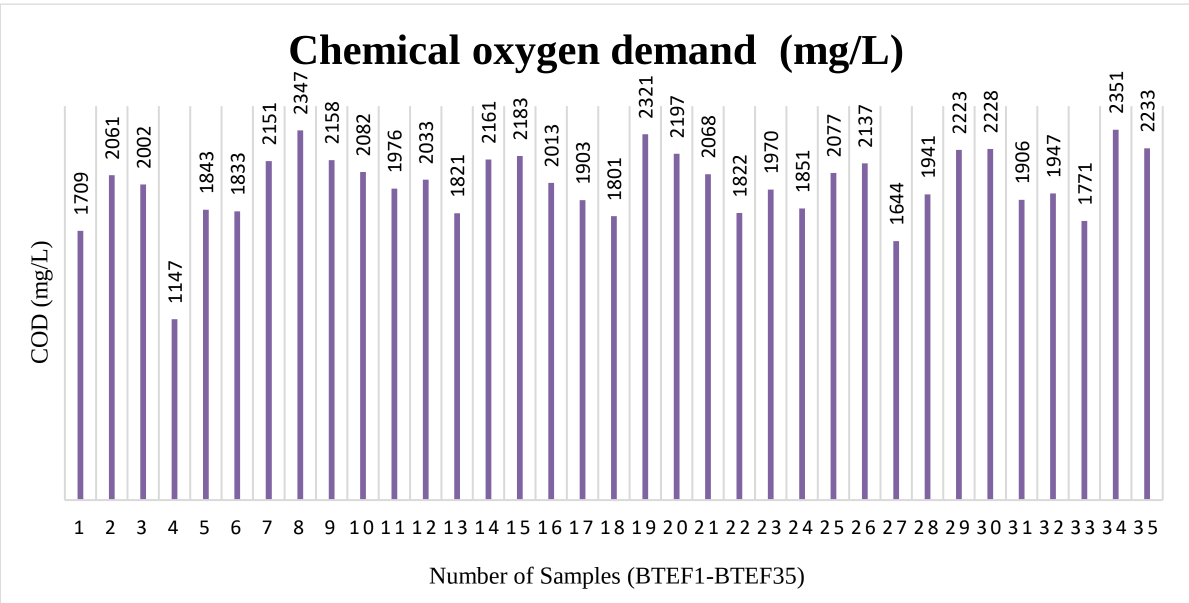

Fig. 6. Chemical oxygen demand (mg/L) analysis of collected water samples

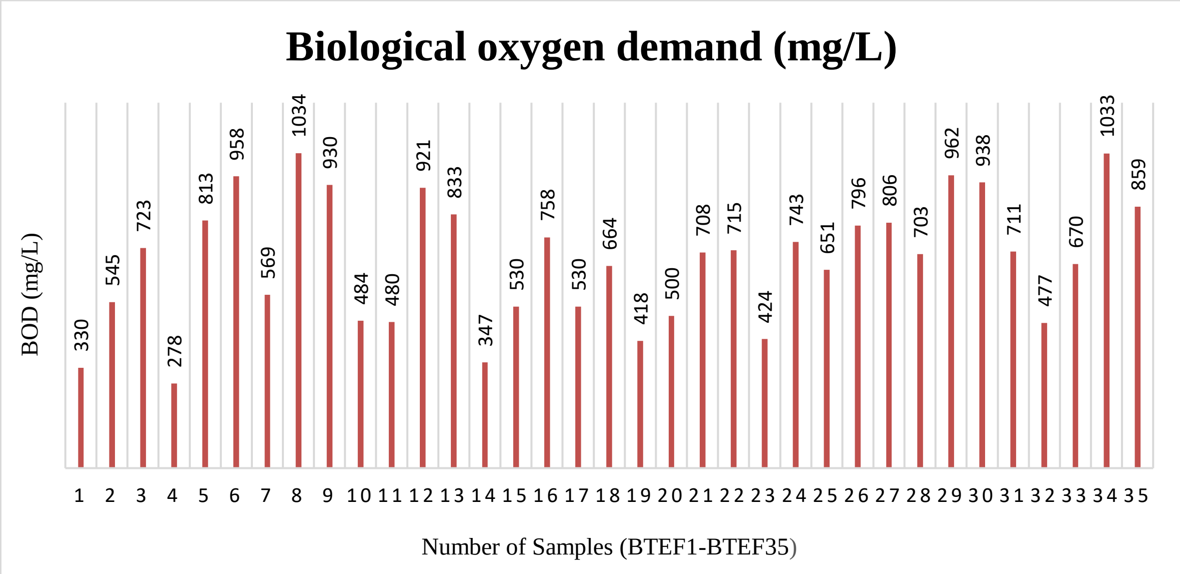

Fig. 7. Biological oxygen demand (mg/L) analysis of collected water samples

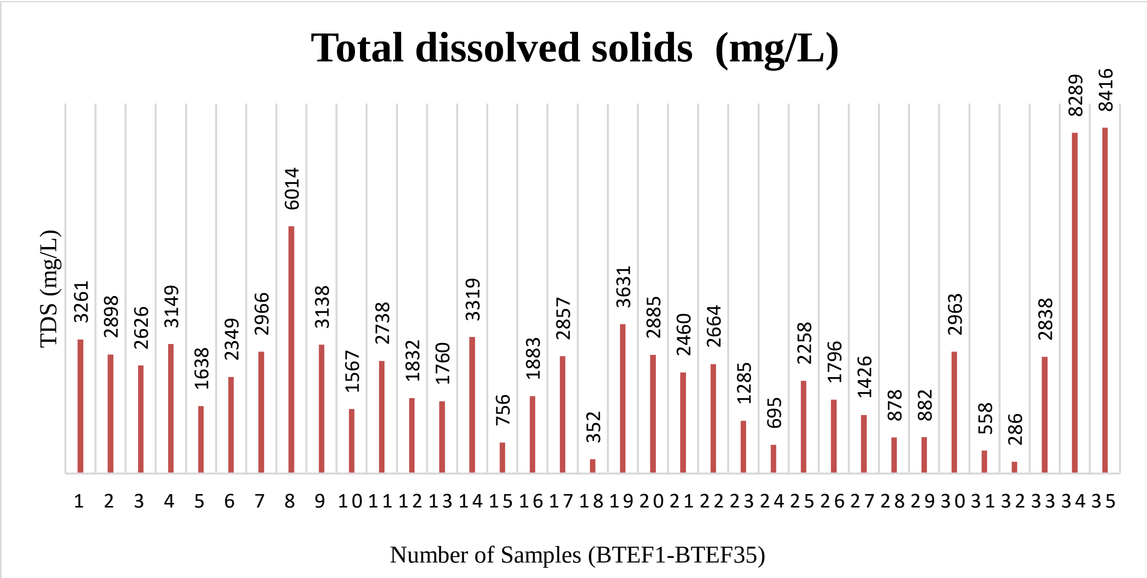

Fig. 8. Total dissolved solids (mg/L) of collected water samples

4. DISCUSSION AND CONCLUSION

Bagru textile area is known for using natural dyes but the results from physico-chemical analysis of water samples collected from various dyeing units present a completely different picture. Textile processing facilities must discharge wastewater with minimal total dissolved solids, biological oxygen demand, chemical oxygen demand, and pH, as per CPCB and WHO requirements. However, the temperature, EC, TDS, BOD, COD, pH, and chloride content showed a high discrepancy from the recommended standard values in the present investigation.

Elevated temperatures can lead to decreased oxygen solubility, which is crucial for the survival of organisms. Warmer water can also encourage the growth of harmful algal blooms (HABs), which can produce toxins detrimental to aquatic life and human health. High or low pH levels can also harm aquatic organisms as low pH can leach metals from sediments, increasing toxicity and high pH can lead to the precipitation of essential nutrients, limiting availability for aquatic plants and impacting the entire food web (Fakayode, 2005). Elevated salinity can adversely affect freshwater organisms, disrupting osmoregulation and potentially leading to mortality. High COD and BOD values indicate elevated levels of organic matter and pollution in water bodies. Excessive organic materials can lead to oxygen depletion as bacteria break down the waste, resulting in hypoxic conditions that threaten aquatic life (Jody and Dons, 2003). Chloride affects osmoregulation in aquatic organisms and can lead to physiological stress (Hussain and Hussain, 2012). The combined effects of these high physico-chemical parameters can lead to cumulative stress on aquatic ecosystems which signifies the necessity for appropriate intervention. So, the treatment of effluents discharged from the Bagru textile industries is crucial for the environment as well as for human health. Installing a CETP (Common Effluent Treatment Plant) along with bacteria-mediated bioremediation for detoxification could lessen the harmful impacts of textile effluents on the environment.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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