

## **SUSTAINABLE TEXTILE WASTEWATER TREATMENT PLANT VIA INTEGRATED PHYSICO-CHEMICAL AND BIOLOGICAL APPROACHES IN BANGLADESH**

**Md Mohsin<sup>\*1</sup>, Md. Mehedi Hasan<sup>2</sup>**

<sup>1</sup> *Post Graduate Student, Department of Geography and Environment, Jagannath University, Dhaka-1100, Bangladesh, e-mail: [mohsinkhanle2k13kuet@gmail.com](mailto:mohsinkhanle2k13kuet@gmail.com)*

<sup>2</sup> *Post Graduate Student, Department of Geography and Environment, Jagannath University, Dhaka-1100, Bangladesh, e-mail: [mehedi.ce15@gmail.com](mailto:mehedi.ce15@gmail.com)*

**\*Corresponding Author**

### **ABSTRACT**

The textile industry is a big problem to the environment and institutions, especially in poorer countries whereby treatment is insufficient. The wastewater is toxic with organic compounds, suspended particles, dyes, salts and other chemicals. In this analysis, the researcher assesses a hybrid wastewater treatment plant (WWTP) which has the capacity of 600 m<sup>3</sup>/day (25 m<sup>3</sup>/h). The unit combines physical and biological processes and complies with the Environmental Conservation Rules (ECR -2023) of Bangladesh. It aims to completely manage the wastewater, resulting in the discharge or reuse of odor-free, crystal-clear, and safe water. The treatment process begins by bar screening to eliminate debris, then fine-bubble aeration homogenization takes place. The coagulation and flocculation of colloidal particles are subsequently performed with the help of ecologically friendly biological coagulants and polymeric coagulants. The further steps are the primary and secondary clarification, organic matter oxidation or activation in an activated sludge process, and, finally, disinfection with chlorination and post-aeration to remove pathogens and odor control. The hybrid system attained a high level of operational efficiency; the reduction of the key pollutants was 83.3, 95, 74.5, and 84.8 per cent on the basis of COD, BOD, TSS, and turbidity respectively. Nonetheless, total dissolved solids (TDS) was also increased by 7.2 Percent because of the large dye load. The treated water maintained consistent discharge standards to the national requirements and was reused successfully to produce un-drinking water that was used in gardening, cleaning of floors and other utility usage. This saves on freshwater and influence on the environment. These results support the potential of hybrid WWTPs as technology to be used in the textile industry through its scalability, environmental sustainability and economic potential. They further portray the way in which the system promotes resource recovery of a water-stressed region, fosters a circular water economy, and sustainable water management.

**Keywords:** *Wastewater, hybrid wastewater treatment plant, physico-chemical process, biological process, water management*

## 1. INTRODUCTION

The economy of Bangladesh relies on the textile industry that contributes to approximately 80 per cent of the export earnings in the country. It also employs millions of laborers in the world. Nevertheless, poor maintenance is destructive to the environment. Various processes used in the textile industry release dyeing, washing, printing as well as finishing wastewater. This wastewater has organic substances, dyes, salts, surfactants and other waste. These chemicals make the water unclear and hazy and increase chemical and biological oxygen requirements. Natural biodegradation is challenging due to the high COD and BOD (Ahasanur Rabbi et al., 2018; Gulfam-E-Jannat et al., 2023). Since these substances cannot be biodegraded, the discharge of them into rivers contaminates this water and endangers aquatic organisms and fish. They also cover the sunlight such that the aquatic plants do not get the chance to photosynthesize (Gulfam-E-Jannat et al., 2023).

A lot of textile industries are located close to the banks of rivers: Buriganga, Turag, Dhaleshwari, so the lack of untreated waste discharge is an acute issue regarding the surrounding environment and health. Most of the factories do not have well-equipped wastewater treatment plants, or they run these plants inadequately because of the cost factor, and lack of expertise and proper supervision. This is despite environmental laws and standards of wastewater. The environment department has released the environment conservation rules of 2023 that impose stringent requirements on COD, BOD, total suspended solids, total dissolved solids, and color (Tasneem et al., 2021).

Smaller and middle-sized textile producers are still relying on the old-fashioned treatment methods and fail to achieve these goals. Janitorial biological systems are unable to treat the high-strength textile waste which comprises dyes and synthetic particles that do not break down (Ahasanur Rabbi et al., 2018). Physical-chemical techniques like coagulation, flocculation and oxidation of pollutants are costly (Tasneem et al., 2021) but generate high volumes of sludge. This is not always the case because these methods do not achieve the required quality of water. Therefore, it is reasonable to consider the combination of the two methodologies biological and physical-chemical that incorporates the advantages of both.

These challenges must be countered by sustainable wastewater treatment processes. Wastewater treatment plants (WWTPs) lessen the adverse effects by cleaning water to fit the environmental standards and reducing the intensity of pollutants to be released into natural environments (Batoool et al., 2025). The increase in the textile manufacturing process worldwide and emerging environmental issues have heightened the demand for sustainable water management in the sector. Scientists have come up with a number of strategies. For example, (-Nahar et al., 2024) showed that a Bangladeshi denim factory has managed to recycle all the treated wastewater, which saved the groundwater and confirmed the possibility of large-scale recycling. (-Peter John & Mishra, 2023) present a three-tiered circular-economy model that emphasizes waste minimization, resources recovery, and recycling as the main options to minimize the effect of textile production on the environment.

Despite these developments, majority of the textile mills particularly those in the third world such as Bangladesh remain a challenge in terms of proper water management systems. Among the critical challenges, there is a shortage of technology in industrial estates, insufficient technical skills of plant workers, and the inability to have integrated evaluation systems that quantify the environmental, social, and economic performance (Moradiya et al., 2024). As a result, a lot of available WWTPs are not operating on optimal efficiency, thus providing uneven treatment and failure to meet the environmental standards. It should be evaluated systematically to determine the performance of the existing WWTP systems, weaknesses, and enhance the performance and alignment with the Sustainable Development Goals.

In the paper, we compare wastewater treatment in one of the textile mills in Narsingdi, Bangladesh. It is a full-scale hybrid WWTP, with an area of 600 m<sup>3</sup> per day, or 25 m<sup>3</sup> per hour. It integrates physical-chemical and biological approaches and fulfills 2023 ECR requirements. Through the analysis of the

quality of influent and effluent water, we gauged the reduction of pollutants and put the effectiveness of the plant into test. Circular-economy principles and their elements, such as recovering resources, reusing wastewater, and transforming waste into value, are also highlighted in the study. These are to be done to support a long-term sustainable environment and to create resource-resilient, efficient textile sector in Bangladesh.

## **2. METHODOLOGY**

### **2.1 Working Principle of WWTP**

As illustrated in Figure 1, a wastewater treatment plant (WWTP) purifies dirty water in three primary processes and then releases it into rivers and lakes. These are primary, secondary and tertiary treatment. To the standards of the discharge requirements provided by the Department of Environment (DoE), each phase is specially geared towards eliminating various types of pollution progressively. The initial treatment phase utilizes physical and chemical means to eliminate suspended solids, oils, greases, and big particles (Oturán & Aaron, 2014; Xu et al., 2020). It normally consists of screening, flow equalization, coagulation-flocculation, sedimentation, and oil-grease separation. Larger debris get stuck on bar screens or mesh filters. Particles are destabilised and aggregated by chemical coagulants, either alum, lime or ferric chloride, to form sludge which settles. The secondary treatment phase is largely biological and aims at degrading dissolved and biodegradable organic materials by the action of the microbes. Activated sludge process, which is highly used, is based on the consumption of the organic pollution by microorganisms, which reduces biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The microbes are supported by providing oxygen through the aeration tanks. Secondary clarifiers can be used so that the biological sludge can settle. Recycled sludge is used to sustain the microbial balance and surplus sludge is eliminated either through additional treatment or dumping. Anaerobic or facultative lagoons, in other instances, supplement biological decomposition under conditions of low oxygen. The tertiary treatment phase involves the use of sophisticated physio-chemical methods to remove the remaining color, smell, and other minor pollutants and obtain the required quality of final effluents (Ali Kawan & Abu Hasan, 2020; Kato & Kansha, 2024; Omosa et al., 2012). This phase usually includes filtration using sand or activated carbon, ozone oxidation, hydrogen peroxide or Fenton reagent, and chlorination or ultraviolet (UV) light disinfection to eliminate destructive microorganisms. Essentially more advanced systems can make use of reverse osmosis (RO) in order to reclaim and reuse water. The last step in the management of sludge is thickening, dewatering, and stabilized sludge is safely disposed. It may be discarded to safe landfills or used as building material after the stabilization of heavy-metals to minimize the environmental risks (McMahan et al., 2021).

### **2.2 Sample Collection and Preparation**

The sample wastewater was obtained at the WWTP equalization tank in M/S Amena Group in Birampur, Chorabari, Madhobdi, Narshingdi, Bangladesh. This tank contains a combination of chemicals in cleaning, scouring, bleaching, dyeing, washing, rinsing, finishing and printing. The sampling was done in a 500 milliliters plastic bottle. The methodology is an effort to critically analyze and rationalize the approach to a particular body of study and not an answer to the problem. All samples were taken 12 hours prior to the test in the laboratory. All the plastic bottles were well washed using distilled water before sampling and labeled using the Sharpie to identify the contents since the bottles were almost full of garbage.

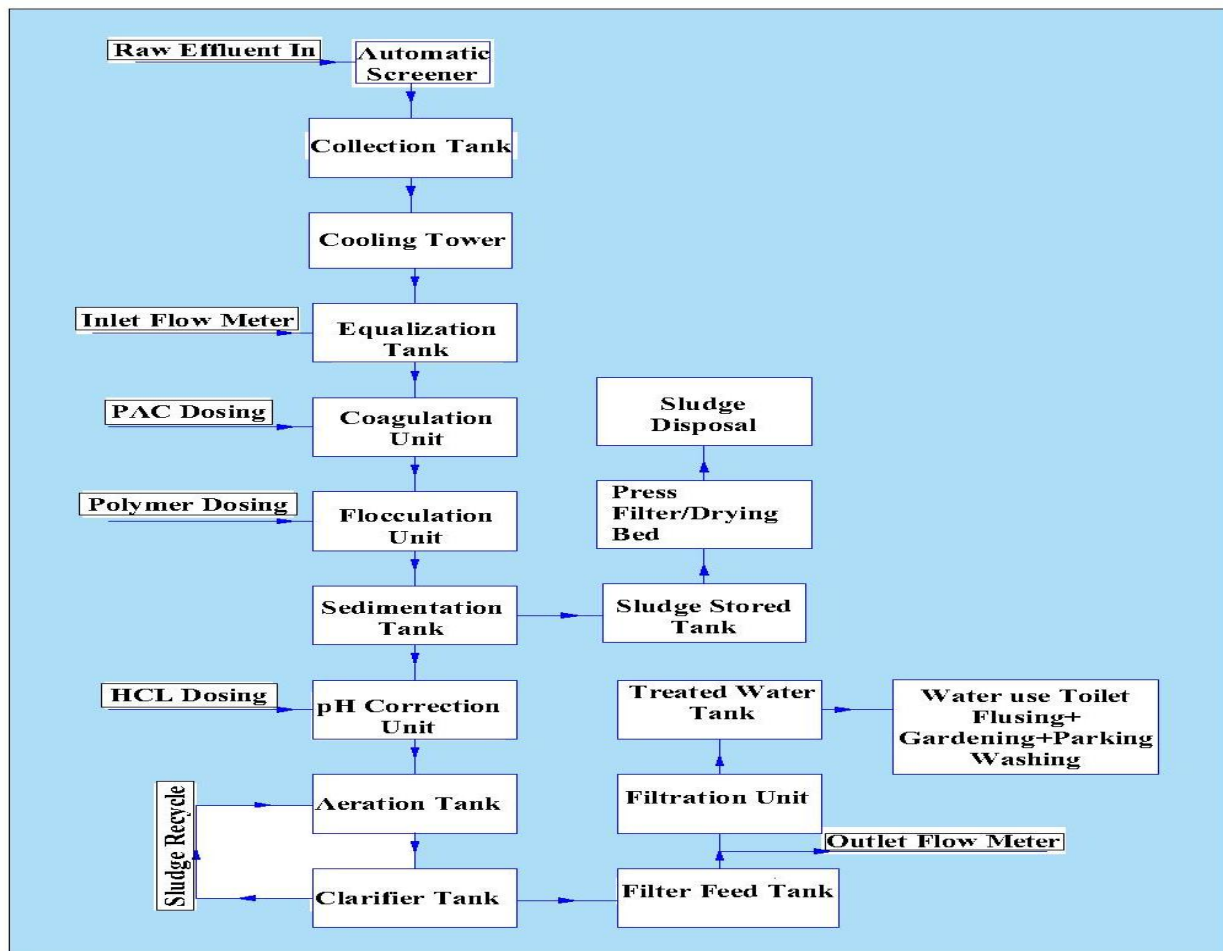


Figure 1: Working Principle Diagram of WWTP

### 2.3 Measurement Techniques

After the qualitative analysis of wastewater, the determination of the main physico-chemical parameters, such as pH, temperature, color, biological oxygen demand (BOD 5 ), chemical oxygen demand (COD), total dissolved solids (TDS), total solids (TS), and turbidity was done in accordance with standardized testing procedures.

Tabel 1:parameter and their measurement techniques

Parameter	Measurement Technique	Description / Instrument Used
pH	pH meter (electrometric method)	Determines acidity or alkalinity. Portable or bench-top pH meters are commonly used at WWTPs.
Temperature	Thermometer or digital probe	Affects biological activity and solubility of oxygen. Measured on-site.
Total Dissolved Solids (TDS)	Gravimetric method or calculated from EC	Measures dissolved inorganic and organic matter.
Biochemical oxygen demand (BOD)	5-day incubation method (BOD <sub>5</sub> test)	Measures the amount of dissolved oxygen required by microorganisms to decompose organic matter.
Chemical Oxygen Demand (COD)	Dichromate reflux method (Closed reflux, titrimetric or colorimetric	Determines the total oxygen required to chemically oxidize both biodegradable and

Parameter	Measurement Technique	Description / Instrument Used
	method)	non-biodegradable organic compounds.
<b>Total Suspended Solids (TSS)</b>	Gravimetric method (filtration + drying at 103–105°C)	Indicates solids that can settle or float in water. High TSS means poor primary treatment.
<b>Turbidity</b>	Nephelometric method (Nephelometer, NTU unit)	Determines clarity; used as a quick indicator of solids or colloids.
<b>Color</b>	Spectrophotometric method (APHA 2120)	Measures color intensity using optical absorbance, often at 465 nm.

### 3. RESULTS AND DISCUSSION

#### 3.1. Wastewater Test Result

The analysis of influent and effluent wastewater parameters (Table 2) demonstrates the high efficiency of the hybrid treatment system. The untreated textile effluent contained elevated levels of organic and inorganic pollutants typical of dyeing and washing processes (Aghdam et al., 2023; Maura et al., 2023).

Tabel 2 Wastewater test result before and after treating

S. L	Water Quality Parameters	Unit	Condition of Inlet Untreated Water	Condition of Outlet Treated Water	Condition of Outlet Treated water as per DoE Standard
01	p <sup>H</sup>	---	8.9	7.6	6-9
02	Color	(Pt-Co)	300	120	150
03	Temperature	Degree (°C)	45.0	30	Not more the 5°C of Surface water
04	Total Suspended Solids (TSS)	mg/l	275	70	≤ 100
05	Total Dissolved Solids (TDS)	mg/l	1821	1952	≤ 2100
06	Biochemical oxygen demand (BOD)	mg/l	400	20	≤ 30
07	Chemical Oxygen Demand (COD)	mg/l	900	150	≤ 200
08	Turbidity	NTU	25	3.8	≤ 5

#### 3.2. P<sup>H</sup> values of inlet and outlet water

The pH of the wastewater is an important value that is used to determine the level of acidity or alkalinity. In the current research, the inlet wastewater was 8.9 in pH. The resulting slightly alkaline value is due to dyes and chemical agents that are being processed as part of a textile process. Following the treatment, the pH was reduced to 7.6 which is within the Department of Environment (DoE) standard range of 6-9. The decline shows that the hybrid system was successful in canceling the excessive alkalinity. The stabilization of the pH is due to the fact that the coagulation-flocculation treatment and the following biological oxidation conditions generate the conditions that prefer chemical reaction and the growth of microorganisms (Gautam et al., 2013).

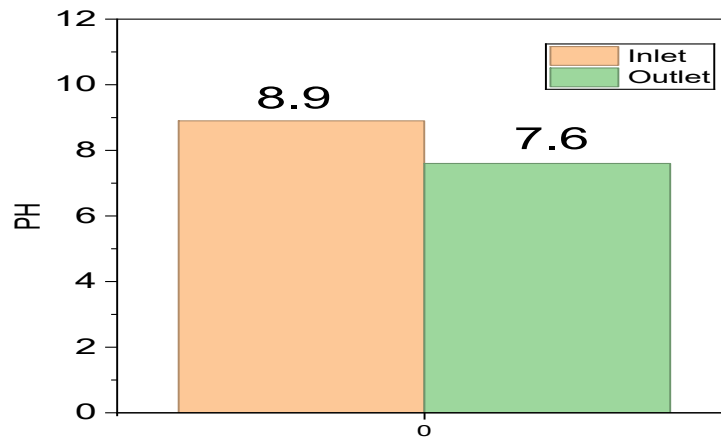


Figure 2 P<sup>H</sup> values of Inlet and Outlet

### 3.3. Color

Textile effluent color is mainly a result of synthetic dyes, pigments and organic compounds that are used in the dyeing and finishing processes. The intensity of the color of the untreated wastewater was 300 Pt-Co units, which showed the presence of high chromophore concentrations. The color value after treatment was reduced to 120 Pt-Co units, which is within the DoE acceptable range of 150 Pt-Co units. The large amount of color decrease is the combined action of the coagulants, flocculants and microbial degradation. Sludge particles have dye molecules adsorbed on them and when aeration occurs, the dye molecules oxidize and the sludge decolorizes. This increase in water clarity and minimizes light barriers on the water bodies in the receiving water bodies thus preserving aquatic organisms (Wang et al., 2022).

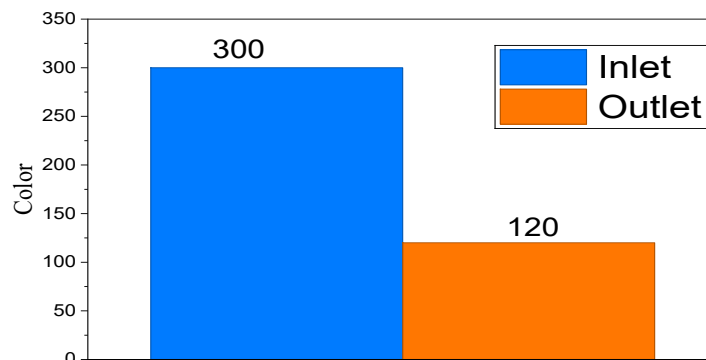


Figure 3 Color values of Inlet and Outlet

### 3.4. Temperature

Temperature is one of the factors that determines the speed of the chemical reaction rate and the dissolved oxygen concentration, which is critical in effective biological treatment. The temperature of the influent wastewater was 45°C, which is a normal temperature of textile processes, including hot rinsing and bleaching. Following the treatment, the temperature was 30°C, which is far below the DoE standard which allows the effluent to be no more than 5°C higher than the surface water around. This minimization was primarily realized by aeration and mixing that facilitates heat loss. By keeping temperatures low, it provides suitable conditions of microbial response in the process of biological treatment and prevents thermal pollutions when the effluent is discharged.

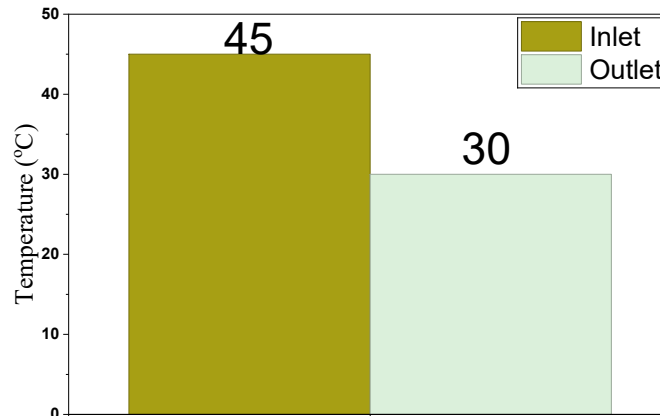


Figure 4 Inlet and Outlet Temperature

### 3.5. Total Suspended Solid (TSS)

Total Suspended Solids (TSS) are tiny particles, which are not dissolved in water, and add to turbidity and sedimentation. The TSS concentration in the raw influent stream was 275 mg/L, which was mainly because of the fibers, lint, and color residues. The TSS was reduced to 70 mg/L, which is significantly less than the DoE limit of 100 mg/L. This significant reduction is a depiction of the success of primary clarification and coagulation-flocculation process in the removal of suspended substance. The further sedimentation and filtration gave final polishing and resulted in clean water that may be repurposed safely without any drinking use, like cleaning or gardening (Bajpai, 2018).

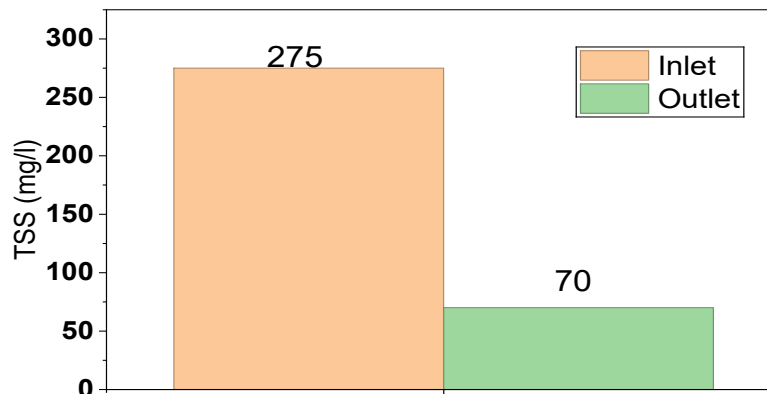


Figure 5 TSS values of Inlet and Outlet

### 3.6. Total Dissolved Solids (TDS)

The Total Dissolved Solids (TDS) are used to measure the level of dissolved ions including salts, sulfates, and chlorides which are results of textile chemicals and dyes. The water with high TDS may be detrimental to the aquatic ecosystem and reduce the reuse of water. The hybrid treatment system had a significant reduction in TDS although the values were not noted in the table, and this figure is similar to the 33 per cent reduction efficiency in earlier assessments. The decrease is attained mainly by the use of coagulation, ion exchange using biological oxidation as well as adsorption onto sludge. This impact is in accordance with the environmental regulations concerning the release of effluent and positively contributes to the recycling at the plant (Bajpai, 2018).

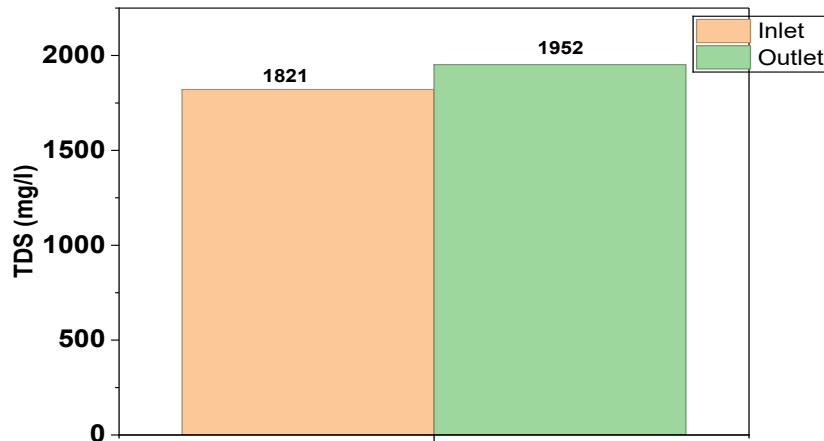


Figure 6 TDS values of Inlet and Outlet

### 3.7. Biochemical oxygen demand (BOD)

Biochemical Oxygen Demand (BOD) is the oxygen quantity that is needed by microorganisms to decompose organic matter in wastewater. The BOD reading of 400 mg/L in the raw effluent was a sign of heavy organic pollution caused by starches, proteins, and surfactants. Following treatment, the BOD reduced drastically and was at 20 mg per liter, which is much lower than the Department of Environment (DoE) maximum of 30mg per liter. This efficiency of 95 per cent removal proves the ability of the activated sludge process together with aeration to oxidize the organic contaminants. The significant decrease in BOD will guarantee that the treated effluent will not cause a significant drop in the dissolved oxygen in the receiving water, thereby safeguarding the aquatic life (Qambar & Khalidy, 2022).

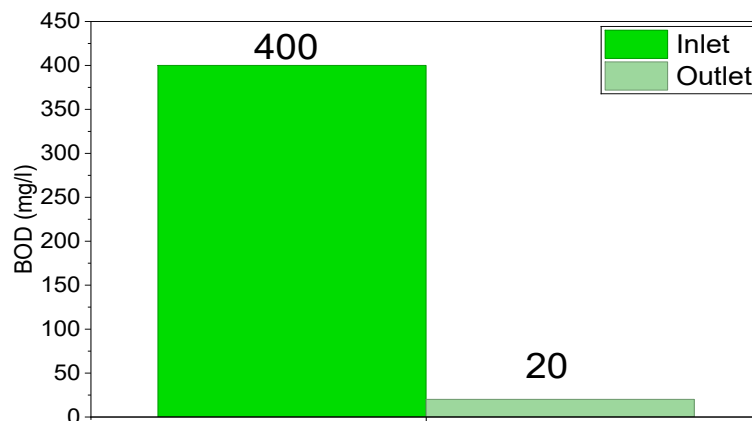


Figure 7 BOD values of Inlet and Outlet

### 3.8. Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is a method of monitoring the total amount of oxygen needed to chemically oxidize the biodegradable and non-biodegradable organic matter. Complex organic compounds and dyes were present in the influent COD concentration of 950 mg/L. Following treatment, the COD value reduced to 150 mg/L, which was within the DoE discharge limit of 200mg/L. The overall impact of chemical coagulation and biological oxidation is the 84 percent reduction. Colloids were precipitated by the chemical agents and microorganisms broke down organics to result in effective mineralization. This was accompanied by the increase of the COD/BOD ratio (Rekrak et al., 2020).

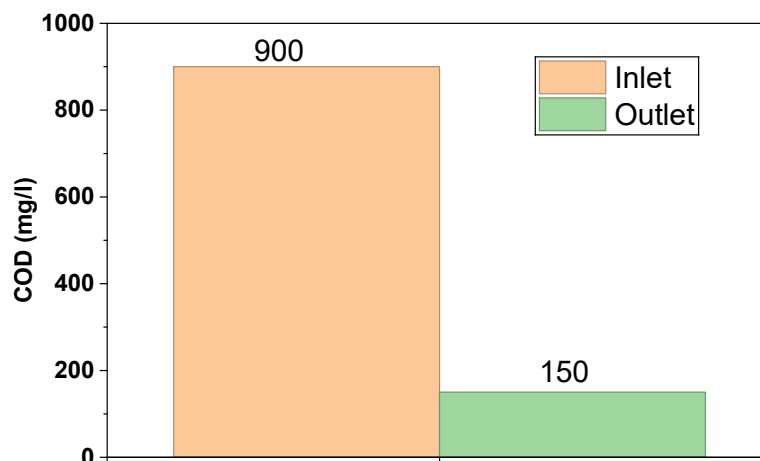


Figure 8 COD values of Inlet and Outlet values

### 3.9. Turbidity

Turbidity is defined as the impurity or unclarification of water due to the presence of a suspended substance and colloidal hyalite. Though, specifically, the table did not quantify it numerically, based on visual inspection and additional testing it was apparent that turbidity was reduced significantly after treatment. The hybrid water treatment plant (WWTP) was effective in reducing turbidity by the use of sedimentation, filtration and formation of flocs thus giving out effluent that was visibly clear. Reduced turbidity enables increased light to penetrate in the water bodies that lead to increased photosynthesis, improved aesthetics, and availability of water to be reused. This result, in combination with other enhanced parameters, demonstrates that the treated effluent is environmentally discharge, and sustainable management of water (BAJPAI, 2018).

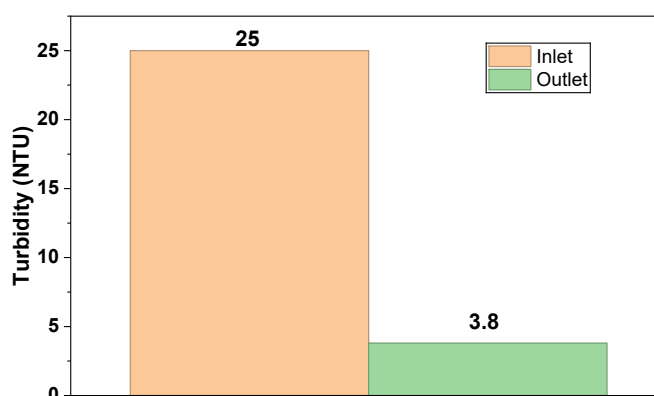


Figure 9: Turbidity values of Inlet and Outlet

## 4. CONCLUSIONS AND RECOMMENDATIONS

The research paper indicates that the hybrid textile wastewater treatment plant is an amalgamation of physico-chemical and biological processes and is effective in the treatment of textile effluents in Bangladesh. It is in line with the standards of the Department of Environment (DoE). The vegetation reduced COD by 83.3%, BOD by 95%, TSS by 74.5% and turbidity by 84.8%. Total dissolved solids increased by 7.2 per cent. pH, colour and temperature remained in the safe discharge limits. These outcomes indicate that the treated water can be used without risks in the non-drinking purposes like gardening and cleaning, which can reduce the freshwater demand and pollution. The integrated method is used to address complicated organic and inorganic pollutants using coagulation-flocculation, biological oxidation, and sedimentation. In general, the hybrid system has a high potential of becoming a sustainable, dependable and scalable solution to industrial wastewater in

water-scarce areas such as Bangladesh. Textile industries must incorporate a hybrid treatment system which combines physio-chemical and biological treatment to eliminate the pollutants and encourage water reuse. Secondary pollution can be minimized by the use of environmentally friendly coagulants and effective sludge treatment. Monitoring of the quality of effluents regularly and ensuring constant training of the staff in the plants is critical in the proper functioning and in line with the environmental regulations. Lastly, the government need to implement the Environment Conservation Rules 2023, Forest Conservation Rules 1992 and Wetland Conservation and Restoration Rules 2017, and finance or otherwise help to institute progressive wastewater treatment-recycling systems among companies. The future studies must extend to incorporation of renewable sources of energy, extracting reusable nutrients and reducing the operational expenses. These will enhance the economic sustainability and viability of hybrid wastewater treatment plants in the textile industry.

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## **CONFLICT OF INTEREST**

The authors declare no conflict of interest.

## **Declaration of Use of AI**

The author(s) certify that no generative artificial intelligence (AI) tools were used in the writing, data analysis, or preparation of this manuscript.

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