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Quantifying Environmental Sustainability of Denim Garments Washing Factories Through Effluent Analysis: A Case Study in Bangladesh

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ABSTRACT

This paper deals with the environmental impact of effluents released by denim garment washing factories in Bangladesh. Both untreated and treated effluent samples were collected from five denim washing factories identified as representative cases and were subjected to chemical testing as a part of the case study. The results were compared against the acceptable limits of parameters-chemical oxygen demand (COD), dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), total suspended solids (TSS), the potential of hydrogen (pH) and color. Findings show that COD and BOD values are well within the acceptable limit in all of the factories studied but only 20% of the factories could achieve acceptable DO levels. Around 40-60% of the studied washing factories showed evidence of improved filtration systems for TDS and TSS values, but only 40% of factories produced clear wastewater. 60% of the factories met an acceptable pH level of 6-8 before releasing their effluent to the environment. The study reveals the technical limitations of effluent treatment practices of the denim garment washing factories in Bangladesh. The findings will appeal to all stakeholders, including academics and researchers, to give serious attention to reducing environmental impact of industrial garment washing process. They will help industry practitioners with more comprehensive information to take strategic action in making denim garment washing factories in Bangladesh more sustainable.

Keywords: "*Denim garments, washing factories, effluents, chemical tests, environmental sustainability."*

1.0 Introduction

The fashion industry is considered as the second highest polluting industry after oil, accounting for nearly 10% of global CO_2 emissions and approximately 20% of waste generation (UNCTAD, 2019). Bangladesh's textiles and apparel industry is an important sector for the socio-economic development of the country, and also considered as a key global fashion supplier (Islam et al., 2020). Bangladesh is the world's second-biggest exporter of clothing after China and its apparel export generates above 84 % of its foreign income (Mohammad Ishaque, 2019). While the apparel industry earns the lion share of export earnings for Bangladesh, its textile and apparel washing industry is considered the major industrial waste generator (Hossain, 2019) due to the use of a very high amount of water and chemicals. Textile wastewater contains oil, grease, caustic soda, glauber salt, ammonia, sulphide, lead, heavy metals, etc. (Muthukumarana et al., 2018). These elements control the parameters like Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Dissolved Solids (TDS), Total Suspended Solids (TSS) and, Potential of Hydrogen (pH) (Hossain et al., 2018). Denim apparel production process involves a series of mechanical and chemicals of treatments. Washing is an important process which is done after the assembling stage to add values, modify the appearance, and feel of the garments (Solaiman *et al.*, 2015). The application of dry treatments (e.g. sandblasting, hand sanding, whiskering, tagging, grinding, destroying, potassium permanganate (PP) spray, colour spray/sponging) (Kan, 2015), and wet treatments (e.g., normal wash, pigment wash, caustic soda wash, stone wash, enzyme wash, bleach wash) are pretty common in denim garment manufacturing (Choudhury, 2017).

There are 30 denim garment washing factories in Bangladesh, with a total investment of over USD 834 M (Nayeem, 2015). Experts predict that Bangladesh will become an unavoidable destination for sourcing denim garments because of its strong production capacity of a vast garment volume at a competitive price (Hasan, 2018). Bangladesh's economic emancipation largely depends on the textiles and RMG sector, despite many barriers and challenges (Islam et al., 2013). The sector is recognised as strategically vital for the socio-economic development of the country including industrialisation, job creations, economic accelerations etc. (Rasel et. al, 2020). Unfortunately, denim garment processing factories have significant impact polluting the nearby environment through unsustainable practices (karthik and Gopalakrishnan, 2014). Research estimates that by 2021, Bangladesh will be producing approximately 2900 M kg of fabric, which will generate 349 M m^3 of wastewater (Hossain, 2019).

The denim washing factories in Bangladesh are substantially producing a large amount of effluents and sludge (Selim, 2018). They are responsible for environmental and health hazards, corrosion of sewer lines, groundwater pollution, and large capital investment in mitigating multidimensional negative impact (Periyasamy et al., 2017). In 2016, textile factories in Bangladesh generated almost 217 M m^3 of wastewater containing different pollutants. The production of wastewater may cross 350 M m^3 by 2021 (Hossain et al., 2018). Therefore, it is essential to quantify effluents released by denim washing industry to devise effective solutions for the mitigation of environmental problems. To our knowledge, there are inadequate studies that focused specifically on determining the quality of discharged effluent from the denim garments washing plants in Bangladesh. Therefore, this study investigates the quality of both untreated and treated effluent from denim washing factories and quantifies accordingly. The specific objective of the research is to investigate the quality parameter of effluents in terms of COD, DO, BOD, TDS, TSS, Turbidity and pH values of wastewater, quantify and compare them against government-prescribed standard levels of those parameters, and propose useful solutions for Bangladesh denim washing industry practitioners to adopt sustainable practices in terms of effluents treatments and management.

2.0 Literature review

2.1 Denim and its impact on the environment

The fashion industry thrives for new diversified products to which fashionable denim apparels through diverse finishing techniques are important inclusions (Khan et al., 2020). Denim is considered one of the oldest fabrics in the world that remains trendy until today and has undergone significant development, innovation, and variations. Since its inception, it has been conventionally produced from 100% cotton, but the different production process variations have evolved (Fig. 1), making denim garments fashionable.

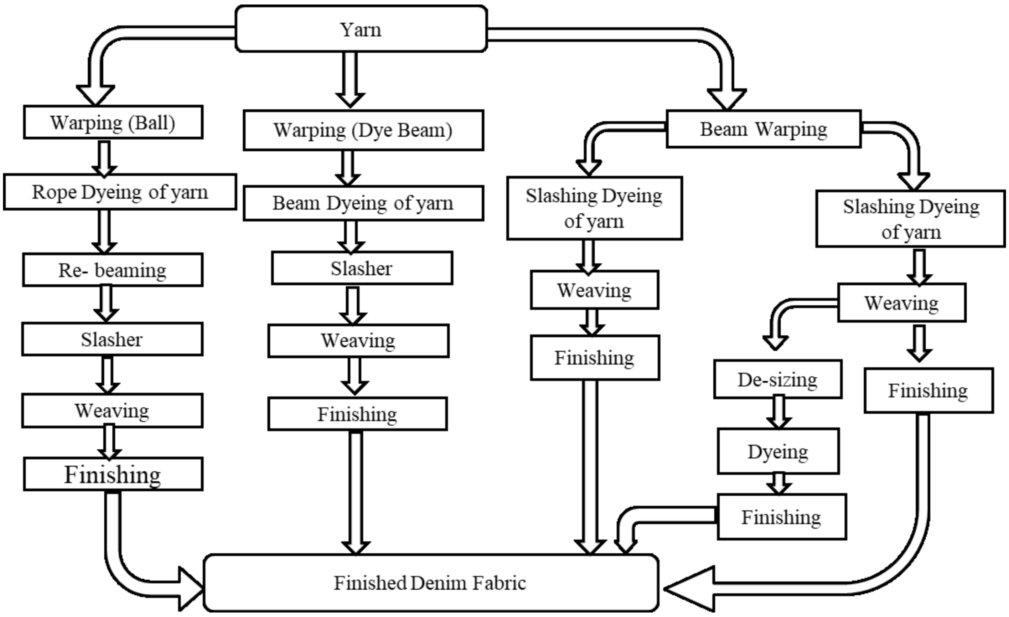


Fig. 1: Typical denim fabrics manufacturing processes

Textiles and apparel, including denim manufacturing, have a significant environmental impact in the life cycle stages, among which washing stages contribute significantly (Khan and Islam, 2015). A Greenpeace report (2016) says that for producing 2 G pairs of jeans, factories need about 1700 M kg of different chemicals and 11.4 G litre of water. The production process releases carbon dioxide and different wastes in liquid and concrete forms (Greenpeace, 2016). Denim wet finishing causes 80% of effluents discharged into local water sources responsible for health, environmental, and climate-related hazards.

Research note that consumers are shifting buying intentions towards the products that are manufactured in eco-friendly ways (Sobuj at el., 2020). Consumption rate for the fashion product is increasing globally that requires more natural resources. Study by Jamy retrace (2020), reveals that approximately 2.3 G jeans will consume about 11,000 liters of water, travel 65,000 kilometers in the earth, and have a significant environmental impact at different stages. However, figure 2 shows the environmental impact of a typical pair of jeans in the life cycle stages.

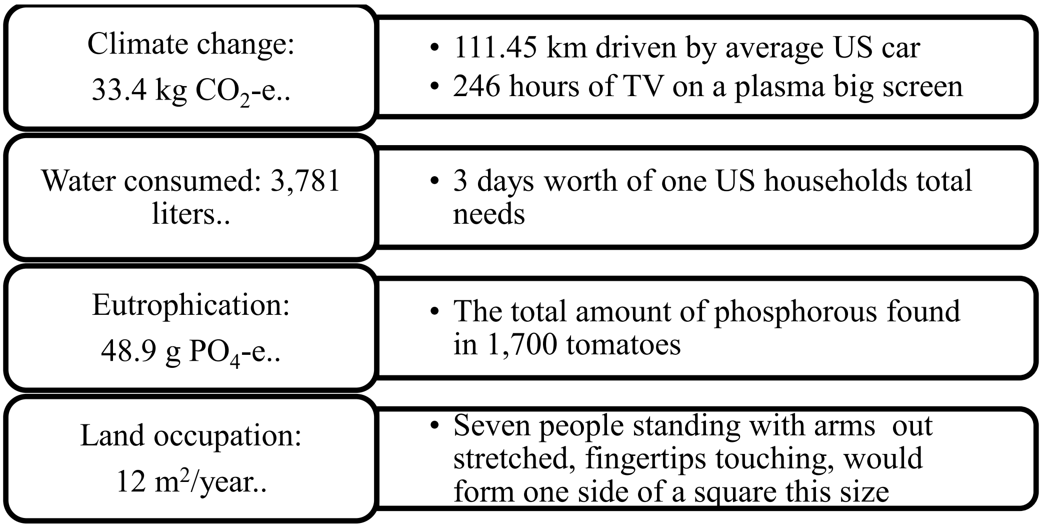


Fig. 2: The life cycle impact of a pair of jeans- adapted from Levi & Strauss (2015)

As mentioned earlier, in order to impart worn out or used look to denim garments, they are subjected to different types of wet industrial processes (Hossain et al., 2017). Normal wash, enzyme wash and potassium permanganate spray are widely used among them (Choudhury, 2017). The reductive stripping process etc. also considered as viable wet processing approaches that contributes to the modifications of apparel properties (Uddin et al., 2015). These washing techniques are responsible for generating a significant effluent volume containing different chemical residues. The discharged chemicals affect air, water, and soil and cause severe injury and even death to human and aquatic animals (Greenpeace, 2016). Their water system presence causes hindrance to light penetration to the lower depth of water, thus preventing photosynthesis in aquatic plants, which has increased the toxicity levels in the aquatic ecosystem (Mani et al., 2018).

2.2. Effluent characteristics and acceptable limits

The effluent discharged by textile mills, including denim garments washing plants, is a source of high COD, BOD, TDS, TSS, Turbidity etc. of the water and contains both organic and inorganic compounds out of standard range (Kabir et al, 2019). When such wastewater is mixed up with a freshwater source, it will increase toxicity (Senthil and Gunasundari, 2018) that can cause skin diseases, including dermatitis, liver damage, and kidneys carcinogenic problems (Dadi et al., 2016). If eco-friendly dyes and chemicals are used widely in the finishing processing of garments, environmental pollution could be minimized to a greater extent (Khan et al., 2014).

Bangladesh's government has set an effluent treatment policy for textiles and garments, and issued specific acceptable wastewater parameters before releasing it to the open environment (Table 1). However, the accepted values differ from country to country by the atmosphere's distinct natures (such as soil, water, temperature, etc.), operation types, and final destination of release (Table 2). For example, US and China do their best practices and set parameters compared to other listed countries (Table 2). However, the parameters approved by the Bangladeshi government are found competitive with other Asian countries (Table 2).

Table 1 Wastewater parameters set by the Government of Bangladesh (Guide for Assessment of Effluent Treatment Plants', 2008)

Parameters	Accepted and Approved by Government of Bangladesh	Grading		
		Excellent Range	Good Range	Poor Range
COD (mg/L)	200	<100	100-200	>200
DO (mg/L)	9	≥9	5-9	≤4
BOD (mg/L)	50	≤10	10-20	>30
TDS (mg/L)	300	<300	300-600	>600
TSS (mg/L)	100	<100	100-200	>200
Turbidity (NTU's)	10	≤10	10-20	≥100
pH	6-9	7	6-8	<4 &>9
Colour	Light Brownish /watery			

Table 2 Standard parameters for wastewater for some key textiles and apparel manufacturing countries (Guide for Assessment of Effluent Treatment Plants', 2008)

Parameter	EU	US	China	India	Pakistan	Bangladesh
pH	6-9	6-9	6-9	6-9	6-10	6-9
COD (mg/L)	160	100	100	156-400	150	200
BOD (mg/L)	30	30	25	80-250	80	50
TSS (mg/L)	30	30	70	200	150	150

2.3. Impact of effluents

Industrial effluent and other discharges are a great concern for the environment and can have detrimental effects.

i) Water Pollution**:** The polluted wastewater from industry has become a severe threat for the aquatic ecosystems, including death risks. (Kanan et al., 2014).

ii) Soil Pollution: The agriculture system and local vegetation get affected by effluents causing chronic health issues since soil gets polluted while being in contact with wastewater (Madhav et al., 2018)

iii) Air Pollution: Air pollution increases various illness and affects daily basis. The toxic gases are released to the environment by small, mid, and large scale factories, causing health hazards for the people (Kanan et al., 2014).

iv) Wildlife Extinction: Industrial pollution severely causes wildlife extinction, sacrifices of the lives of habitants, and it becomes harder to recover from each natural disaster (Madhav et al., 2018).

v) Global Warming: Global warming has been increasing since pollution is increasing by the industry. The release of smoke and greenhouse gases causes global warming, responsible for the melting of glaciers, extinction of polar bears, floods, tsunamis, hurricanes, etc. (Singh and Tiwari, 2019).

2.4. Effluent treatment and chemicals used

Figure 3 shows effluent processing flow chart of an effluent treatment plant (ETP). The following chemicals are used to treat wastewater in an ETP (Wang et al, 2008).

- ✓ H2SO4: dispensed in the neutralization tank to neutralize the pH of wastewater
- ✓ Polyelectrolyte: coagulates/sediments the sludge and also kills bacteria
- ✓ Antifoaming Agent: reduces/controls foam formation
- ✓ De-colorant: applied in the sedimentation feeding tank for removal of colouring material.
- ✓ Sodium Hypochlorite: used in the biological oxidant tank to kill harmful chemicals
- ✓ Aluminium Sulphate: generally purifies the wastewater by reacting with chemicals and produces antigens that break down hazardous and water-insoluble chemicals
- ✓ Polymer: coagulates solid dirt, works in diluted water to free materials from suspension.
- ✓ Sodium Hydroxide: works as pH stabilizer, metal precipitant and alkaline cleaner
- ✓ Ferric Chloride: It is used to corrosive chemicals and removes the metal substance from waste that is highly prone to harm the environment and living being.
- ✓ Hydrochloric Acid: Elevates the pH level of effluents.

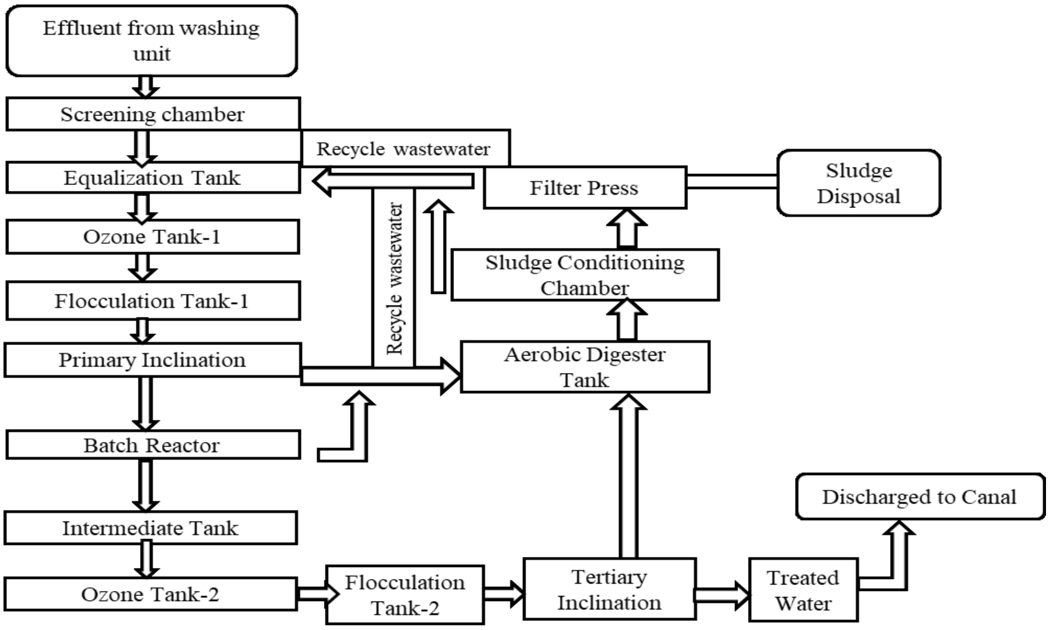


Fig. 3: A typical flow chart of effluent treatment plant (ETP) adopted from Buscio, (2017)

3.0 Research Methodology

A case study was conducted on the existing denim garment washing plants in Bangladesh. Effluent samples from five (05) different denim garment washing factories (approximately 17% of the total) sampled as A, B, C, D and E, were collected. The factories were performing normal wash, enzyme wash and P.P. spray to the denim garments during that time in line with research design. Factories were located in different areas of Bangladesh. Table 3 shows the case factories' general specifications, washing capacity and type of wash they perform.

Table 3 Sample studied factories with washing capacity and type of washes they perform

Factory Name	Factory Capacity, pcs/day	Types of denim garment wash
A	300,000	Laser fading, sandblasting, hand sanding, whiskering, tagging, grinding, destroying, potassium permanganate (PP) spray, normal wash, pigment wash, caustic soda wash, stone wash, enzyme wash, bleach wash
B	40,000	Whiskering, potassium permanganate (PP) spray, normal wash, pigment wash, stone wash, enzyme wash, bleach wash
C	60,000	Whiskering, tagging, grinding, destroying, potassium permanganate (PP) spray, normal wash, pigment wash, caustic soda wash, stone wash, enzyme wash, bleach wash
D	15,000	Whiskering, potassium permanganate (PP) spray, normal wash, caustic soda wash, stone wash, enzyme wash.

E	120,000	Ozone Fading, sandblasting, hand sanding, whiskering, tagging, grinding, destroying, potassium permanganate (PP) spray, normal wash, pigment wash, caustic soda wash, stone wash, enzyme wash, bleach wash

The inlet ETP wastewater samples consisting of normal wash, enzyme wash, and PP spray were collected. A brief description of them each of these processes is presented below.

Normal Wash: The purpose of normal wash is to remove soils, dust, dirt and stains from the garments' surface. The wash starts with the direct application of detergent and softener in hot water in the washing tank. Then the garments are rinsed with plain water and dried in a tumble dryer. The temperature of washing, detergent, and softener ratio is adjusted as per types of fabrics and origin of fibres (Choudhury, 2017).

Enzyme Wash: The application of enzymes breaks cellulosic materials (known as sizing materials applied on warp yarns before weaving) from the fabric's surface and removes them during washing. Depending on the types of fabrics, liquid and dry enzymes are applied. The temperature of the washing bath lies between 40°C and 70°C. Very high or low temperature stops the functioning of enzymes. The rest of the enzyme washing processes included final rinsing and softening and then followed by hydro-extracting and drying (Hossain et al., 2017).

Potassium permanganate (PP) Spray: PP whitens the background indigo color shade when applied by spraying or brushing on the garments' desired area. The garment is mounted on dummy according to their sizes and shapes, followed by spraying and neutralization. The concentration of PP depends on the requirements of fading effects (Dakuri et al., 2013).

3.1 Collection of effluent samples

Both untreated and treated effluents were collected in glass containers and coded, as presented in table 4. The untreated effluents were collected from the equalization tank of ETP plant, and treated effluents were collected at the plants' releasing point after treatment.

Table 4 Sample coding from different factories.

Factory Codes	Untreated Effluents	Treated Effluents
A	A_1	A_2
B	B_1	B_2
C	C_1	C_2
D	D_1	D_2
E	E_1	E_2

Note: The factories had shown reluctance to expose their names and data due to privacy or other compliance-related issues. The effluent samples from denim garment processing factories have been named A, B, C, D, and E. These factories were conducting normal wash, enzyme wash, and P.P. spray during the time of sampling as per research design.

Fig. 4: Samples collected from different denim garments processing factories

3.2. Preparation and preservation of effluents for test

The samples were preserved in a refrigerator at around 4° C and tested within 24-60 hours of collection for effluent analysis. The ratio of normal wash, enzyme wash, and P.P. spray was unknown since generated effluents passed directly to the ETP plant and released after treatment. Parameters such as TDS, pH were determined soon after sampling.

3.3. Chemical preparation

The following chemicals were prepared before conducting the tests.

a) Preparation of 0.025N Sodium thiosulfate ($Na_2S_2O_3$) 250 ml solution

The following formula (Eq. 1) was used to measure the weight of $Na_2S_2O_3$, which was dissolved in distilled water to make a solution of 250 ml.

Formula = $\frac{\text{molecular weight} \times \text{Normality}}{4} = \frac{248.2 \times 0.025}{4}$ = 1.5513 gm. Eq. (1)

b) Preparation of 0.5M Potassium Iodide (KI) 200 ml solution

Eq. 2 was used to measure the weight of KI which was dissolved in distilled water to make a solution of 200 ml.

Formula = $\frac{\text{molecular weight} \times \text{Molality}}{5} = \frac{166.0 \times 0.5}{5}$ = 16.6 gm. Eq. (2)

c) Preparation of 0.5M Manganese Sulfate ($MnSO_4$) 200 ml solution

The following formula (Eq. 3) was used to measure the weight of $MnSO_4$which was dissolved in distilled water to prepare a solution of 200 ml.

Formula = $\frac{\text{molecular weight} \times \text{Molality}}{5} = \frac{169.06 \times 0.5}{5}$ = 16.906 gm. Eq. (3)

d) Preparation of 0.02M Potassium per Manganate ($KMnO_4$) solution

The following formula presented as Eq. 4 was used to measure the weight of $KMnO_4$which was dissolved in 1000 ml distilled water to prepare a solution.

Formula = $\text{molecular weight} \times \text{Molality} = 158.034 \times 0.02$ = 3.2 gm. Eq. (4)

e) Preparation of 0.05M Ammonium Oxalate ($C_2H_8N_2O_4$) solutions

The following formula (Eq. 5) was used to measure the weight of $C_2H_8N_2O_4$which was dissolved in 1000 ml distilled water to prepare a solution.

Formula = $\text{molecular weight} \times \text{Molality} = 124.096 \times 0.05$ = 6.2 gm. Eq. (5)

f) Preparation of 1% (w/v) of starch solution

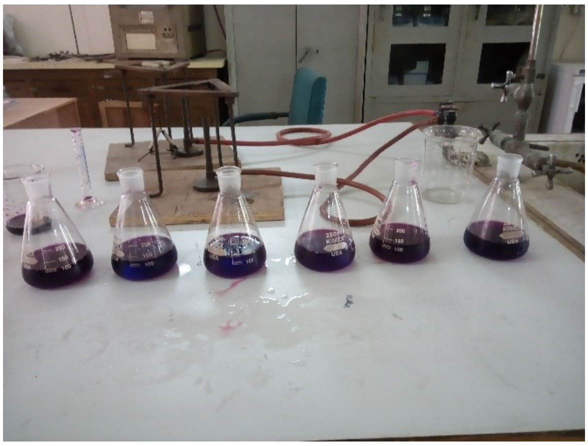
1 gm starch powder was dissolved in 10 ml of distilled water, then boiled until its colour turned watery, and then cooled.

3.4 Methods of Testing

a) Determination of COD value of wastewater (Winkler method)

Chemical oxygen demand (COD) values were measured according to ISO 6060, 1989 standard (ISO 6060, 1989) (Fig-5). According to the titration's obtained value (Winkler titration), COD value was measured by using the following formula (Eq.6).

$$=\frac{\text{Titrant values Concentration of PP molecular weight} \times 10 \times 4 \times 16 \times 1000}{1000} \text{ mg/L. Eq. (6)}$$



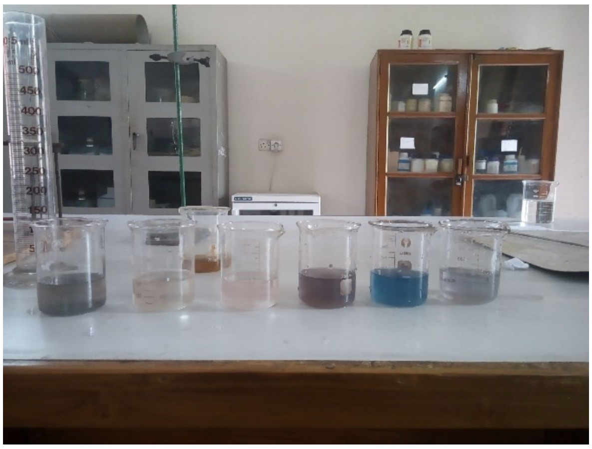
Sample preparation for COD test　　　Sample boiled in a water bath

Fig. 5: Sample preparation and testing of COD values of water

b) Determination of Dissolved Oxygen (DO) value of wastewater

According to ASTM D888 (ASTM D888-18), known as Winkler titration (Carpenter, 2006) method, DO values were measured (fig. 6). Each sample was tested accordingly and used the following formula (Eq. 7) to calculate DO of effluents.

Dissolved Oxygen (DO) = ml of 0.025M Sodium thiosulphate ($Na_2S_2O_3$) added × 2. Eq. (7)



Sample preparation for DO Test　　　Samples after titration

Fig. 6: Sample preparation and testing of DO values of water

c) Determination of BOD Value of wastewater

Wastewater (approximately 300 ml) was taken to a BOD bottle and kept for five days in a dark place. After five days, a similar procedure has been carried out to determine the final DO_f (Holenda et al., 2008). The differences between the final DO_f and the initial DO_i indicate the BOD values of wastewater (fig.7). The standard method for BOD measurement is 5210 (Gooch, 2011).

Formula-related: as such, BOD = $[DO_i - DO_f] \times$ D.F. Eq. (8)

$$\text{D.F.} = \text{Dilution Factor} = \frac{\text{Volume of waste water + Dilution water}}{\text{Volume of wastewater}} \frac{300+0}{300} = 1$$

DO_i = Initial Dissolved Oxygen

DO_f = Final Dissolved Oxygen

Samples preparation for Final DO Test

Samples after titration after 5 days

Fig. 7: Testing of DO values (Final) of water after 5 days

a) Determination of Total Dissolved Solids (TDS) of wastewater

According to ASTM D5907 method (ASTM D5907, 2018) the TDS values of effluents were measured (Eq. 9) (fig. 8).

$$\text{TDS} = \frac{\text{Dried wt. of the beaker} - \text{Wt. of the beaker}}{20} \times 1000 \times 1000 \text{ mg/L. Eq. (9)}$$

Fig. 8: Total Dissolved Solids (TDS) determination from effluents

b) Determination of Total Suspended Solid (TSS) of wastewater

Total suspended solid values were measured by ASTM D 5907 (ASTM D5907, 2018) method (Dramais et al., 2018) using theEq.10.

$$\text{TSS} = \frac{\text{Final dried wt.of filter paper} - \text{Initial wt.of filter paper}}{\text{Initial wt.of filter paper}} \times 10 \times 1000 \text{ mg/L. Eq. (10)}$$

c) Determination of Turbidity of effluents

According to ISO 7027 method (ISO 7027-1:2016), effluents' turbidity was measured in NTU (Nephelometric Turbidity Unit). Here, the Lovibond tester was used to determine values determined by scattered light at an angle of 90° (fig. 9) (World Healdth Organization, 2011).

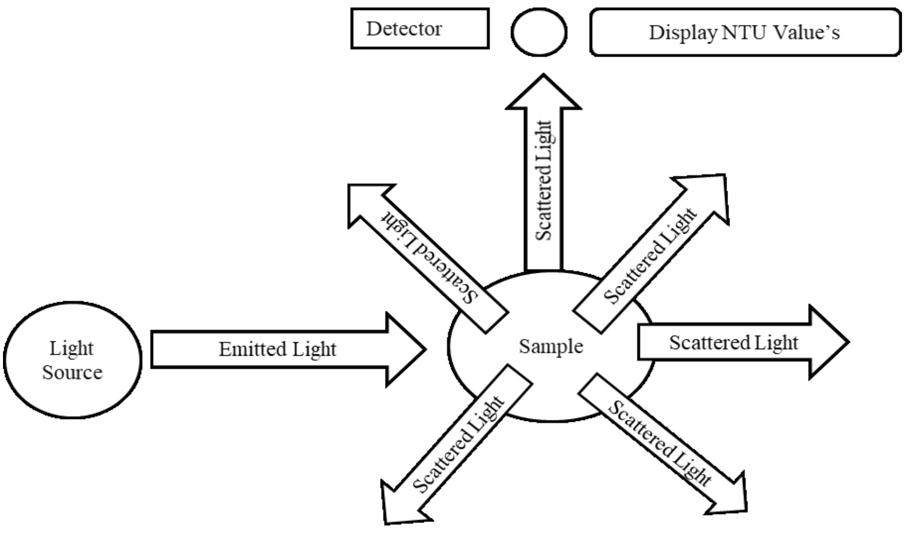


Fig. 9: Principle of Nephelometric turbidity unit (NTU) of Lovibond Turbidity meter

d) Determination of pH of the wastewater

By using HANNA pH 211 microprocessor meter (Hanna Instruments, 2000), pH values were measured (fig. 10) according to ASTM D1293 method (ASTM D1293-18).

Fig. 10: Hanna pH meter was used during pH test of samples

4.0 Results and Discussion

The resultant parameters obtained from the five factories' effluents were compared with the standard values set by the Bangladesh government as presented in Table 1 in terms of COD, DO, BOD, TDS, TSS, pH, and turbidity of the effluents.

4.1 Impact of Chemical Oxygen Demand (COD)

The COD value indicates the amount of oxygen required to breakdown organic matters (Akpor and OTohinoyi, 2014). Higher COD value results in toxic and anaerobic water conditions, and lower value can fully oxidize almost any organic compounds to CO2 with lower oxygen consumption (Edokpayi et al., 2017).The acceptable value of COD is ≤ 300 mg/L.

Table 5 Data table of the COD value test result of effluents

Factory	1st Burette reading	Differences	2nd Burette reading	Differences	Average differences	COD value (mg/L)
A_1	25.2 - 26.6	1.4	26.6-28.2	1.6	1.5	19.20
A_2	28.2-29.9	1.7	29.9-31.7	1.8	1.8	23.04
B_1	31.7-33.1	1.4	33.1-34.6	1.5	1.5	19.20
B_2	34.6-36.3	1.7	36.3-37.9	1.6	1.7	21.76
C_1	37.9-40.7	2.8	40.7-43.3	2.6	2.7	34.56
C_2	25.0-26.8	1.8	26.8-28.5	1.7	1.8	23.04
D_1	28.5-29.9	1.4	29.9-31.3	1.4	1.4	17.92
D_2	31.3-33.3	2.0	33.3-35.6	2.3	2.2	28.16
E_1	35.6-38.8	3.2	38.8-41.7	2.9	3.0	38.40
E_2	41.7-43.9	2.2	43.9-46.2	2.3	2.3	29.44

Table 5 shows the total test values stepwise with detailed calculations i.e. the titrant value of the effluent. The burette reading differences indicate the required amount of potassium per manganite solution for the effluents to turn into light pink color during titration. We conducted titration twice and taken the average value to calculate the final results. It shows that detergents, softeners during processing, and impurities in the denim garments contribute to the COD values.

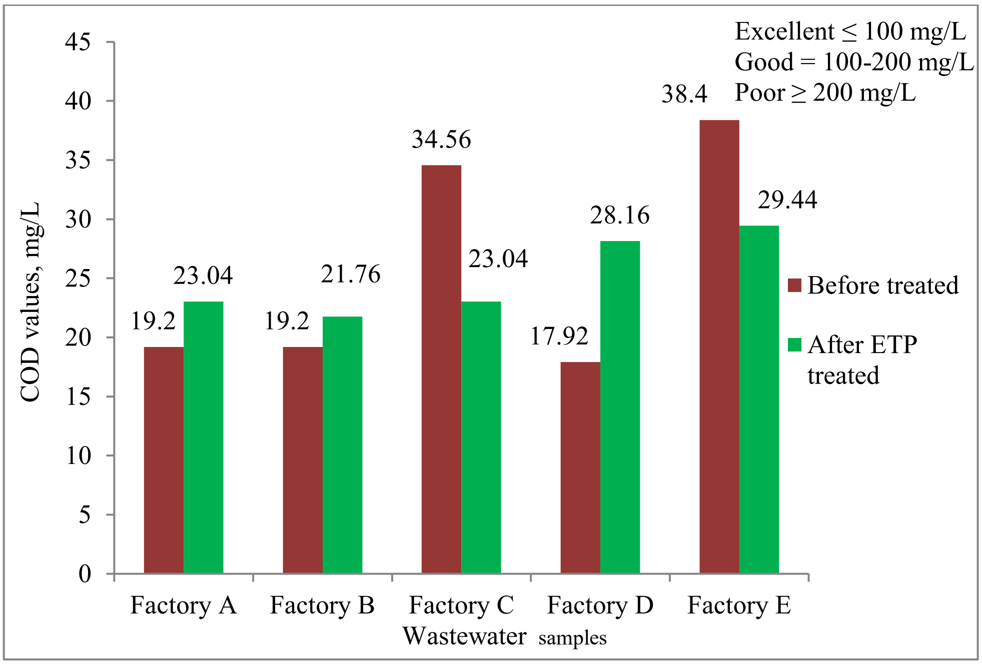


Fig. 11: Impact of COD values of wastewater

We found comparatively lower COD values in each case due to the non-toxic and non-hazardous dyes and environment-friendly wash chemicals used in the particular washing process. Therefore, chemical and organic matters are properly oxidized to CO_2 from the wastewater samples (Figure 11) and not degrading water quality. However, the investigation revealed fluctuated values over the factories A, B and D. The reason behind are (i) the presence of potassium dichromate or potassium per manganite and (ii) delay of the treatment process which have oxidised to $KMnO_4$ (although it is a strong oxidant) that deteriorate the COD values. To sum up, all (100%) of the factories under scrutiny have ensured excellent COD values having less affect to the aquatic animals, plants, growth of microbial and plankton, human being and so on.

4.2 Impact of Dissolved Oxygen (DO)

A healthy DO level ensures a balanced ecosystem for the survival of fish, invertebrates, bacteria and underwater plants (Priyanka and Sujata, 2014). The standard value is 9 mg/L and above; below 4 mg/L aquatic species can hardly sustain (Edokpayi et al., 2017). Moreover, DO value changes from 1 mg/L to 20 mg/L at the time of diffusion, aeration, photosynthesis, respiration and decomposition. Table 6 has shown the initial DO (DO_i) values of tested effluents.

Table 6 Initial dissolved oxygen values (DOi) values of wastewater samples

Factory	1st Burette reading	Difference	2nd Burette reading	Difference	Average Difference	DO_i = ml of 0.025M $Na_2S_2O_3$ added × 2
A_1	11.0-11.7	0.7	11.7-12.2	0.5	0.6	1.2
A_2	12.2-13.5	1.3	13.5-15.1	1.6	1.5	3.0
B_1	15.1-16.9	1.8	16.9-18.8	1.9	1.9	3.8
B_2	18.8-21.3	2.5	21.3-24.0	2.7	2.6	5.2
C_1	24.0-24.6	0.6	24.6-25.1	0.5	0.6	1.2
C_2	25.1-26.3	1.2	26.3-27.4	1.1	1.1	2.2
D_1	27.4-28.1	0.7	28.1-28.7	0.6	0.7	1.4
D_2	28.7-30.5	1.8	30.5-32.2	1.7	1.7	3.4
E_1	32.2-33.3	1.1	33.3-34.5	1.2	1.2	2.4
E_2	34.3-36.3	1.8	36.3-38.1	1.8	1..8	3.6

The effluents turn into watery colour after titration. The burette reading differences indicate the amount of sodium thiosulphate ($Na_2S_2O_3$) required to turn the effluents to watery color (Table 6). Average titrant values were taken to determine the DO level in the wastewater. The grading scale in figure 12 indicates only factory B having achieved the standard DO level, i.e., only one fifth (20%) of the factories under observation. The faulty (i) diffusion, aeration, and decomposition, (ii) inaccurate addition of calcium peroxide, and (iii) re-oxidation of potassium permanganate are responsible for the deteriorated DO value even after ETP treatment. These factors enhance the faster growth of bacteria and micro-organisms since partial or no photosynthesis takes place. Eventually, the water turns toxic and deteriorates the quality of neighbouring water sources.

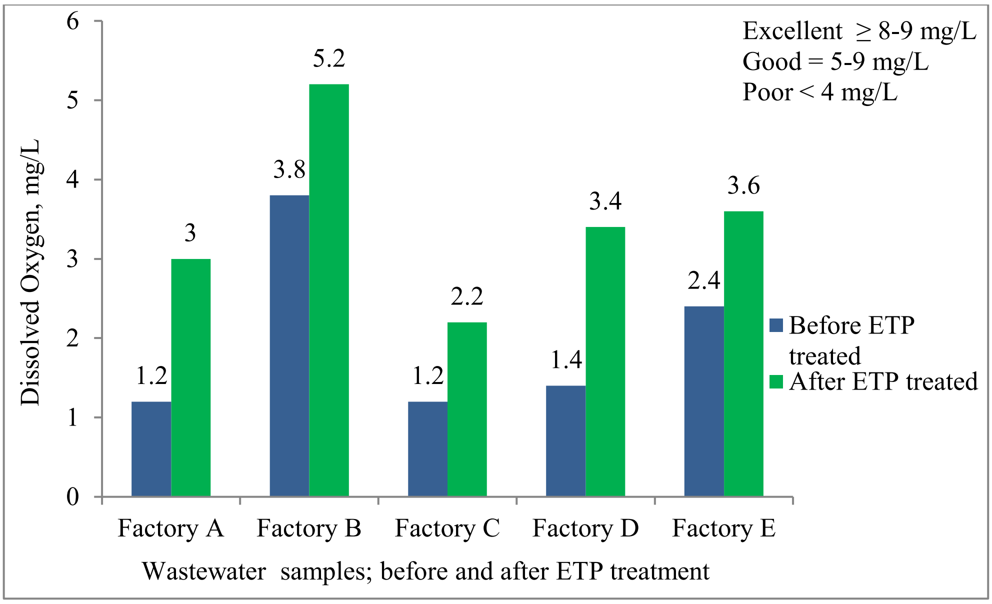


Fig. 12: Impact of DO values of wastewater

4.3 Impact of Biological/Biochemical Oxygen Demand (BOD)

The amount of DO required by aerobic microorganisms during the decomposition of organic matter is known as BOD of water. The presence of active microbial, plankton, etc. consume dissolved oxygen over time. So, the amount of DO_f (i.e. final dissolved oxygen) degraded and is always lower than DO_i (i.e. initial dissolved oxygen). As a result, water becomes toxic and converts to dead zones for aquatic plants, algae photosynthesis, and diffusion (Akpor and oTohinoyi, 2014). Generally, the allowable concentration of BOD is 10 mg/L for direct release to the environment. However, it largely depends on the Dissolved Organic Carbon (DOC), Particulate Organic Carbon (POC) and Total Organic Carbon (TOC) value of water. The following Table 7 indicates the DO_f values, and table 8 indicates BOD values.

Table 7 Final DO test table for wastewater samples after five days (DO_f)

Factory	1^{st} Burette reading	Difference	2^{nd} Burette reading	Difference	Average Difference	$DO_f = 2 \times$ Difference
A_1	9.0-9.9	0.9	9.9-10.6	0.7	0.8	1.6
A_2	10.6-11.9	1.3	11.9-12.9	1.0	1.15	2.3
B_1	12.9-13.5	0.6	13.5-14.3	0.8	0.7	1.4
B_2	14.3-15.8	1.5	15.8-17.4	1.6	1.5	3.1
C_1	17.4-18.0	0.6	18.0-18.5	0.5	0.5	1.0
C_2	18.5-19.3	0.8	19.3-20.1	0.9	0.8	1.6
D_1	20.1-20.8	0.7	20.8-21.4	0.6	0.7	1.4
D_2	21.4-22.9	1.5	22.9-24.6	1.7	1.6	3.2
E_1	24.6-25.5	0.9	25.5-26.6	1.1	1.0	2.0
E_2	26.6-28.0	1.4	28.0-29.3	1.3	1.3	2.6

Bacteria and micro-organisms consumed almost 50% of dissolved oxygen at five days period (Table 7). The poorer TDS and TSS value have generated turbidity and hampered oxygen generation. As a result, higher toxicity in water was obtained for which no aquatic life can sustain there.

Table 8 BOD table from initial and final DO calculation

Factory	Before ETP treated			After ETP treated		
	DO_i (Initial DO)	DO_f (Final DO)	BOD = $(DO_i – DO_f)$ ×D.F.	DO_i (Initial DO)	DO_f(Final DO)	BOD = $(DO_i – DO_f)$ × D.F.
A	1.2	1.6	0.4	3.0	2.3	0.7
B	3.8	1.4	2.4	5.2	3.1	2.1
C	1.2	1.0	0.2	2.2	1.6	0.6
D	1.4	1.4	0.0	3.4	3.2	0.2
E	2.4	2.0	0.4	3.6	2.6	1.0

[Note: DO_i = Initial DO value, results took from table 5 and DO_f from table 6]

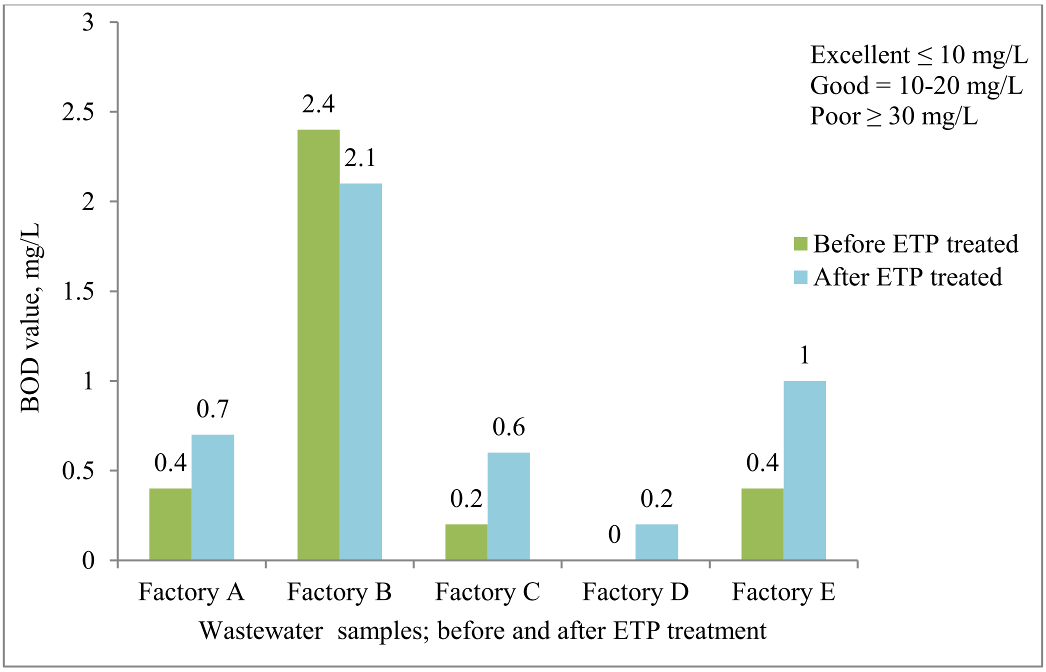


Fig.13: Impact of BOD values of wastewater

The presence of oxygen-consuming organisms reduced DO value with time (Figure 13) although BOD value was found under acceptable range (<10 mg/L). However, lower oxygen hampered the photosynthesis and turned to dead zones for aquatic, algae, and others. Thus, it indicates the supplementary wind and wave's action to be deficient during ETP treatment.

4.4 Impact of Total Dissolved Solids (TDS) values

TDS depends on organic (carbonates, nitrates, bicarbonates, chlorides and sulphates, which are anions) and inorganic (calcium, potassium, magnesium, and sodium) cations) chemicals present in wastewater/effluent. This mainly increases toxicity to water through increasing in salinity and changing in ionic composition. A higher TDS value leads to turbid and causes various diseases to aquatic plants, fisheries. living there (Hussain and Rao, 2013). Table 9 describes the stepwise calculated values to measure total solids' quantity in dissolved conditions in effluents.

Table 9 Data table of TDS values of wastewater samples after the test

Factory	Wt. of the beaker, W_1 gm.	Dried wt. of the beaker, W_2 gm.	Differences, W_2-W_1	TDS = $\frac{W2 - W1}{20} \times 1000 \times 1000$ mg/L
A_1	109.1	109.152	0.052	2600
A_2	101.62	101.653	0.033	1650
B_1	103.0	103.0382	0.00382	1910
B_2	103.90	103.923	0.023	1150
C_1	108.828	108.898	0.07	3500
C_2	101.055	101.059	0.004	200
D_1	102.92	103.014	0.094	4700
D_2	103.554	103.578	0.024	1200
E_1	101.632	101.682	0.05	2500
E_2	101.962	101.996	0.034	1700

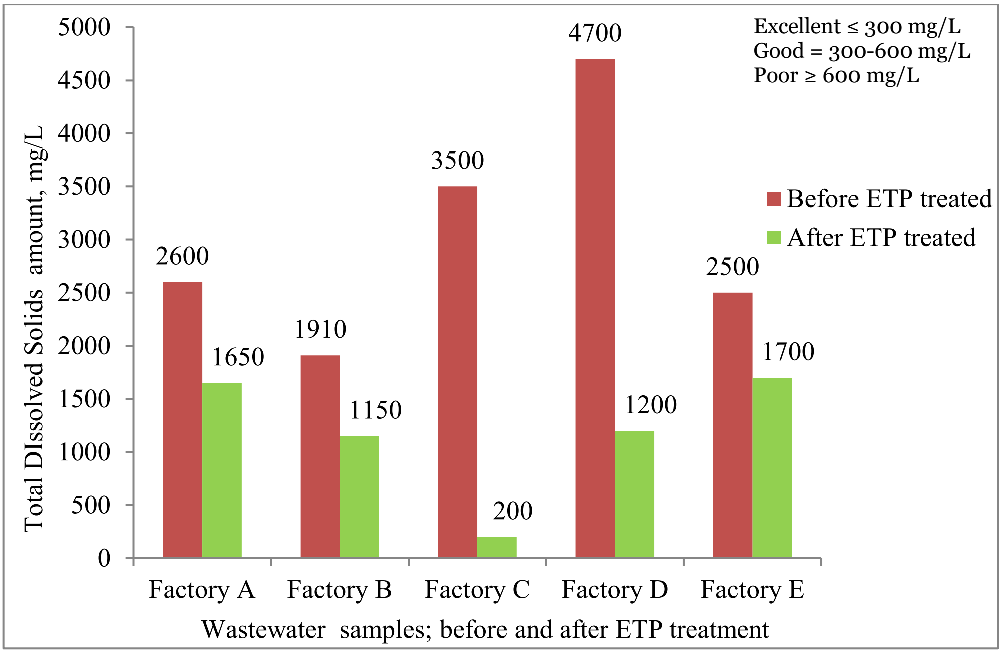


Fig.14: Impact of TDS values of wastewater

The effluents have shown great potentiality to turn into pure conditions after ETP treatment (figure 14). Unfortunately, only Factory C met the standard TDS value, which is only 20% of Bangladeshi denim washing factories under the observation. Inorganic salts and minerals such as calcium, magnesium, potassium and sodium were not properly removed or purified at ETP treatment causing the haziness of water which hinders the free movement of aquatic species, spreads bad odour to the surrounding and increases higher level of salinity. Besides, oxygen generation for photosynthesis may disrupt since light cannot reach to the lower depth properly.

4.5 Impact of Total Suspended Solids (TSS) value

The organic and inorganic matters in effluents clog together as suspended solids which are removed through screening, filtration or settling/flotation. These large particles absorb light in a significant amount, decrease oxygen level, increase water temperature and turbidity level. According to the National Pollutant Discharge Elimination System (NPDES), TSS level should be less than 200 mg/L (Gaba, 2007). The data in Table 10 shows the stepwise calculated values to measure the amount of suspended solution in the water. Moreover, a comparative analysis of TSS values of wastewater both before and after ETP treatment has shown in figure 15.

Table 10 Data table of TSS test result of effluents

Factory	Before wt. of filter paper, W_1 gm.	After dried wt. of filter paper, W_2 gm.	Differences $W_2 - W_1$ gm.	TSS = $\frac{W2-W1}{W1} \times 10 \times 1000$ mg/L
A_1	0.86	0.89	0.03	350
A_2	0.87	0.885	0.015	175
B_1	0.87	0.912	0.042	485
B_2	0.87	0.896	0.026	300
C_1	0.87	0.908	0.038	440
C_2	0.87	0.897	0.027	310
D_1	0.86	0.902	0.042	490
D_2	0.87	0.886	0.016	185
E_1	0.87	0.924	0.054	620
E_2	0.86	0.894	0.034	400

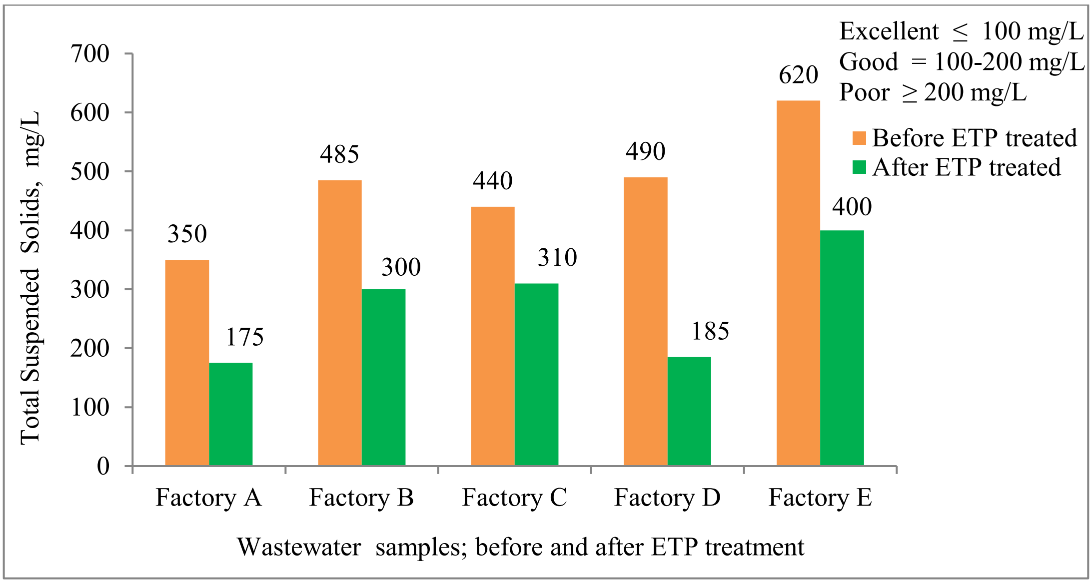


Fig.15: Impact of TSS values of wastewater

Around 40% of denim washing factories (A and C) have met the standard TSS values after ETP treatment, where others are out of range (Figure 15). The faulty sedimentation, clarifiers and coagulation during ETP treatment are responsible for this outcome. This hinders the light reaching the lower depth of water, obstructs photosynthesis, and infertile the soil by lowering the nutrition.

4.6 Impact of Turbidity values

The effluents turned opaque, hazy, or muddy due to higher TDS and TSS in the water, which resists the light reaching the lower depth, which is responsible for hindrance in photosynthesis, free movement and also diseases of aquatic life (World Health Organization 2017). Sometimes larger particles scatter the light passing through the water. Standard turbidity for drinking water is < 1 NTU and wastewater is < 10 NTU. However, at 100 NTU, water becomes muddy, and at 2000 NTU, water is completely opaque (World Healdth Organization, 2011).

Table 11 Data table for turbidity of effluents

Factory	NTU's Values	
	Before ETP treated effluents	After ETP treated effluents
A	87.10	5.50
B	177.0	18.20
C	21.50	6.98
D	508.0	19.10
E	248.0	25.50

At the initial stage, wastewater was found very turbid; only factory A and C could turn into standard values (table 11). The faulty sedimentation, grit chamber, coagulation and filtration during ETP treatment is supposed to be responsible for low turbidity. Besides, higher TDS, TSS and pH value will be responsible for a significant threat to the respiratory system and free movement of aquatic species in water.

4.7 Impact of pH value

The contamination of chemical or metal pollutants cause a low or high pH value of effluents (Baldwin and Campbell, 2001). The pH of water depends mainly on temperature (Nyanti et al., 2018), water flow, and chemical mixed up. Extreme alkalinity blocks metal pipes and corrodes water carrying appliances, generates bad smells or tastes of the effluents. However, water's acidity destroys water's nutrition and is unsafe to drink and makes the soil infertile (Dey and Islam, 2015). Figure 16 illustrates the pH value both before and after ETP treatment.

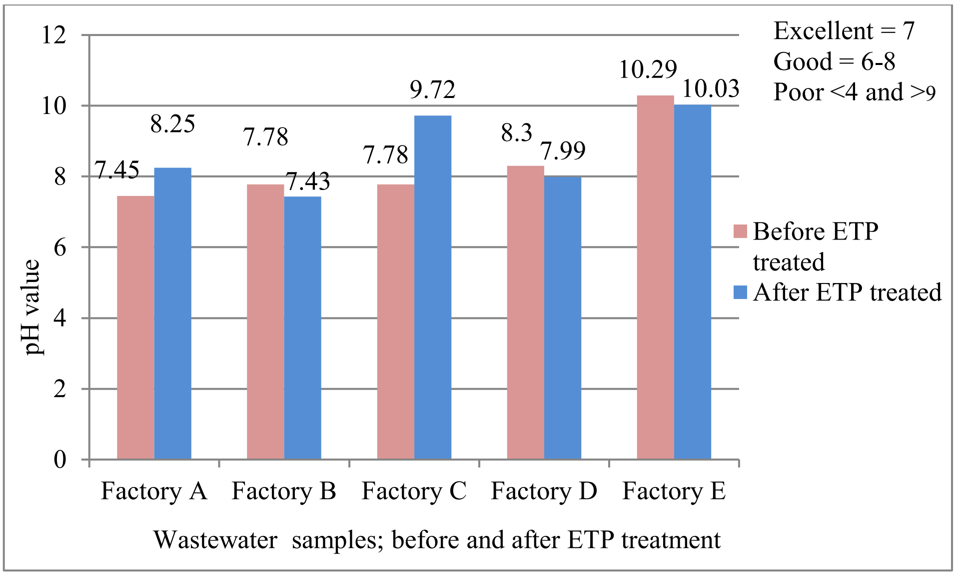


Fig.16: Impact of pH value of the effluents

Figure 16 reveals the alkalinity of wastewater except for factory B. Factory C and E have extreme alkaline conditions. This is due to the improper addition of buffer solution during neutralization treatment. The favourable conditions and nutrition supply flourish the growth of microbial organisms that have consumed dissolved oxygen and hampered photosynthesis. It will also be responsible for corrosion to metal that will hinder the flow of water. If the wastewater of A, C, and E is released to the croplands, it will destroy the nutrition and turn the soil infertile for cultivation.

4.8 Summary of the key findings

It is noticeable that the effluent parameters under observation exceeded the Bangladesh standards, specifically in case of DO, TDS, TSS, and pH values. Analysis of the COD, DO, BOD, TDS, TSS, pH, and turbidity of the effluents from denim garment washing factories indicates the technical limitations of wastewater management to mitigate environmental impact. The COD and BOD values of the effluents categorised as excellent for the factories under observation are the eco-friendly dyes and chemicals used in the washing process. DO values were recorded low for 80% factories and good for 20% factories respectively under observation. Poor DO values will become a threat to aquatic species. Likewise, 80% and 60% of the factories showed poor TDS and TSS values, respectively. It indicates that it will hinder the aquatic animal movement and damage soil nutrition quality. The presence of higher TDS and TSS in the water turned the effluents opaque, hazy or muddy. The improved filtration system, color removal and proper neutralisation were needed to achieve acceptable TDS and TSS values. Turbidity values were not at satisfactory levels by most of the factories. Key factors impacting low turbidity values are sedimentation, coagulation and filtration during ETP treatment. Lastly, pH values were not at a satisfactory level for most of the factories. Proper controlling of temperature, water flow and chemical mixing is necessary on which pH level depends. To overcome the technical limitations of effluents management, proper controlling, continuous monitoring and effective ETP, plant management is mandatory. Therefore, relevant parties, including factory top management, middle management, workers, supplier, trainer, government inspection team, and other stakeholders should work efficiently and proactively.

Table 12: Key summary of findings from the effluent tests

Parameters	No. of factories in percentage			
	Excellent	Good	Poor	Comments
COD	100%	×	×	Organic matters can be fully oxidized to CO_2chemically
DO	0%	20% (B)	80%	Aquatic species can hardly sustain growth over there
BOD	100%	×	×	Excellent BOD value; but poorer DO_i and DO_f degraded the water quality
TDS	20% (C)	×	80%	With the increase of water temperature turns turbidity levels
TSS	×	40%(A, D)	60% (B, C, E)	Hinders the movement of aquatic animals and damages the nutrition of the soil
Turbidity	40% (A, C)	60% (B, D, E)	×	Water turned turbid and responsible for water borne diseases
pH	20% (B)	40% (A, D)	40% (C,E)	Disrupt soil fertility and drainage systems

5.0 Theoretical and Industrial Implication

We claim this work to be novel regarding the effluent analysis of the garments washing industry from Bangladesh contexts. Most research studies have covered effluent analysis from textiles dyeing, printing and finishing processes with less focus in garment washing. The outcome of this research will draw the decision-makers' attention, which will guide especially industry practitioners and policy-makers for reforming existing effluents treatment policy and management to achieve sustainable performances. Factories should trace the problems and prepare a data bank on effluent treatment, which will guide themselves to upgrade overall performance towards the sustainable approach. The critical areas that need attention in reducing the denim industry's life cycle impacts can be identified through this approach. Besides, this information can be used to explore sustainability measures and assess the feasibility of implementing such strategies to facilitate denim production and washing innovation. Thus, it will help practitioners in denim manufacturing through eco-friendly wash processes in Bangladesh that can compete with global market challenges in futures. Besides, research output would be economically emancipative if the findings can be fully implemented.

Furthermore, the government, industry management and technologists can use these findings to initiate and implement a viable action plan for formulating policies on promoting sustainable denim production in Bangladesh. Environmental quantification can also encourage in developing master-plan to produce eco-friendly products and systems through ETP treatment practices and technologies. Moreover, the researchers and academics will get more scopes for further research considering the Bangladeshi environmental sustainability and that of the other countries. Besides, they will get strategic technical knowledge to work for other textile processing units to determine the causes and remedies for implementing a model regarding environmental sustainability while managing wastewater and effluent treatment.

6.0 Conclusions and Recommendations

The overall finding reveals the effluent quality scenario of the denim garments washing industry from the quantified parameters and their potential environmental impact under study. The findings show that the existing operations of filtration, purification, sedimentation, clarifiers and coagulations cannot eliminate solids from the water. It indicates faulty diffusion, aeration and decomposition that hinder light from reaching the lower depth of water causing inferior DO and BOD values even after effluent treatment. Moreover, water remains turbid, mostly due to the low functioning of the grit chamber. Finally, this study found faulty neutralization treatment in the ETP plant that could not neutralize water's pH value to a satisfactory level.

The vast amount of generated waste from apparel washing factories needs to be treated appropriately; otherwise, the actual impact will be more severe and acute for the environment. Indeed, many denim washing factories cannot keep the environment safe, which indicates a low wastewater management policy by factory practitioners. Therefore, it is expected that the washing phase of denim garments will result in a significant environmental burden for the surrounding environment by producing significant amount of wastewater to be discharged without proper effluent treatment. Environmental issues and subsequent impact of denim garments washing is on the rise, thus challenging the sustainability of denim industry. Therefore, considering the effluent quality and the economic factors, strong regulations and monitoring systems are needed to ensure sustainable denim production from the finishing perspective. A strategic action plan with measurable outcomes regarding extraction of effluents and sludge should be appropriately implemented. In this regard, the government, buyers and industry practitioners should act more responsibly and if necessary, they should be motivated or compelled to do so. In some cases, the government should seal, penalty and warn some irresponsible factory management for operating the ETP plant in the faulty way.

This study has some limitations. The types of equipment, factory types, sludge content, production process, chemical types, dyes content, etc. can vary effluents' characteristics. Thus, we have limited the generalizability and adaptability of the result, and have focused only on the key environmental impact. Moreover, cost analysis of wastewater treatment was not possible because of the time limit to investigate economic and environmental interplay. A detailed and section-wise investigation is necessary to identify the critical issues related to effluents based on diverse washing techniques and released effluents. We recommend future investigation on the running of ETP to identify why some values are within acceptable limits and some are not in line with the findings. In the future, a comprehensive study is required by bringing the overall denim washing factories under analytical studies in order to measure the actual scenarios of environmental and health hazards. Wastage such as effluents and sludge from knit-dyeing, woven-dyeing, garment washing, etc. are equally responsible for producing hazards. Hence, a comprehensive investigation is needed to cover all the processes in the upstream manufacturing stages if sustainable water resources practices are to be achieved.

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References

Akpor, O.B. and OTohinoyi, D.A. 2014. Pollutants in Wastewater Effluents: Impacts and Remediation Processes. International Journal of Environmental Research and Earth Science. **27**(44), pp.249–253. http://eprints.lmu.edu.ng/1023/1/IJERES_2014.

ASTM D5907, 2018. Standard Test Methods for Filterable Matter (Total Dissolved Solids) and Nonfilterable Matter (Total Suspended Solids) in Water, ASTM International, West Conshohocken, PA. https://www.astm.org/Standards/D5907.html (accessed 15 May 2020).

ASTM D888-18, 2018. Standard Test Methods for Dissolved Oxygen in Water, ASTM International, West Conshohocken, PA. Available from https://www.astm.org/Standards/D888.html (Accessed 15 May 2020).

ASTM D1293-18, 2018. Standard Test Methods for pH of Water, ASTM International, West Conshohocken, PA. Available from https://www.astm.org/Standards/D1293.html (Accessed 15 May 2020).

Baldwin, D.D. and Campbell, C.E. 2001. Short-term effects of low pH on the microfauna of an activated sludge wastewater treatment system. Water Quality Research Journal of Banerjee, S. and Banerjee, M.T. 2018.Canada. 36(3), pp.519–535. https://www.semanticscholar.org/paper/Short-Term-Effects-of-Low-pH-on-the-Microfauna-of-Baldwin-Campbell/040da75a2c8f7da168eca8d22528404095300ed9.

Buscio, V. (2017) 9-Chemicals and effluent treatment in indigo denim processes, Sustainability in Denim. Elsevier Ltd. pp-235-255. http://doi.org/10.1016/B978-0-08-102043-2.00009-5.

Carpenter, J.H. 2006. Determination of dissolved oxygen by Winkler Titration. Environmental Chemistry of Boston Harbor. pp 1-10. https://docplayer.net/20930071-12-097-environmental-chemistry-of-boston-harbor-iap-2006-determination-of-dissolved-oxygen-by-winkler-titration.html

Choudhury. A.K.R., 2017. Environmental impacts of denim washing, In The Textile Institute Book Series, Sustainability in Denim, Woodhead Publishing, Pages 49-81, ISBN 9780081020432, https://doi.org/10.1016/B978-0-08-102043-2.00003-4.

Dadi, D., Stellmacher, T., Senbeta, F., Passel, S.V., & Azadi, H., 2016. Environmental and health impacts of effluents from textile industries in Ethiopia: the case of Gelan and Dukem, Oromia Regional State. *Environmental Monitoring and Assessment, 189 (1)*, pp. 1-30.

https://doi.org/ 10.1007/s10661-016-5694-4.

Dakuri, A., Hiranmayee, J. and Farhee, M.N. 2013. MNF Technology of industrial denim washing : review. International Journal of Industrial Engineering & Technology (IJIET) ISSN 2277-4769 Vol. 3, Issue 4, pp. 25-34. http://www.tjprc.org/publishpapers/2-9-1378365069-3.%20Technology%20of%20industrial.%20full

Dey, S. and Islam, A. 2015. A Review on Textile Wastewater Characterization in Bangladesh. Resources and Environment. **5**(1), pp.15–44. https:// doi.org/10.5923/j.re.20150501.03.

Dramais, G., Camenen, B., Le Coz, J., Thollet, F., Le Bescond, C., Lagouy, M., Buffet, A. and Lacroix, F. 2018. Comparison of standardized methods for suspended solid concentration measurements in river samples. E3S Web of Conferences. **40**. pp 1-8. https://hal.archives-ouvertes.fr/hal-01930679/document.

Edokpayi, J.N., Odiyo, J.O. and Durowoju, O.S. 2017. Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa. Water Quality., pp.400–416.. www.intechopen.com. London, U.K. https.//doi.org/10.5772/66561.

Gaba, J.M. 2007. Generally illegal: NPDES general permits under the Clean Water Act. Harvard Environmental Law Review. California, U.S. **31**(2), pp.409–473. https://harvardelr.com/wp-content/uploads/sites/12/2019/07/31.2-Gaba

Greenpeace, 2016. The detox catwalk 2016-campaign and criteria explained Detox My Fashion-state of play. pp 1-6. Amsterdram, Netherlands. https://www.greenpeace.org.cn/site/toxics/2016/ catwalk/download/Detox_Catwalk_Explained_2016

Gooch, J. W., 2011. Biochemical Oxygen Demand (B.O.D.). Encyclopedic Dictionary of Polymers, 5000, 80–80. Springer, New York, NY, U.S. https://doi.org/10.1007/978-1-4419-6247-8_1310

Guide for Assessment of Effluent Treatment Plants', 2008. Department of environment, Ministry of Environment and Forest, Bangladesh. pp-1-79. http://old.doe.gov.bd/publication_images/15_etp_assessment_guide.pdf

Hanna Instruments., 2000. Instruction Manual: pH 210, pH 211, pH 212, pH 213 Microprocesssor- based Bench pH/mV /°C Meters. 01, 920010. Available from http://www.hannacan.com/PDF/manpH210.pdf (Accessed- 16 July 2020).

Hasan Abir, 2018. Bangladesh's denim washing and its fashion scenario. Textile Today. [Online]. Available from: https://www.textiletoday.com.bd/bangladeshs-denim-washing-fashion-scenario/ [Accessed 27 June 2020].

Holenda, B., Domokos, E., Rédey, Á. and Fazakas, J. 2008. Dissolved oxygen control of the activated sludge wastewater treatment process using model predictive control. Computers and Chemical Engineering. 32 (6), pp-1270-1278. https://link.springer.com/article/10.1007 /s00034-016-0282-y

Hossain, M., Rony, M.S., Hasan, K., Hossain, M.K., Hossain, M.A., & Zhou, Y., 2017. Effective Mechanical and Chemical Washing Process in Garment Industries. American Journal of Applied Physics, 2(1), pp. 1-25. https://ivyunion.org/index.php/ajaphy/article/view/1101

Hossain, L., Sarker, S.K. and Khan, M.S. 2018. Evaluation of present and future wastewater impacts of textile dyeing industries in Bangladesh. Environmental Development. Vol. **26.** pp.23–33. https://doi.org/10.1016/J.ENVDEV.2018.03.005

Hossain, A, 2019. Waste Water Production in Fabric Processing in Bangladesh, European Online Journal of natural and social sciences, 8(3), pp. 558–563. http://european-science.com/eojnss/article/view/5812

Hussain, M. and Rao, T.P. 2013. Effect of Industrial Effluents on Surface Water Quality - A Case Study of Patancheru, Andhra Pradesh, India. Current World Environment Journal. **8**(3), pp.445–454. http://dx.doi.org/10.12944/CWE.8.3.14

Islam, M.M., Khan A.M. and Islam, M.M. 2013. Textile Industries in Bangladesh and Challenges of Growth. Research Journal of Engineering Sciences. Vol. 2(2), 31-37. http://www.isca.in/IJES/Archive/v2/i2/7.ISCA-RJEngS-2013-002.php

Islam, M. M., Perry, P. & Gill, S. 2020. Mapping Environmentally Sustainable Practices in Textiles, Apparel and Fashion Industries: A Systematic Literature Review. Journal of Fashion Marketing and Management. https://doi.org/10.1108/JFMM-07-2020-0130.

ISO 6060:1989. Water quality — Determination of the chemical oxygen demand. Available from https://www.iso.org/obp/ui/#iso:std:iso:6060:ed-2:v1:en (Accessed on 15 July 2020).

ISO 7027-1:2016. Water quality-Determination of turbidity-part 1: Quantitative methods.

Available from https://www.iso.org/standard/62801.html (Accessed on 15 July 2020).

Jamy retrace l'itinéraire d'un jean – YouTube." [Online]. Available: https://www.youtube.com/watch?v=U9xoi7RSOwo. [Accessed: 01-Jan-2020]

Kabir, S.M.F.; Chakraborty, S.; Hoque, S.M.A.; Mathur, K. 2019. Sustainability Assessment of Cotton-Based Textile Wet Processing. *Clean Technologies*. 1(*1)*, pp. 232-246. https://doi.org/10.3390/cleantechnol1010016

Kan, C.W., 2015. Washing Techniques for Denim Jeans. In: Paul, R., Ed., Denim: Manufacture, Finishing and Applications, Woodhead Publishing, Cambridge, 313-256. http://dx.doi.org/10.1016/b978-0-85709-843-6.00011-1

Kanan, A. H., Marine, S.S., Raihan, F., Redwan, M. andMiah, M. D. 2014. Textile effluents change Physiochemical parameters of Water and Soilthreat for Agriculture. African Journal ofAgronomy, **10**: 219-223. https://www.internationalscholarsjournals.org/print.php?article=textile-effluents-changes

Karthik T., Gopalakrishnan D., 2014. Environmental Analysis of Textile Value Chain: An Overview. In: Muthu S. (eds) Roadmap to Sustainable Textiles and Clothing. Textile Science and Clothing Technology. Springer, Singapore. http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-981-287-110-7_6

Khan, A.M., Islam, M.M. and Khan, M.M.R. 2020. Chitosan incorporation for antibacterial property improvement of jute-cotton blended denim fabric. Journal of the Textile Institute. 111(05), pp-660-668. https://www.tandfonline.com/doi/abs/10.1080/00405000.2019.1657220

Khan, M. M. R., & Islam, M. M., 2015. Materials and manufacturing environmental sustainability evaluation of apparel product: knitted T-shirt case study. Textiles and Clothing Sustainability, 1(1), 8. https://doi.org/10.1186/s40689-015-0008-8.

Khan, A.M., Islam, M.M. and Khalil, E., 2014. Investigation on Effluent Characteristics of Organic Cotton Fabric Dyeing With Eco-Friendly Remazol Reactive Dyes. AASCIT Journal of Chemistry. Vol. 2, No. 2, 2015, pp. 19-23. https://dokumen.tips/engineering/investigation-on-physical-properties-of-organic-cotton-t-shirt-by-bio-scouring.html

Levi Strauss & Co., 2015. The life cycle: understanding the environmental impact of a pair of Levi's ® 501 ® jeans retrieved from https://www.levistrauss.com/wp-content/uploads/2015/03/Full-LCA-Results-Deck-FINAL.pdf?fbclid=IwAR2-ZX-DaGzzQ9Ma3ynIgY8C1PqJNsIw4SIbTZlm3f7lwzmt1jJhTyd1QxQ, [Accssed: 21 August 2020]

Madhav, S, Ahamad, A, Singh, P, Mishra, PK. 2018. A review of textile industry: Wet processing, environmental impacts, and effluent treatment methods. *Environmental Quality Management*. 27: 31– 41. https://doi.org/10.1002/tqem.21538

Mani, S., Chowdhary, P. and Bharagava, R.N. 2018. Textile wastewater dyes: Toxicity profile and treatment approaches In: Emerging and Eco-Friendly Approaches for Waste Management. Book chapter, U.S. 11(2). pp 219-244. http://springer.nl.go.kr/chapter/10.1007%2F978-981-10-8669-4_11

Md. Shamsuzzaman Rasel, Dip Das and Malaz Rahman Khan, 2020, Current Scenario of Textile Sector in Bangladesh (2019); A Comprehensive Review. International Journal of Innovative Studies in Sciences and Engineering Technology. 4863(2019), Volume 6(1), pp. 52–55. https://www.researchgate.net/publication/338750654_Current_Scenario_of_Textile_Sector_in_Bangladesh_2019_A_Comprehensive_Review

Mohammad Ishaque., 2019. RMG Industry Outlook, Retrived from http://textilefocus.com/rmg-industry-outlook-2019. [Accessed 26 October 2020]

Muthukumarana, T., Karunathilake, H., Punchihewa, H., Manthilake, M., & Hewage, K. (2018). Life cycle environmental impacts of the apparel industry in Sri Lanka: Analysis of the energy sources. Journal of cleaner production, 172, 1346-1357. https.//doi.org/10.1016/j.jclepro.2017.10.261

Nyanti L., Soo C. L., Danial-Nakhaie M. S., Ling T. Y., Sim S. F., Grinang J., Ganyai T., Lee K. S. P., 2018 Effects of water temperature and pH on total suspended solids tolerance of Malaysian native and exotic fish species. AACL Bioflux 11(3):565-575. https://www.cabi.org/ISC/FullTextPDF/2018/20183236723.

Nayeem Abanty Huque., 2015. Present scenario of denim industry in Bangladesh" [Online]. Available from: https://www.academia.edu/14531239/Denim_Industries_in_Bangladesh. pp 1-38. [Accessed 25 June 2020].

Periyasamy, Aravin Prince & Wiener, Jakub & Militky, Jiri. 2017. Life-cycle assessment of denim. Book chapter: Sustainability in Denim, pp. 83-101. https://doi.org/10.1016/B978-0-08-

102043-2.00004-6.

Priyanka Sharma and Sujata Gupta, 2014. Study of amount of Oxygen (BOD, DO, COD) in water and their effect on fishes. American International Journal of Research in Formal, Applied & Natural Sciences, 7(1), pp. 53-58. http://iasir.net/AIJRFANSpapers/AIJRFANS14-343.

Selim, S., 2018. Environmental Compliance Opportunities in the Bangladeshi Ready Made Garments Industry : Lessons from the Green High Achievers', Economic Dialogue on Green Growth, UK aid. pp 1-115 Available from https://www.greengrowthknowledge.org/research/environmental-compliance-opportunities-bangladeshi-ready-made-garments-industry-lessons (Accessed on 15 June 2020).

Senthil Kumar, P. and Gunasundari, E. 2018. Sustainable Wet Processing—An Alternative Source for Detoxifying Supply Chain in Textiles In:, springerprofessional.de. U.S. pp.37–60. https://www.springerprofessional.de/en/sustainable-wet-processing-an-alternative-source-for-detoxifying/12312236

Sobuj, M., Khan, A.M. and Islam M.M., 2020. Factors Influencing Eco-friendly Apparel Purchase Intention of Young Consumers: A Case Study in Bangladesh. Research Journal of Textile and Apparel.24 (4), (In press)

Solaiman, & Rouf, Md.Abdur & Rasel, Md & Khalil, Elias., 2015. Investigation of Different Washing Effects on Physical and Mechanical Properties of Cotton Knitted Garments. Journal of Textile Science and Technology. 01. 101-109. https.//doi.org/10.4236/jtst.2015.13011.

Singh S., Tiwari S., 2019. Climate Change, Water and Wastewater Treatment: Interrelationship and Consequences. In: Singh R., Kolok A., Bartelt-Hunt S. (eds) Water Conservation, Recycling and Reuse: Issues and Challenges. Springer, Singapore. https://doi.org/10.1007/978-981-13-3179-4_11

Strauss, L., 2007. 'APPENDIX V : Global Effluent Guidelines'.pp-141-176. Available from http://www.levistrauss.com/wp-content/uploads/2014/01/Global-Effluent-Guidelines (Accessed on 10 January 2020).

Uddin, M.G., Islam, M.M. and Islam, M.R., 2015. Effects of reductive stripping of reactive dyes on the quality of cotton fabric. Fashion and Textiles, 2(1), p.1-8. https.// doi.org/10.1186/s40691-015-0032-y

UNTACD 2019, "Environmental impact of fashion industry" [Accessed on 30 June 2020] Available from: https://news.un.org/en/story/2019/03/1035161

Wang, G. Zenga, and J. Zhua., 2008. Treatment of jean-wash wastewater by combined coagulation, hydrolysis/acidification and Fenton oxidation, Journal of Hazardous Materials, vol. 153, 2008, pp. 810-816. https.//doi.org/10.1016/j.jhazmat.2007.09.030.

World Health Organization, 2017. Water quality and health - review of turbidity: Information for regulators and water suppliers. Who/Fwc/Wsh/17.01., p.10. Available from https://www.who.int/water_sanitation_health/publications/turbidity-information-200217 (Accessed on 20 March 2020).

World Healdth Organization, 2011. Guidelines for drinking-water quality - 4th ed. WHO Library Cataloguing-in-Publication Data. Pp. 1-564. Available from https://apps.who.int/iris/bitstream/handle/10665/44584/9789241548151_eng.pdf;jsessionid=4BF8976F84B318BC0EEB35A6AABAE092?sequence=1 (Accessed on 20 March 2020).