MATERIAL BALANCE APPROACH TO MEASURE WATER POLLUTION IMPACT OF INDUSTRIAL DEVELOPMENT IN BANGLADESH

By

SUMIT KANTI SARKER

Student ID: 1015022013

Supervised by

Dr. Mohidus Samad Khan

Submitted in partial fulfillment of the requirements for the degree of M.Sc. Eng. in Chemical Engineering

DEPARTMENT OF CHEMICAL ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DHAKA, BANGLADESH

SEPTEMBER, 2017

DECLARATION

I hereby declare that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

September 2017

SUMIT KANTI SARKER

Student No: 1015022013

The thesis titled "**Material Balance Approach to Measure Water Pollution Impact of Industrial Development in Bangladesh**" submitted by Sumit Kanti Sarker, Roll No. 1015022013, Session: October/2015 has been accepted as satisfaction in partial fulfillment of the requirement for the degree of Master of Science in Chemical Engineering on 12th September 2017.

BOARD OF EXAMINERS

Dr. Mohidus Samad Khan
Assistant Professor
Department of Chemical Engineering,
BUET, Dhaka

Chairman
(Supervisor)

Head
Department of Chemical Engineering,
BUET, Dhaka

Member
(Ex-Officio)

Dr. Syeda Sultana Razia
Professor
Department of Chemical Engineering,
BUET, Dhaka

Member

Dr. Mohammed Abed Hossain
Associate Professor
Institute of Water and Flood Management
(IWFM),
BUET, Dhaka

Member
(External)

Acknowledgement

I would like to express my heartiest gratitude to my honorable supervisor of the thesis project, Dr. Mohidus Samad Khan, Assistant Professor of Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), for his valuable guidance, constant encouragement and keen interest at every stage of this study without which it would have been extremely difficult to accomplish the thesis work. This research was partially supported by BCEF Academic Research Fund. I am grateful to the Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), for providing all the facilities which aided me to carry out the thesis work. I would also like to thank Ms Laila Hossain (Post-graduate student, BUET) and environmental laboratory assistants of Chemical Engineering Department of BUET for their valuable assistance. Finally, I would like to thank Dr. Ijaz Hossain, Dr. Syeda Sultana Razia and Dr, Mohammed Abed Hossain for their valuable suggestions on this thesis to make it more organized.

Abstract

The rapidly developing economy of Bangladesh is mainly driven by its uprising industries over the past few decades. Among these industries Ready Made Garments (RMG) and leather industries are the largest export sectors. In Bangladesh, RMG and leather industries currently have an export value of nearly 28 billion USD and 1 billion USD per year respectively which contributes about 85% of the total export earnings. It is projected that the annual RMG and leather export value will be about 50 billion USD and 5 billion USD respectively by 2021. However, this rapid growth of RMG and leather sector is associated with different environmental issues mostly caused by wastewater generated by textile and tannery industries. Both of these industries consume high volume of water per unit to process fabric and raw salted hide, which may cause depletion of groundwater level at a high rate. Besides, in many cases effluents from these industries are discharged to river or wetlands without proper treatment. Improving conventional technology and adapting cleaner production options may reduce water consumption and effluent volume. However, additional investment, and lack of technological knowhow and awareness are the limiting factors of adapting cleaner production options. To take effective measures for future improvement it is important to develop a nationwide wastewater impact tracking system.

In this study, a material balance approach is applied to predict the trend of pollution loads (2011-2021) associated with textile dyeing and tannery industries of Bangladesh. It is estimated that in 2016, textile industries produced about 1.80 million metric tons of fabrics which generated around 217 million m^3 of wastewater and leather industries produced 300 million square feet of leather which generated around 12 million m^3 of wastewater with a wide range of pollution

characteristics in Bangladesh. It is projected that around 403 million m^3 of wastewater will be produced in 2021 by textile dyeing and tannery industries using conventional dyeing practices. Gradual adaptation of improved technology and cleaner production options may reduce wastewater volume around 23% for textile process and 50% for leather process by 2021. This projection will help policy makers to take necessary mitigation measures for treatment and pollution management. This analysis will also provide a baseline scenario and open new opportunities for engineers and environmentalists to develop innovative technologies for textile dyeing, leather tanning and effluent treatment.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Bangladesh has achieved a tremendous growth rate in its industrial production over the last few decades. The Government is keen to expand the industrial base of the economy and encourage both domestic and foreign investment in the sector. The major industries of the country are Readymade Garments (RMG), leather, pharmaceuticals, pulp and paper, fertilizer, cement etc. Among these, RMG and leather are the two largest industries in Bangladesh.

Despite the significant economic contribution, textile and tannery industries in Bangladesh cause a range of environmental problems, mostly pollution of water resources of the country (Ahmed and Tareq,2008). Textile and tannery sectors are also the most intensive industrial water user of the country. Effluents from these industries contain various chemicals such as oil, grease, caustic, chromium, glauber salt, ammonia, sulfide, lead, color, heavy metals and other toxic substance (Islam, Chowdhury et al., 2012). Typical characteristics of textile and tannery industry wastewater generally include a wide range of pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), heavy metal sand strong color (Rott and Minke,1999; Nergis, Sharif et al.,2009; El-Gohary, Tawfik et al.,2010; Dey and Islam,2015). Untreated effluent generated by these industries is one of the major sources of water pollution (Khan, Selim et al., 2011).

High volume of textile and tanning wastewater may cause alteration of the physical, chemical, and biological properties of aquatic environment, and could be harmful to public health, livestock, wildlife, fish and other biodiversity (Sultana, Islam et al., 2009; Islam, Chowdhury et al., 2012). Under the 'Bangladesh Environment Conservation Act (ECA, 1995)' and

‘Environmental Conservation Rules (ECR, 1997)’, textile dyeing and tannery industries are categorized as “Red industries”, and must treat and monitor the wastewater quality conforming to national discharge quality standard (Environmental Conservation Rules, 1997; Sharif and Hannan 1999; Huq, 2003). However, it is reported that in most of the cases, industrial effluents are discharged to nearby river or wetlands without proper treatment (Ali, Ahmed et al., 2010).

1.2 Current Scenario

There are many studies which have been conducted to characterize the effluent parameters of the textile and tannery industries. Several studies have also been conducted to analyze the pollution load on selected zones and specific types of effluents. But no studies have been conducted yet to project the water pollution load on national level by material balance approach.

The Bangladesh Government has set target that the annual RMG and leather export value will be about 50 billion USD and 5 billion USD respectively by 2021. However, the initial growth of these sectors was mostly unplanned, and the wastewater data tracking system is not up to the mark. Considering the future projection, Government, international brands, and policy makers are creating pressure on local industries to adapt cleaner production options to improve productivity and reduce pollution load. Considering the current and future environmental impacts, a database was developed in this study indicating production growth rate and wastewater pollution loads. This database can be helpful to plan effective measures to address environmental issues related to these sectors.

1.3 Objectives of the Study

The main objective of this study is to characterize the present trend and future projection of pollution loads by material balance approach associated with Bangladesh textile dyeing and tannery industries; future pollution load is calculated considering existing dyeing and tanning practice as well as possible adaptation of cleaner production options. This database will help industries and policy makers to plan for environmental measures and regulations for the upcoming years. This study will be also useful in water footprint calculation, and analyzing pollution load from other major industries.

1.4 Challenges of the Study

The most major challenge for this study was unavailability of wastewater volume data of past few years. So wastewater volume for the years 2011-2016 were calculated using the production data and by analyzing the production trend, pollution load projection was made. For textile sector, yearly export data is available only in price which was converted to total production in weight using the average price and average weight of a garment product. Again, for leather sector the similar approach was not possible as because there are a huge varieties of leather products with a wide range of product price. So for leather production trend analysis, yearly growth percentage value was used. It was also challenging to collect the samples from many of the industries in Bangladesh due to the lack openness of the management towards the environmental issues.

2. Literature Review

2.1 Industrial Growth in Bangladesh

The ready-made garments (RMG) industry occupies a unique position in Bangladesh economy. It is the largest exporting industry in Bangladesh, which has experienced phenomenal growth during the last few decades (Hasan, Mia et al., 2016). This sector creates about 4.2 million employment opportunities and contributes significantly to the GDP (Gross Domestic Product) (Kiron, 2015). Bangladesh is world's second largest exporter of clothing after China (Islam, Khan et al., 2013).Table 1 describes RMG sector export statistics of Bangladeshfor last six years (2011-2016).

Table 1: RMG Sector Export Statistics of Bangladesh

Year	Export of RMG (million USD)	Percentage increase in export of RMG	Total export of Bangladesh (million USD)	Percentage of RMG's to total export
2010-11	17,914	43.35	22,924	78.15
2011-12	19,090	6.56	24,302	78.55
2012-13	21,516	12.71	27,027	79.61
2013-14	24,492	13.83	30,187	81.13
2014-15	25,491	4.08	31,209	81.68
2015-16	28,094	10.21	34,257	82.01

It can be seen from Table 1 that the average annual production growth rate for the last six years has been 10%. To achieve the Government goal of 50 billion USD garments industry by 2021, the production should be continued to increase by 10% in every year.

The second largest exporting industry in Bangladesh is the leather industry which also plays a vital role in creating employment in the country. Bangladesh is currently exporting leather and leather products to 53 countries (LFMEAB, 2016). Currently, the largest leather exporter in the world, China is withdrawing from the global leather market which creates a huge opportunity for Bangladesh to take over the market. International buyers are also showing keen interest in exporting leather from Bangladesh (Mirdha, 2015). Table 2 represents the leather sector export statistics of Bangladesh in the last six years (2011-2016).

Table 2: Leather sector export statistics of Bangladesh

Year	Export of leather (million USD)	Percentage increase in export of leather	Total export of Bangladesh (million USD)	Percentage of leather's to total export
2010-11	631	-	22,924	2.75
2011-12	765	17.51	24,302	3.15
2012-13	981	28.19	27,027	3.62
2013-14	1124	32.12	30,187	3.72
2014-15	1131	0.56	31,209	3.62
2015-16	1230	8.8	34,257	3.59

In the last few years the yearly production growth percentage for the leather sector has been 20% and this growth percentage need to be 35% yearly to achieve the Government goal of 5 billion USD. However, lack of mitigation plan towards the high environmental hazards associated with the tannery industries restraining the buyers to export from Bangladesh. Currently the leather sector in Bangladesh is in a transition phase where most of the country's tannery industries are being relocated from Hazaribagh tannery area to Savar tannery estate (Mirdha, 2015). Previously in Hazaribagh, effluents were released to the nearby Buriganga river without proper treatment (Rouf, Islam et al., 2013). Now, though an effluent treatment plant has been built in the Savar tannery estate, still the functionality of this plant is controversial. If the responsible bodies do not take immediate actions towards these concerns of ETP functionality, it will be very challenging to achieve the Government goal by 2021.

2.2 Pollution Load Characterization in Textile and Leather Industries

Effluents from the textile and tannery industries have different types of chemicals. The textile effluent typically contains acetic acid, ammonium sulphate, caustic soda, organic solvent, hydrochloric acid, hydrogen peroxide, sulphur and reactive dyes etc. However, effluent from the tannery industries typically contains chromium, dissolved lime, hydrogen sulfide, dyes oils, organic matter, suspended solids, etc. (Chowdhury, Mostafa et al., 2013).Key characteristics of wastewater produced from various stages during wet processing of cotton-based textile industries are shown in Figure 1.

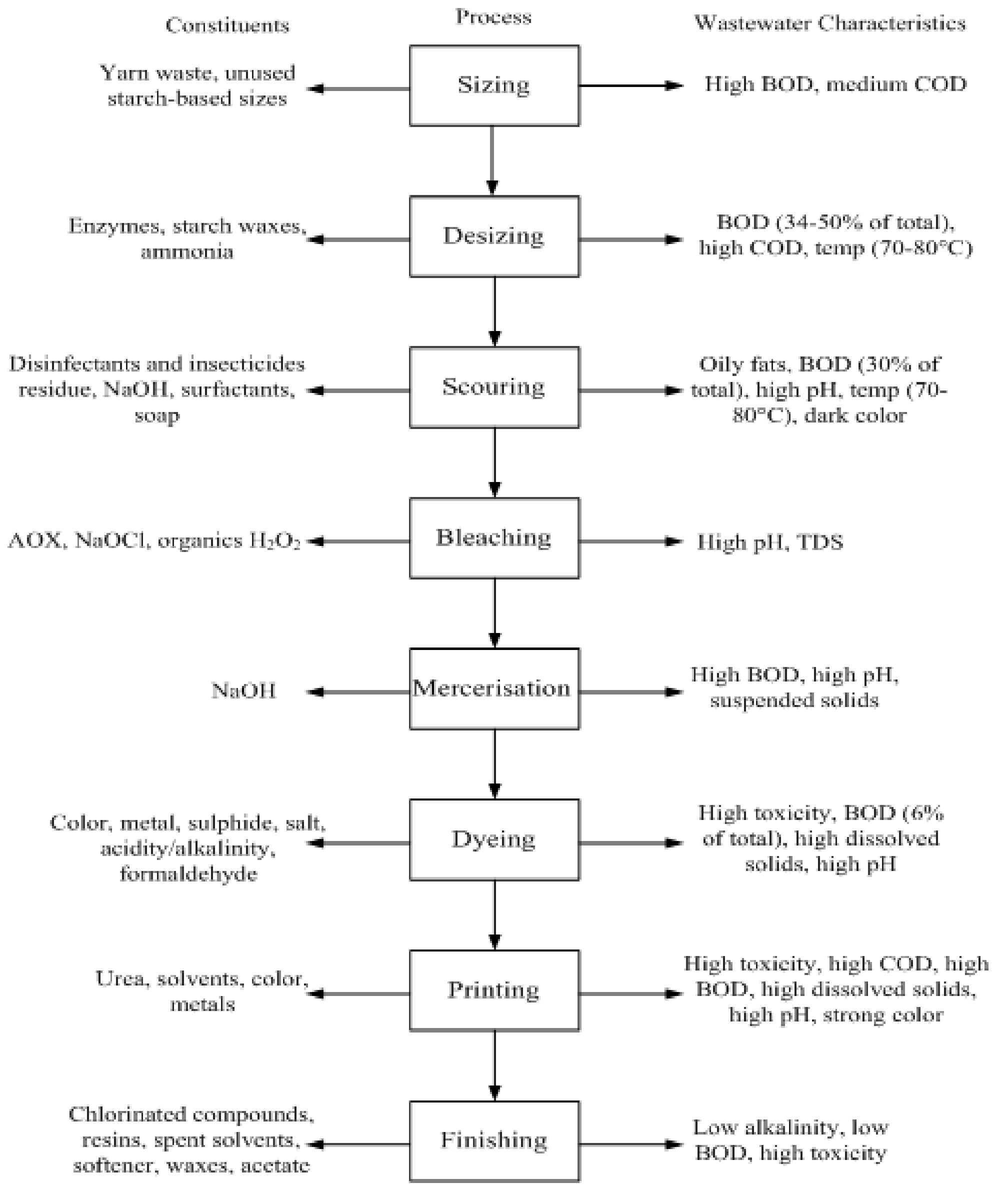


Figure 1: Textile process flow chart with major pollutants

Figure 2 presents a flow diagram of the tanning-process. Hides are a by-product of slaughter activities and can be processed into a wide range of end products. For each end product, the tanning process is different and the kind and amount of waste produced may vary enormously.

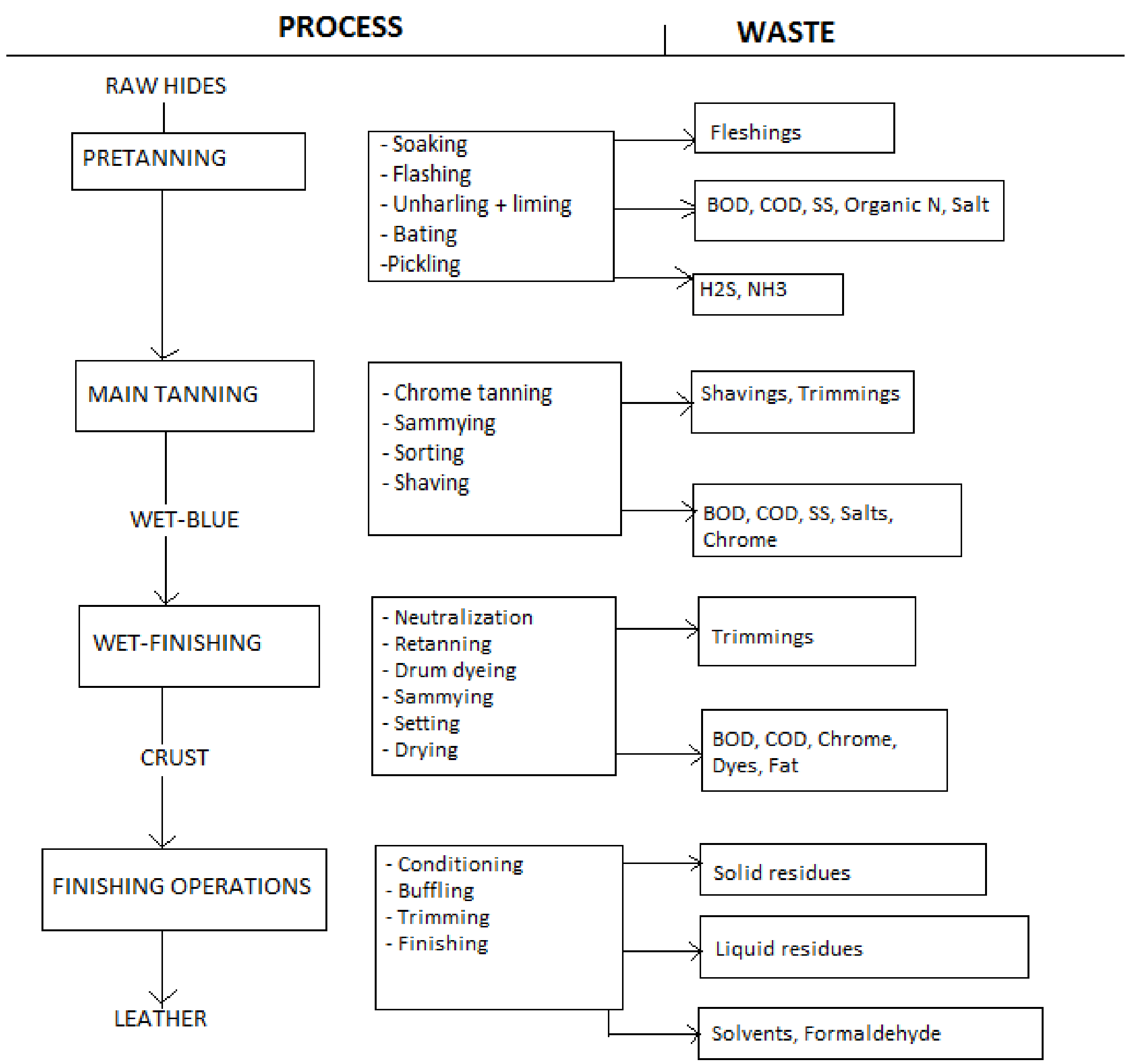


Figure 2: Tannery Process Flow Chart with major pollutants

The typical values of major pollution load of textile and tannery industries and ECR'97 standards and BSR standards for wastewater discharge into an inland surface water body are presented in Table 3.

Table 3: Typical values of major pollution load of textile and tannery industries

Parameter	Knit dyeing industries	Woven dyeing industries	Tannery industries	ECR'97 standards (maximum allowable limit)	BSR standards (maximum allowable limit)
pH	6-11	8-10	7-10	6-9	6-9
Total dissolved solid (TDS)	2000-3000 ppm	5000-6000 ppm	3000-10000 ppm	2100 ppm	-
Total suspended solid (TSS)	50-166 ppm	200-300 ppm	1200-7000 ppm	150 ppm	≤ 30 ppm
Biochemical oxygen demand (BOD)	350-550 ppm	500-600 ppm	500-1000 ppm	50 ppm	≤ 30 ppm
Chemical oxygen demand (COD)	1200-1400 ppm	1500-1750 ppm	1200-3200 ppm	200 ppm	≤ 200 ppm

2.3 Material Balance Approach

A material (or mass) balance approach for contaminants of public health and environmental concern is used to determine the presence, fate and transport of contaminants in the environment. The material balance approach, a fundamental principle of science, engineering, and industrial research and risk analysis, is familiar to professionals trained in the physical or life sciences and engineering. The use of a material balance approach provides a technique to describe the environment as it is today and as it might be under conditions resulting from remedial actions or from changes in the way society produces, uses, and disposes of chemicals of environmental concern. It also provides a rational and fundamental basis for asking specific questions and for obtaining specific information, which is necessary for determining fate and transport of contaminants, selecting and evaluating remedial treatment options, and monitoring treatment effectiveness (Sims, 1990).

The determination or construction of a materials balance is dependent on conservation of materials. Material is not created nor is it destroyed by ordinary processes, but it is transformed. When applied to chemicals of environmental concern, conservation of materials requires that a chemical entering a specific environment must be transformed, held in, or transported out of the environment. The amount of a chemical that leaves any process, environmental compartment, or area must be exactly balanced by the amount that enters minus net accumulation within the process or compartment boundaries. This materials balance can be stated as a simple equation:

Change in mass in a volume = Mass entering a volume - Mass leaving a volume

2.4 Cleaner Production

Cleaner production is defined as the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner production can be applied to the processes used in any industry, to products themselves and to various services provided in society.

For production processes, cleaner production results from one or a combination of the following - conserving raw materials and energy, substituting toxic/hazardous materials by more benign ones and reducing the quantity and toxicity of all emissions and wastes before they leave a production process (Hoque and Clarke, 2013). For products, cleaner production focuses on the reduction of environmental impacts over the entire life cycle of a product, from raw material extraction to the ultimate disposal of the product, by appropriate design. For services, cleaner production entails incorporating environmental concerns into the design and delivery of services (Shi, Peng et al., 2008).

In the last ten years, cleaner production has led to a paradigm shift in environmental management at the level of industries, businesses and financial institutions globally, as well as local Governments and communities. However, there have been a number of barriers to the promotion and adaption of cleaner production.

Many stakeholders have an attitude to follow business as usual and not adapt to change. Any change is considered as unwarranted, risky and not necessarily profitable. There are also cases when the stakeholders are interested in the concept of cleaner production but are unable to put it in practice, due to information gaps and lack of technical assistance.

Again at times, a stakeholder gets interested in cleaner production and has the necessary skills or expertise. However, the stakeholder is unable to communicate the concept and its benefits to the top management. This creates a barrier to implement cleaner production. A significant impediment to the adaption of cleaner production is the emphasis of enterprises on short-term profitability. Since enterprises are judged by markets and investors principally on short term performance, they have difficulties in justifying some of the investment in cleaner production processes and technologies; even when there are demonstrably attractive long-term financial returns. Cleaner production also involves possibilities of process modification, equipment replacement or product/packaging redesign. Some stakeholders view this as risky, especially if the technology is not proven, or the product is not tested in the market (Shi, Peng et al., 2008). Investment in new, cleaner technology is a major decision for enterprises to undertake. In addition to the substantial costs of new technology, there are several potential external barriers, which may discourage or prevent enterprises from updating their existing plant and equipment. These can include the complexity of new technology, the level of technological specificity etc. A lack of orientation in the existing national policy and regulatory framework towards cleaner production is another impediment to the adaption of the cleaner production strategy.

In recent years, to conserve water and to reduce water consumption in RMG production, the Government, funding agencies, international brands and industry managements are considering cleaner production options for textile industries (International Textile Manufacturers Federation, 2014; Partnership for Cleaner Textile, 2017), which include installing dyeing machines of low liquor ratio, reducing process steps, reusing dye liquors, electrolytes and cooling water, counter current washing, good housekeeping, etc (Kar, 2012). In leather sector though cleaner production is yet to be introduced, but the success of cleaner production in textile sector is inspiring the

Government and other stakeholders to introduce it in leather sector also. Some cleaner production options for tannery industries are chrome recovery and chrome liquor recycle, counter current soaking, enzyme assisted soaking, mechanical desalting, ammonia free deliming using carbon dioxide etc. (Suresh, Kanthimathi et al., 2001). Researchers have reported that adaptingimproved technologies and cleaner production options will reduce the KPI to 0.3-0.1 m^3/kg fabric and 10-20 m^3/ton (Suresh, Kanthimathi et al., 2001; Ferdous, 2011). Local industries are slowly adapting cleaner production options. However, additional investment, and lack of technological knowhow and awareness are the key limiting factors of adapting cleaner production options. It is anticipated that existing and new textile dyeing and tannery industries will adapt cleaner production option in the upcoming years, therefore, overall water KPI will reduce every year. For projection with more water efficient technologies, it is assumed that for 2017-2021, water KPI will reduce 5% per year for textile and 5 m^3 per ton in every year for tannery. Reduction of KPI may increase the concentration of pollution load of textile wastewater, which is not considered in this study.

To continue growth in the industrial sectors by addressing growing environmental issues it is important to ensure strict application of environmental regulations, and to introduce new technologies which will be more environmental friendly. One of the most successful inventions in the recent years is the waterless dyeing in the textile industries. In this technology air or compressed and pressurized CO_2 is used as dyeing medium instead of water. As a result, the amount of water use can be cut drastically near to zero. However, at present the waterless dyeing machines are expensive and industry owners are hesitant to install this modern technology. Also, till now these technologies are cloth specific and they can only be used for polyester, not cotton. Similarly, several researches are ongoing to introduce waterless chrome tanning technology in the industry scale. In future, if these kinds of technologies become more advanced and less expensive, they will be highly useful to reduce effluent volume and pollution loads.

3. Methodology

3.1 General Methodology

In the first step of this study wastewater characterization was done to determine the pollution load of different effluents. Based on the product price and weight, production volume was calculated from the export data and a projection on production trend was made. Finally, pollution load associated with the production was calculated for both the conventional technology and improved technology.

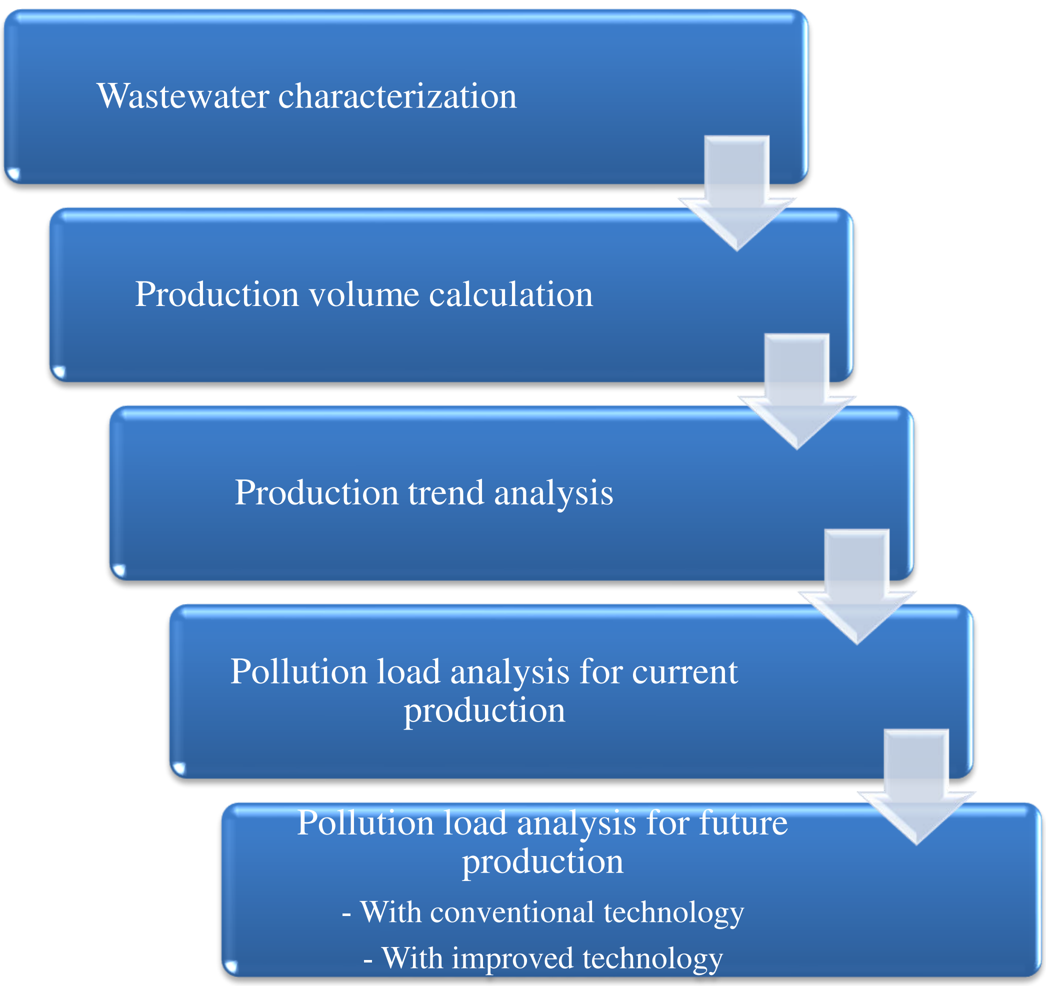


Figure 3: Overall flow diagram of the methodology

3.2 Wastewater Sampling and Characterization

Wastewater samples were collected from the outlet of the process of 12 different textile and tannery industries (4 knit dyeing, 3 woven dyeing, 2 denim dyeing and 3 tannery industries) situated in Savar, Narayanganj and Gazipur. Each of these samples was tested 3 times in the Environmental Laboratory of Chemical Engineering Department, BUET. Additionally, wastewater characterization data for 6 samples from the previous experimental database of BRTC, Department of Chemical Engineering, BUET were also analyzed for the authenticity of the parameter load. Typical pollution parameters of the textile and tannery industries are suspended solids, BOD, COD, nitrogen, phosphate, temperature, toxic chemicals (phenol), chromium and other heavy metals, pH-value, alkalinity and acidity, oils and grease, sulphide, and coliform bacteria. Textile and tannery effluents are high in BOD compared to other pollution parameters due to the presence of fibre residues, hairs and suspended solids (Dey and Islam, 2015). Considering the higher water pollution impact, pollution load was calculated for only four major parameters (TDS, TSS, BOD, and COD).

TDS was measured by a digital water quality analyzer. TSS was measured gravimetrically following standard methods (APHA 1998). BOD was measured by BOD_5day test (APHA-AWWA-WPCF, 1989) and COD was measured by titrimetric method, (75 mL of conc. H_2SO_4 was added to25 mL of 0.25N $K_2Cr_2O_7$solutions then reflux it for two hours. The excess dichromate was then titrated with 0.25N ferrous ammonium sulphate solution using phenanthrolineferroussulphate indicator) (Mendham 2006; Rouf, Islam et al., 2013). The average of the test results is presented in Table 4 with standard deviations.

Table 4: Test result for knit dyeing, woven dyeing and tannery effluent characteristics

Parameters	Knit dyeing effluent, ppm (Average ± Standard Deviation)	Woven dyeing effluent, ppm (Average ± Standard Deviation)	Tannery effluent, ppm (Average ± Standard Deviation)
TDS	2700 ± 75	5560 ± 570	3480 ± 295
TSS	160 ± 10	320 ± 55	1675 ± 130
BOD	460 ± 25	535 ± 50	550 ± 60
COD	1370 ± 90	1630 ± 140	1690 ± 80

The values considered for the pollution load calculation is presented in Table 8 and Table 9. These effluents have wide range of characteristics and the parameters can vary a lot depending upon the process and chemicals used.

3.3 Key Performance Indicator (KPI) Analysis

In this study, the yearly total wastewater volume has been calculated since proper data tracking system is not available. Generally, all the water used in the process is drained in the effluent line and goes to the effluent treatment plant (ETP). So, to calculate the wastewater volume, it was necessary to analyze how much water is consumed in the dyeing and tanning process.

Water consumption and production data was collected from nine textile industries situated in different zones of Bangladesh. These industries have water flow meter installed in the productions floors and water consumption is being tracked regularly. Total six months' data has been collected from these factories and using the average of those data KPI has been calculated. This analysis is presented in the below Table 5:

Table 5: Water KPI analysis for textile industries

Factory	Average production (ton/month)	Average production water consumption (m^3/month)	KPI (Litre/kg)
Factory A (BSCIC, Narayanganj)	425	29,325	69
FactoryB (Ashulia, Dhaka)	190	20,800	110
Factory C (Fatullah, Narayanganj)	510	63,750	125
Factory D (Sonargaon, Narayanganj)	320	42,880	134
Factory E (BSCIC,Tongi)	270	36,450	135
Factory F (Maona, Gazipur)	335	45,895	137
Factory G (Bhulta, Narayanganj)	265	37,100	140
Factory H (Kashimpur, Gazipur)	750	106,500	142
Factory I (Kashimpur, Gazipur)	240	35,280	147

Taking the average of these KPI data and considering the practical scenario, the KPI considered for this study is 120 Litre/kg.

Again, for the leather sector, the tanneries do not have any metering system. Thus, the water KPI analysis could not be conducted in the similar way. In this study, water KPI for tannery was used from a previous study and the amount is 40 m^3/ ton of wet slated hide (ARUP, 2016).

3.4 Production Volume Calculation

To calculate the wastewater volume, the total weight based production data need to be measured. Export value has been collected and then converted using necessary production specification data.

Export data for different types of RMG products are collected from BGMEA database (Bangladesh Garment Manufacturers and Exporters Association, 2017). To convert these data into weight based production, two information need to be analyzed; product price per piece and product weight per piece. Different types of garments products have been collected and their weight and export price per piece has been analyzed which is presented in Table 6.

Table 6: Textile product price and weight analysis

Product Type	Price per piece (USD)	Weight per piece (gm)
Shirt	3.5 – 5	200 – 300
T-shirt	3 – 5	200 – 300
Hoodies & Sweatshirt	6 – 8	400 – 500
Sweater	4 – 5	350 – 500
Denim	6 – 8	400 – 500
Pant	5 – 8	250 – 300
Blouses and other basic women wear	5 - 6	200 - 400

Considering the high volume of shirt, T-shirt, pant and sweater production in the Bangladesh market, the average price and the average weight considered for this study is 5 USD and 300 gram respectively.

For leather sector, the similar approach cannot be applied because of the variety of product and their price range. Yearly hide production volume data has been collected from LFMEAB (Leathergoods & Footwear Manufacturer and Exporters Association). Table 7 represents the data which has been collected from the tannery industries to analyze the weight of hide per square feet. The average weight considered per square feet of hide is 1 kg.

Table 7: Weight analysis of different types of hides

Hide category	Average weight (kg/piece)	Average area (Sq. feet/piece)
Bovine (cow)	15 – 18	18 – 20
Bovine (buffalo)	25 – 27	27 – 30
Ovine and caprine (Sheep and goat)	2 - 3	2 – 4

3.5 Textile Sector: Material Balance Approach

The ready-made garments (RMG) manufactured in Bangladesh can be broadly classified into two categories: woven products and knitted products. Woven product includes Shirts, Pants and Trousers. On the other hand, knitted product includes T-Shirts, Polo Shirts, Undergarments, Socks, Stockings and Sweaters (Murad Fabrication, 2016).

To calculate wastewater impacts of textile industries, a material balance approach is applied which considers production data of RMG industries, production growth rate, and water key performance indicator (KPI). For pollution load calculation, four key parameters: total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD; 5 day) and chemical oxygen demand (COD) are taken into account.

Effluent characteristics presented in Table 8are used to calculate present and future pollution load (Department of Environment 2008; Khan, Selim et al., 2011).

The following procedure was used for textile wastewater and pollution load calculation:

P = Price of the product (USD/piece)

W = Weight of the product (kg/piece)

E = Total export value (USD/year)

Pr = Total production (kg/year)

= (E x W)/ P

Wastewater volume, V (m3/year) = Pr x KPI

BOD_5 (ton/year) = Pr x KPI x BOD_5

COD (ton/year) = Pr x KPI x COD

TDS (ton/year) = Pr x KPI x TDS

TSS (ton/year) = Pr x KPI x TSS

Table 8: Textile pollution load and considerations to calculate wastewater output

Type of industry	TSS (ppm)	TDS (ppm)	BOD (ppm)	COD (ppm)
Knit dyeing	150	2700	450	1366
Woven dyeing	300	5600	550	1600

3.6 Leather Sector: Material Balance Approach

The leather sector in Bangladesh includes 200 tanneries, 3500 MSMEs (Micro, Small & Medium Enterprises), 2500 footwear making units and 90 large firms. The effluent is mainly produced from the tanneries(LFMEAB, 2016). Material balance approach was used to calculate the volume and pollution load impacts. Similar to the textile sector pollution load calculation, for leather sector also four key parameters (TDS, TSS, BOD_5, COD) are considered for calculation.

The calculation procedure used for the leather wastewater and pollution load using the effluent characteristics presented in Table 9 is mentioned below:

P = Total production (million square feet/year)

W = Weight of the salted hide (kg/square feet)

Pr = Total production (kg/year)

= P x W

Wastewater volume, V (m^3/year) = Pr x KPI

BOD5 (ton/year) = Pr x KPI x BOD_5

COD (ton/year) = Pr x KPI x COD

TDS (ton/year) = Pr x KPI x TDS

TSS (ton/year) = Pr x KPI x TSS

Table 9: Tannery pollution load and considerations to calculate wastewater output

Type of industry	TSS (ppm)	TDS (ppm)	BOD (ppm)	COD (ppm)
Tannery	1650	3450	540	1450

Figure4 represents the material balance flow chart used in this study:

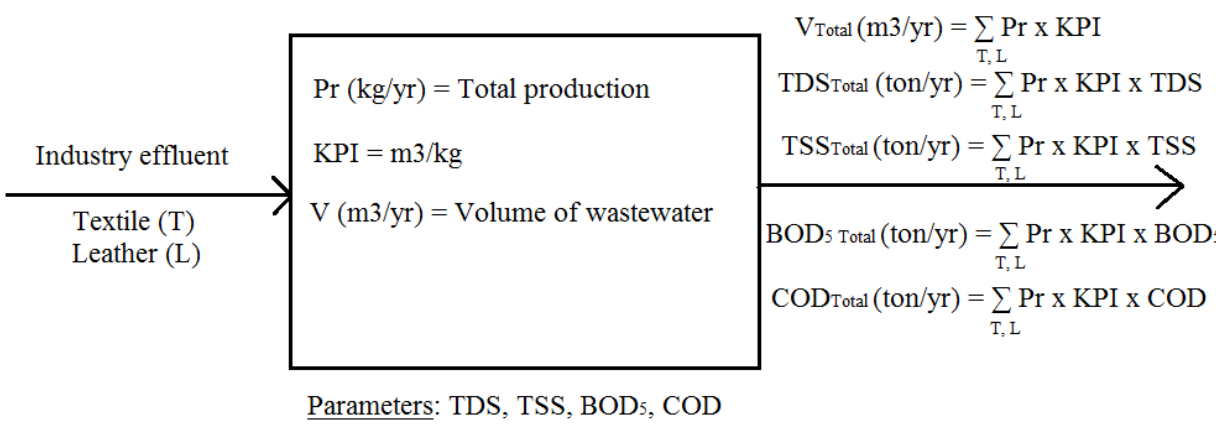
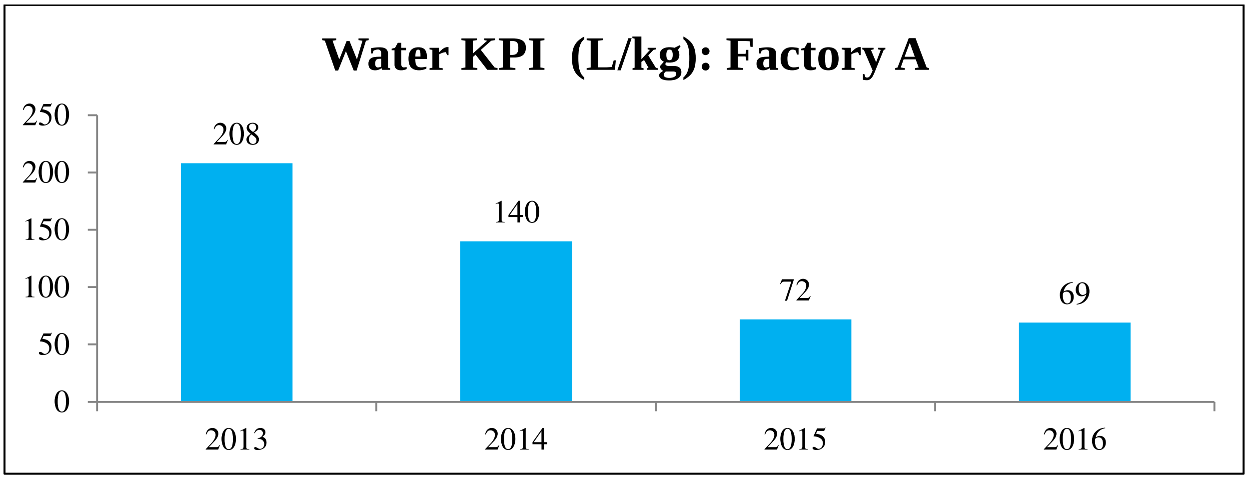


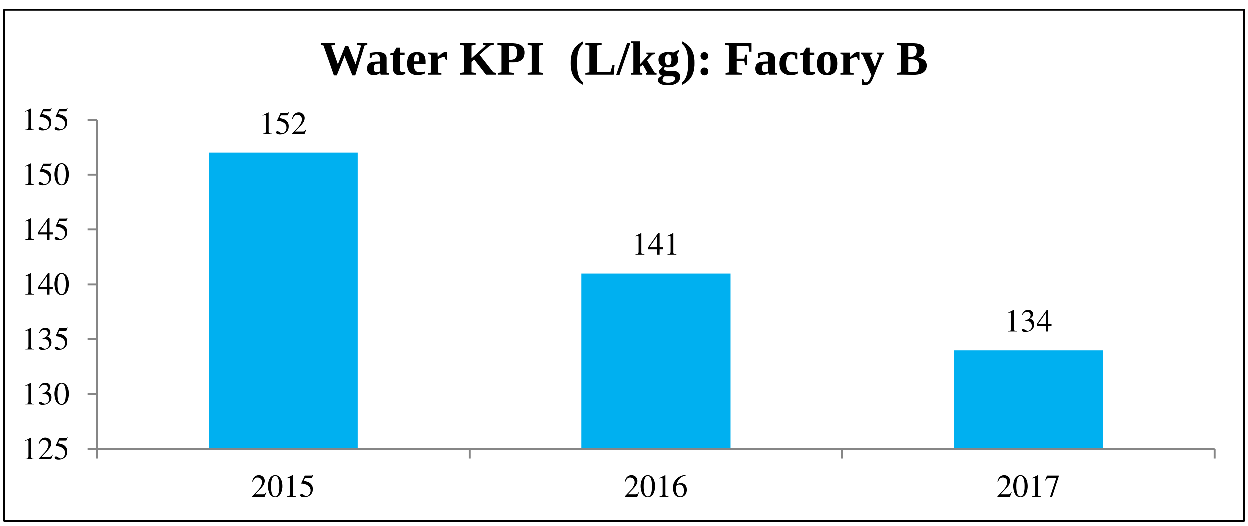
Figure 4: Material balance flow chart to calculate the textile and tannery wastewater volume and pollution load

3.7 Key Performance Indicator (KPI) Analysis with Cleaner Production

Since implementation of cleaner production options has reduced water consumption in many textile factories of Bangladesh, it is anticipated that in the upcoming years the average KPI will reduce more. In this research, two textile factories have been studied where cleaner production options have been implemented in the last few years. The analysis is shown in Figure 5:



(a)



(b)

Figure 5: KPI reduction with CP implementation (a) Factory A (b) Factory B

It can be seen that, for “Factory A” the KPI has reduced by 67% over the last 4 years (Figure 5a) and for “Factory B” over 3 years timeframe the KPI has reduced by 12% (Figure 5b). Most of the factories in Bangladesh still consume very high amount of water in their dyeing process. Currently cleaner production is getting a well-known concept among the industry management and gradually all factories are planning to implement it. Analyzing the KPI of the two factories studied and considering the practical scenario, it is estimated that in the next 5 years KPI reduction for textile industries with cleaner production will be yearly 5%.

In the leather sector cleaner production has not been yet implemented in the tanneries of Bangladesh. However, international buyers and development organizations along with the industry management are planning to introduce it gradually. In the more advanced tanning processes, the water KPI used is nearly 20 m^3 per ton of hide while for Bangladesh currently it is 40 m^3 per ton of hide. It is estimated that by implementing more water efficient technologies in the next 5 years, the KPI will reduce 5 m^3 per ton of hide in every year.

4. Results and Discussion

4.1 Textile industries: Present and projected wastewater volume and pollution load

Table 10 presents trend analysis of textile production from 2011 to 2021, and corresponding wastewater volume produced by textile dyeing. For textile production analysis from 2011 to 2016, available production data of textile industries from 2011-2016 are considered (Bangladesh Garment Manufacturers and Exporters Association, 2017); 10% annual growth is considered to project textile production from 2017 to 2021. To calculate corresponding wastewater volume produced by textile dyeing industries, KPI is considered 120 L/kg fabric for conventional dyeing technology.

In a more optimistic scenario, it is anticipated that textile industries will gradually adapt developed and more water efficient dyeing technologies, which will reduce generation of wastewater volume and corresponding pollution loads; gradual adaptation of improved technology and cleaner production options is considered to reduce KPI 5% per year from 2017(Table 10).

Table 10: Trend analysis of textile production (from 2011 to 2021) and wastewater volume

Year	Production (million kg)		Water KPI (m^3/kg)		Wastewater volumein conventional practice(million cubic meter)		Wastewater volume in improved practice (million cubic meter)	
	Knit	Woven	Conventional practice	Improved practice	Knit	Woven	Knit	Woven
2011	628	583	0.120	--	75	70	-	-
2012	609	637	0.120	--	73	76	-	-
2013	721	759	0.120	--	87	91	-	-
2014	766	783	0.120	--	92	94	-	-
2015	806	870	0.120	--	97	104	-	-
2016	865	941	0.120	-	104	113	-	-
2017	952	1035	0.120	0.114	114	124	109	118
2018	1047	1138	0.120	0.108	126	137	113	123
2019	1152	1252	0.120	0.103	138	150	119	129
2020	1267	1377	0.120	0.098	152	165	124	135
2021	1394	1515	0.120	0.093	167	182	129	141

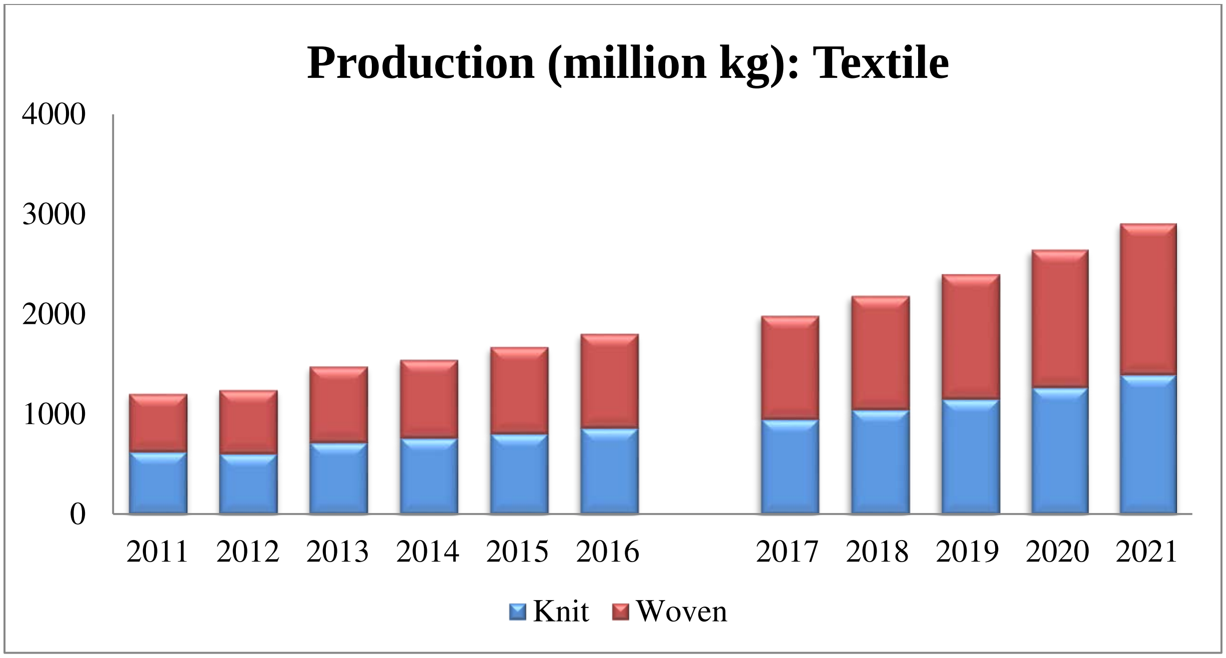


Figure 6: Trend analysis of annual textile production in Bangladesh (2011-2021).

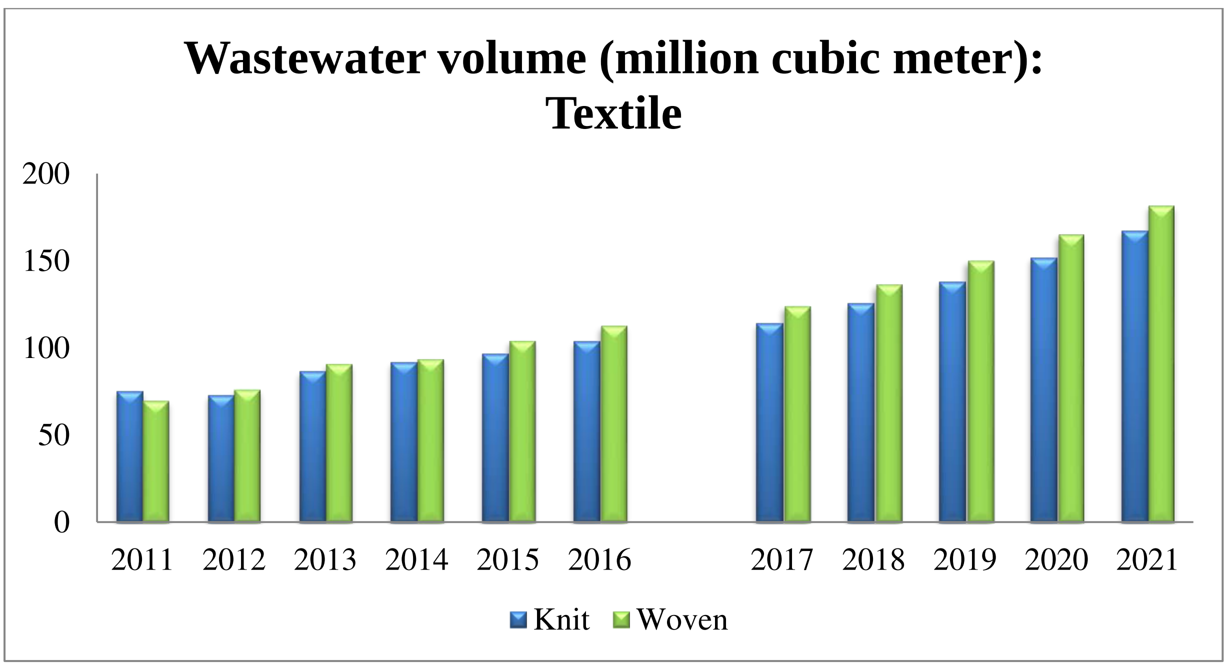


Figure 7: Yearly wastewater volume produced by textile industries using conventional dyeing technology.

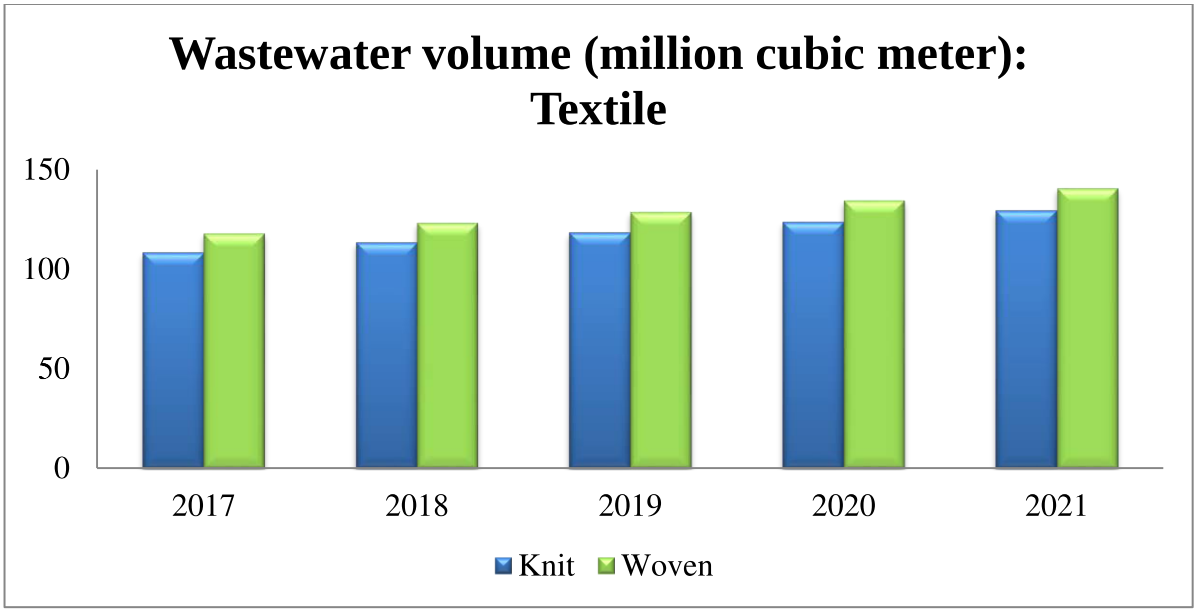


Figure 8: Projected wastewater volume generated by textile dyeing industries for improved KPI (year 2017-2021);

Figures 6, 7 and 8 give graphical representation of trend analysis (2011-2021) of textile production in Bangladesh and corresponding wastewater production. Table 10and Figure 6show that by 2021 the total production will be around 2.9 million metric tons of fabrics, which is about 1.61 times of the fabric produced in 2016. This huge production will generate about 349 million m^3 wastewater (2021) (Table 10 and Figure 7) for conventional KPI (120 L/kg fabric). From linear interpolation, it can be considered that in 2021 effluent volume and pollution load generated by textile dyeing industries would be 1.61 times higher than those of in 2016.

Adaptation of improved technologies and cleaner production option will improve KPI and reduce wastewater generation (Table 10and Figure 8). In 2021, the KPI is expected to be reduced to 0.093 m^3/kg fabric (Table 10); therefore, effluent production caused by textile dyeing industries will be reduced to 270 million m^3 which is 22.6% less than the effluent volume for conventional

KPI. Considering the linear relationship, adaptation of improved technologies is expected to reduce pollution load by 22.6% by 2021.

Pollution loads of 2011-2021 corresponding to textile dying industries (Tables 11-13, Figures 9-10) were calculated considering wastewater characteristics presented in Table 8. Table 11 presents pollution load for knit and woven dyeing industries for 2011-2016. Tables 12 and 13present projected future pollution load data for knit and woven dyeing industries, respectively. Figures 9 and 10 present the annual pollution loads generated by textile dyeing industries following conventional dyeing practice and improved practice, respectively.

Table 11: Pollution load analysis for both knit and woven dyeing industries for 2011-2016.

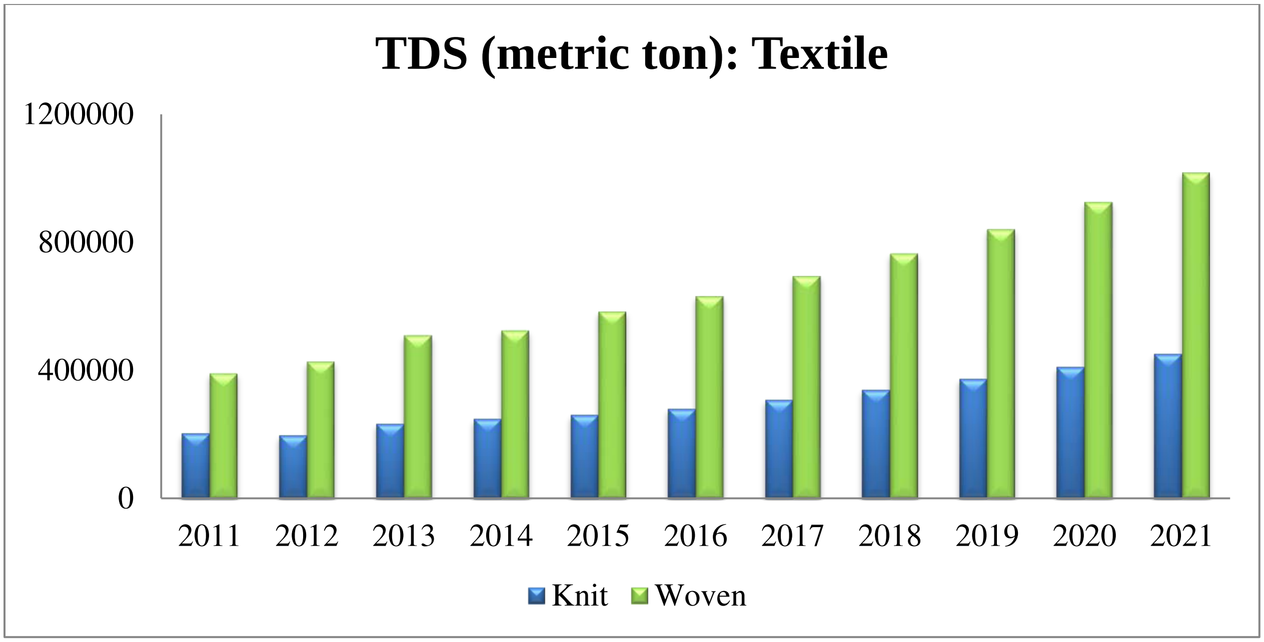
Year	Knit dyeing industries (metric ton)				Woven dyeing industries (metric ton)			
	TDS	TSS	BOD	COD	TDS	TSS	BOD	COD
2011	203,338	11,297	33,890	102,874	391,727	20,985	38,473	111,922
2012	197,399	10,967	32,900	99,869	428,332	22,946	42,068	122,380
2013	233,690	12,983	38,948	118,230	510,246	27,335	50,113	145,785
2014	248,265	13,793	41,378	125,604	525,866	28,171	51,648	150,248
2015	261,218	14,512	43,536	132,157	584,467	31,311	57,403	166,991
2016	280,399	15,578	46,733	141,861	632,133	33,864	62,084	180,609

Table 12: Future pollution load analysis for knit dyeing industries (2017-2021).

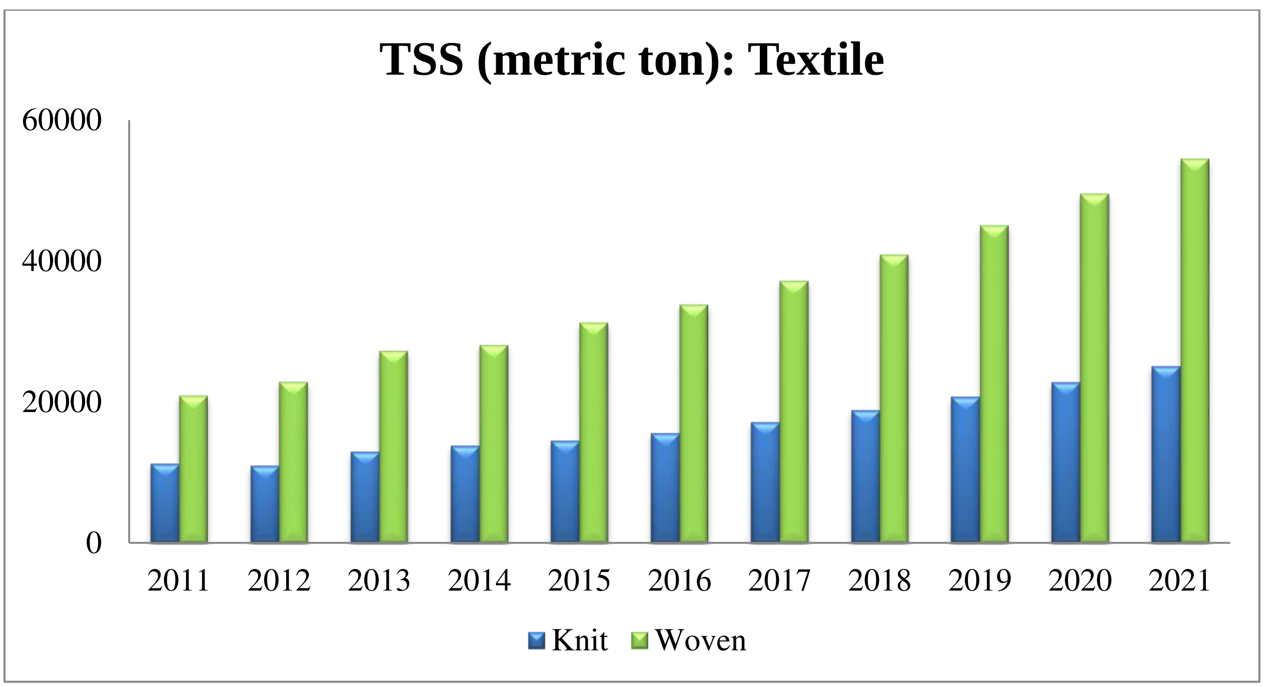
Year	Knit dyeing industries in conventional practice (metric ton)				Knit dyeing industries in improved practice (metric ton)			
	TDS	TSS	BOD	COD	TDS	TSS	BOD	COD
2017	308,438	17,135	51,406	156,047	293,017	16,279	48,836	148,245
2018	339,282	18,849	56,547	171,651	306,202	17,011	51,034	154,916
2019	373,211	20,734	62,202	188,817	319,981	17,777	53,330	161,887
2020	410,532	22,807	68,422	207,699	334,381	18,577	55,730	169,172
2021	451,585	25,088	75,264	228,469	349,428	19,413	58,238	176,785

Table 13: Future pollution load analysis for woven dyeing industries (2017-2021).

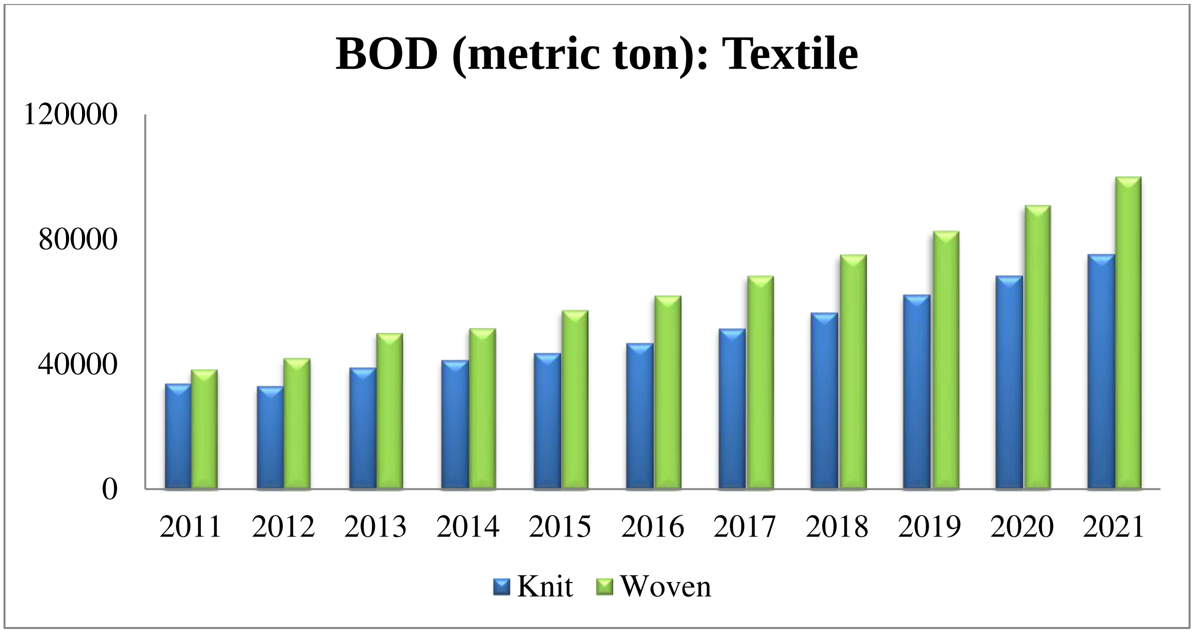
Year	Woven dyeing industries in conventional practice (metric ton)				Woven dyeing industries in improved practice (metric ton)			
	TDS	TSS	BOD	COD	TDS	TSS	BOD	COD
2017	695,346	37,251	68,293	198,670	660,579	35,388	64,878	188,736
2018	764,881	40,976	75,122	218,537	690,305	36,981	67,798	197,230
2019	841,369	45,073	82,634	240,391	721,369	38,644	70,849	206,105
2020	925,506	49,581	90,898	264,430	753,830	40,383	74,037	215,380
2021	1,018,056	54,539	99,988	290,873	787,752	42,201	77,369	225,072


TDS (metric ton): Textile
1200000
800000
400000
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Knit
Woven

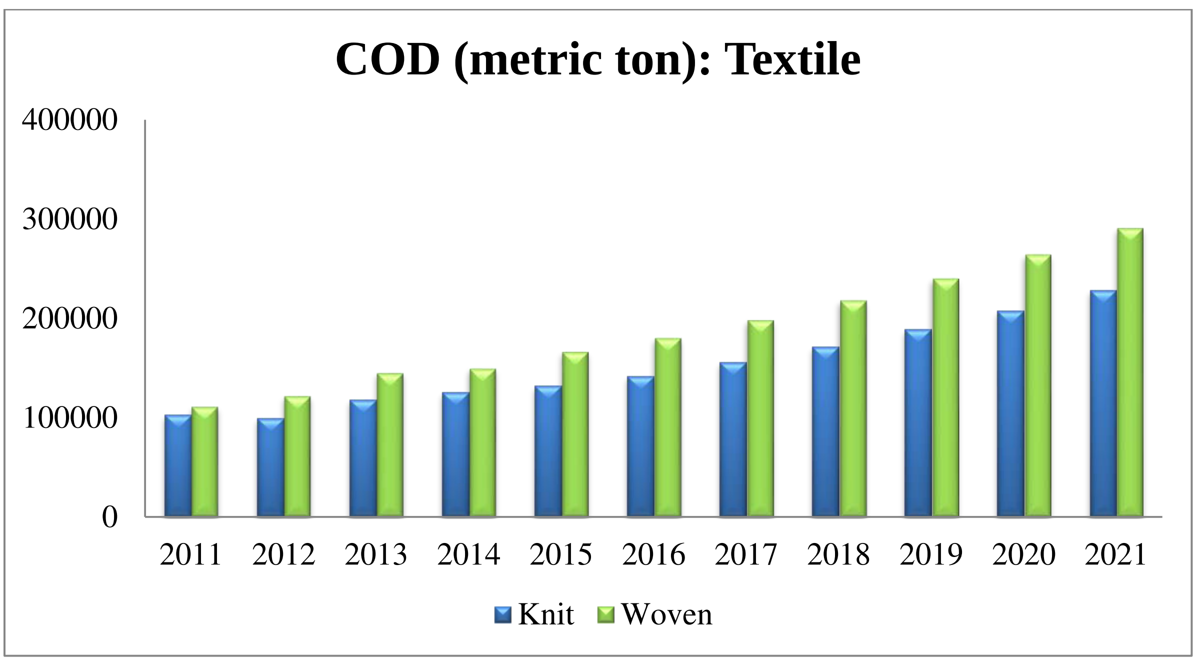
(a)


TSS (metric ton): Textile
60000
40000
20000
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Knit
Woven

(b)

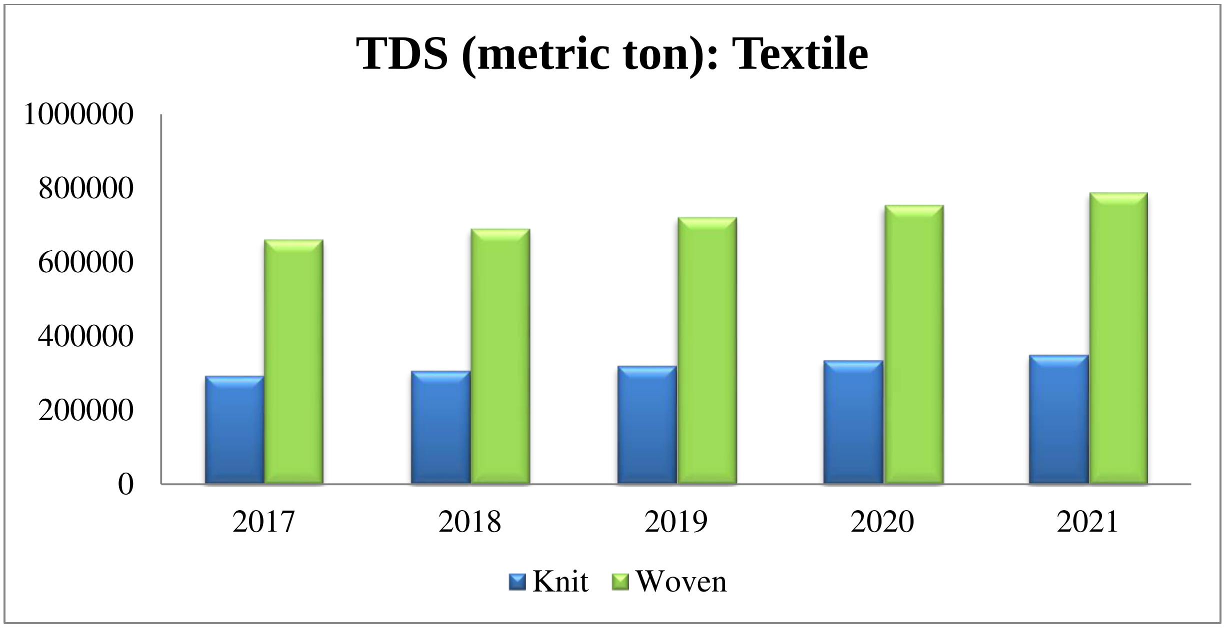


(c)

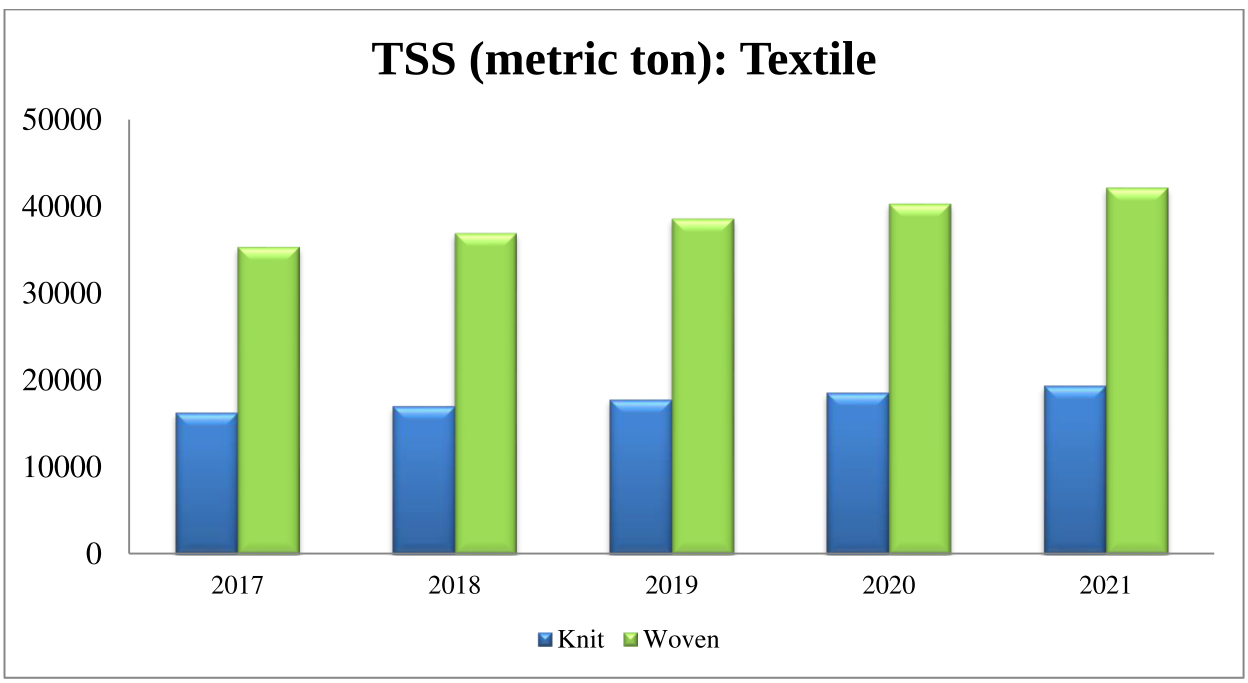


(d)

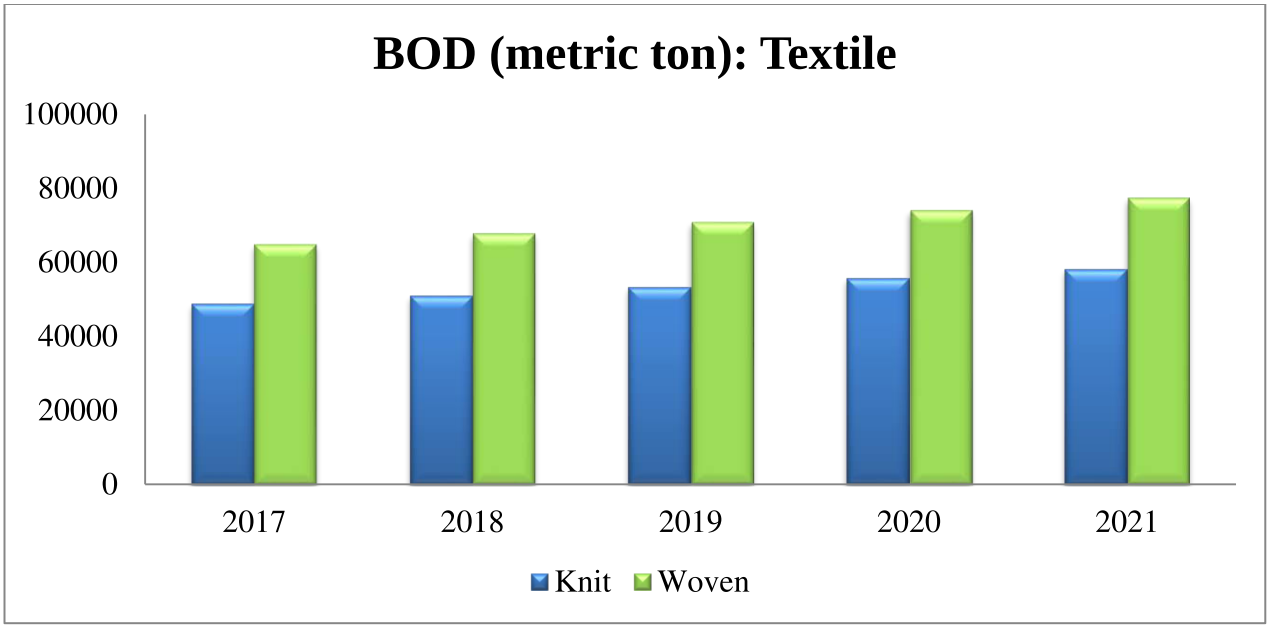
Figure 9: Annual pollution loads caused by textile industries following conventional practice; (a) TDS, (b) TSS, (c) BOD, (d) COD.


TDS (metric ton): Textile
1000000
800000
600000
400000
200000
0
2017
2018
2019
2020
2021
Knit
Woven

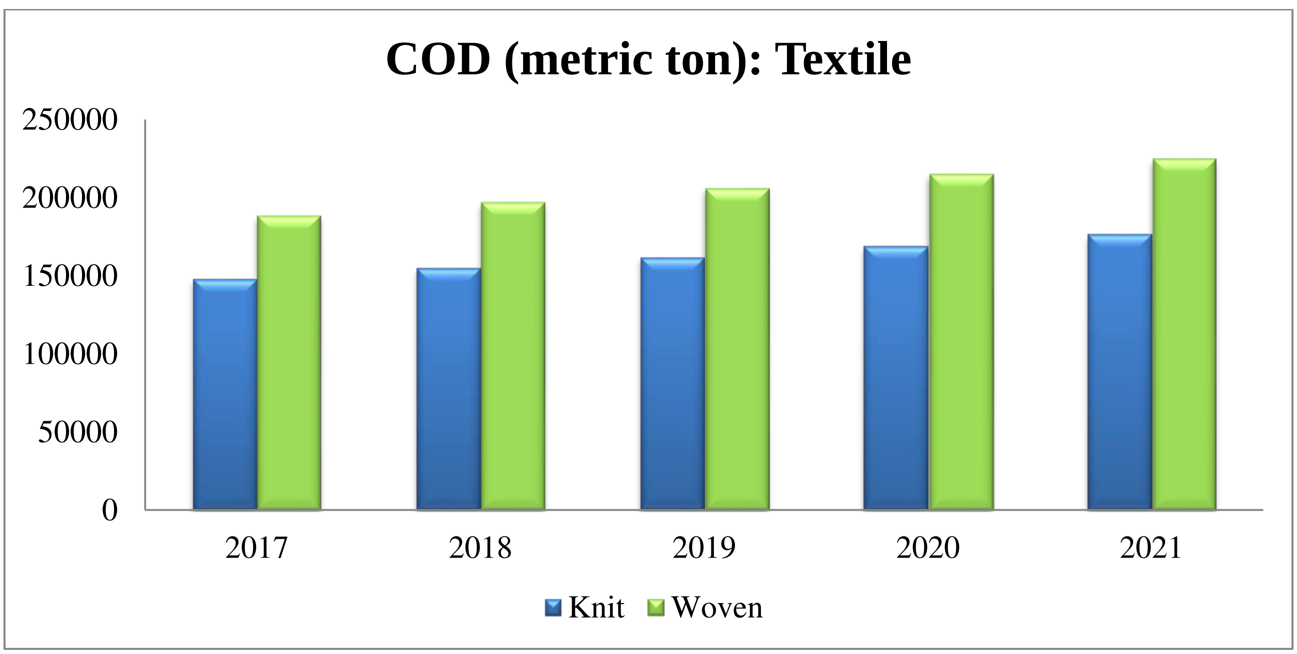
(a)


TSS (metric ton): Textile
50000
40000
30000
20000
10000
0
2017
2018
2019
2020
2021
Knit
Woven

(b)



(c)



(d)

Figure 10: Annual pollution loads caused by textile industries adapting improved practice; (a) TDS, (b) TSS, (c) BOD, (d) COD.

Total Dissolved Solids (TDS) in textile dyeing effluent contains various salts like chloride, phosphates, carbonates, bicarbonates and nitrates of calcium, organic matter, sodium, potassium, magnesium and manganese, and other particles (Vaishali and Punita, 2013). Water having higher TDS is unpalatable and potentially harmful for health and environment (Hussain and Rao, 2013). In 2016, the calculated TDS produced by knit and woven dyeing effluent were 280,399 metric ton and 632,133 metric ton, respectively (Figure 9a, Table 11). It is projected that in 2021,TDS for knit and woven dyeing effluent will be 451,585 metric ton and 1,018,056 metric ton (Figures 9a, Tables 12,13), respectively for conventional technology. It is expected that with improved KPI, TDS for knit and woven dyeing effluent will be reduced to 349,428 metric ton and 787,752 metric ton (Figure 10a, Tables 12-13), respectively.

Total suspended solids (TSS) of textile effluent include various types of material suspended on the water. Suspended solids can lead to sludge deposits and anaerobic condition when untreated wastewater is discharged in the aquatic environment. In 2016, TSS produced by knit and woven dyeing effluent was 49,442 metric ton (Figure 9b, Table 11), whereas, in 2021, the values will be 79,627 metric ton for existing KPI (Figure 9b, Tables 12-13), and 61,614 metric ton for improved KPI (Figure 10b, Tables 12-13), respectively.

Biochemical Oxygen Demand (BOD) is a measurement of the amount of dissolved oxygen (DO) that is used by aerobic microorganisms when decomposing organic matter in water. It is an important water quality parameter since it provides a biological index to assess the effect of discharge water on the environment. Higher BOD value causes depletion of dissolve oxygen in aquatic life. In 2016, BOD produced by knit and woven dyeing effluent was 108,817 metric ton (Figure 9c, Table 11), whereas, in 2021, the values will be 175,252 metric ton for existing KPI

(Figure 9c, Tables 12-13), and 135,607 metric ton for improved KPI (Figure 10c, Tables 12-13), respectively.

Chemical oxygen demand (COD) is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals, such as ammonia and nitrite. It is also a measure of water and wastewater quality. In 2016, COD value for knit and woven dyeing industries was 322,470metric ton (Figure 9d, Table 11), whereas, for 2021, the values will be 519,342 metric ton existing KPI (Figure 9d, Table 12-13) and 401,857 metric ton with improved KPI (Figure 10d, Tables 12-13), respectively.

4.2 Leather industries: Present and projected wastewater volume and pollution load

Leather production data analysis has been presented in Table 14. In the last 5 years the annual average production growth rate is observed as 20%(LFMEAB, 2016). As the government has set a target of 5 billion USD export value from leather industry by 2021, the production growth rate has to be increased by a large scale which is nearly 35% in every year. Since this sector is in a transition phase because of the relocation of the tannery industries from Hazaribagh to Savar, the production has been projected for both annual growth rate of 20% and 35%. Since the conventional and high water consuming tanning process is the common scenario in Bangladesh, KPI considered for calculating corresponding wastewater volume produced by tannery industries is 40 m^3 per ton of wet salted hides.

In the more developed and water efficient tanning process, the water KPI is nearly 20-25 m^3/ton of wet salted hides. It is anticipated that tannery industries in Bangladesh will also gradually adapt the water efficient technologies in the upcoming years, which will reduce generation of wastewater volume and corresponding pollution loads. In this study, it is considered that KPI will reduce 5 m^3 per ton in every year in the tannery industries of Bangladesh.

Table 14: Trend analysis of leather production and wastewater volume

Year	Production (million kg)		Water KPI (m^3/ton)		Wastewater volumein conventional practice(million cubic meter)		Wastewater volume in improved practice (million cubic meter)	
	20% annual growth rate	35% annual growth rate	Conventional practice	Improved practice	20% annual growth rate	35% annual growth rate	20% annual growth rate	35% annual growth rate
2011	84	-	40	-	3	-	-	-
2012	167	-	40	-	7	-	-	-
2013	232	-	40	-	9	-	-	-
2014	272	-	40	-	11	-	-	-
2015	274	-	40	-	11	-	-	-
2016	300	-	40	-	12	-	-	-
2017	360	405	40	-	14	16	14	16
2018	432	547	40	35	17	22	15	19
2019	518	738	40	30	21	30	16	22
2020	622	996	40	20	25	40	16	25
2021	746	1345	40	25	30	54	15	27

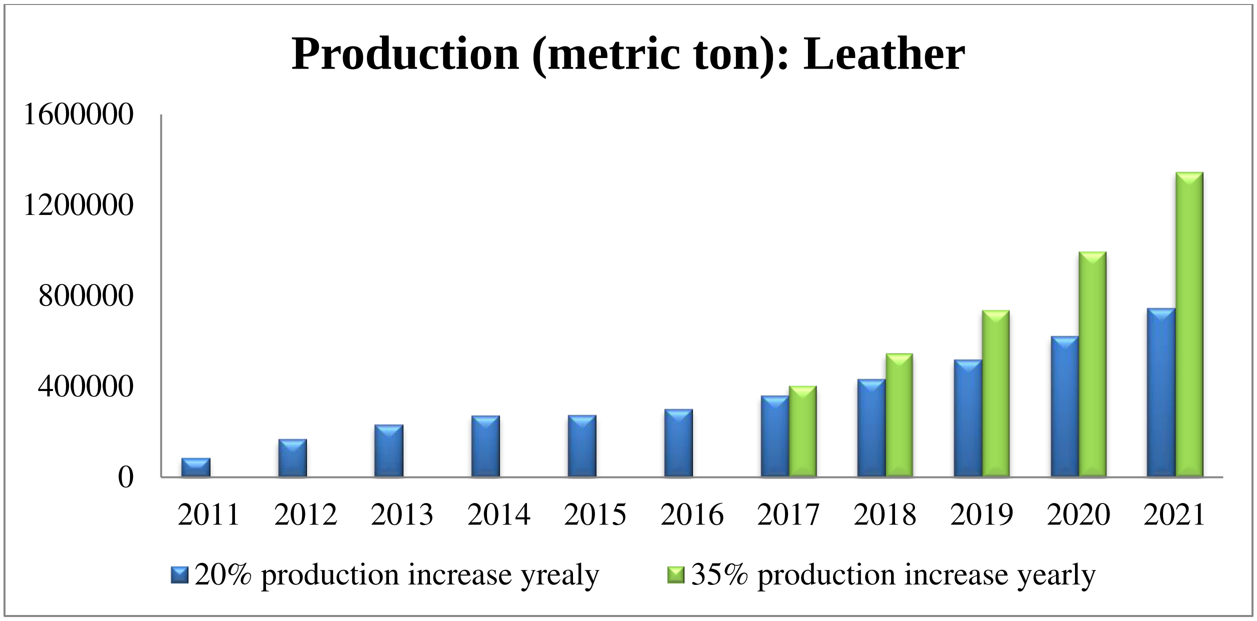


Figure 11: Trend analysis of annual leather production in Bangladesh (2011-2021).

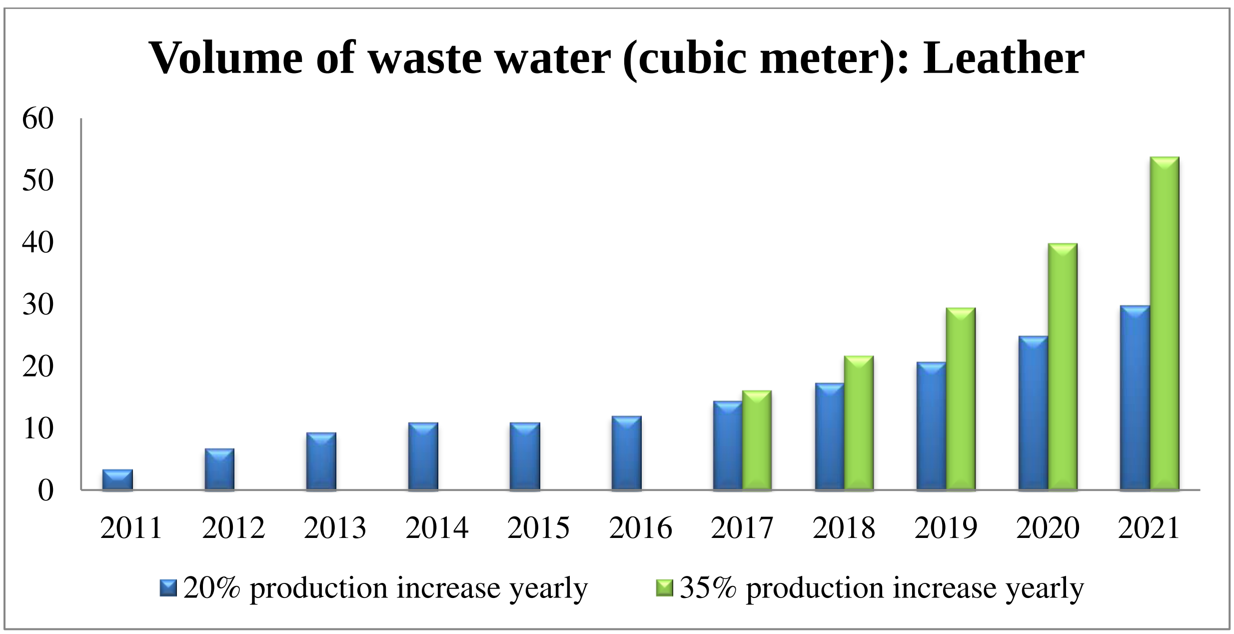


Figure 12: Yearly wastewater volume produced by tannery industries using conventional tanning technology

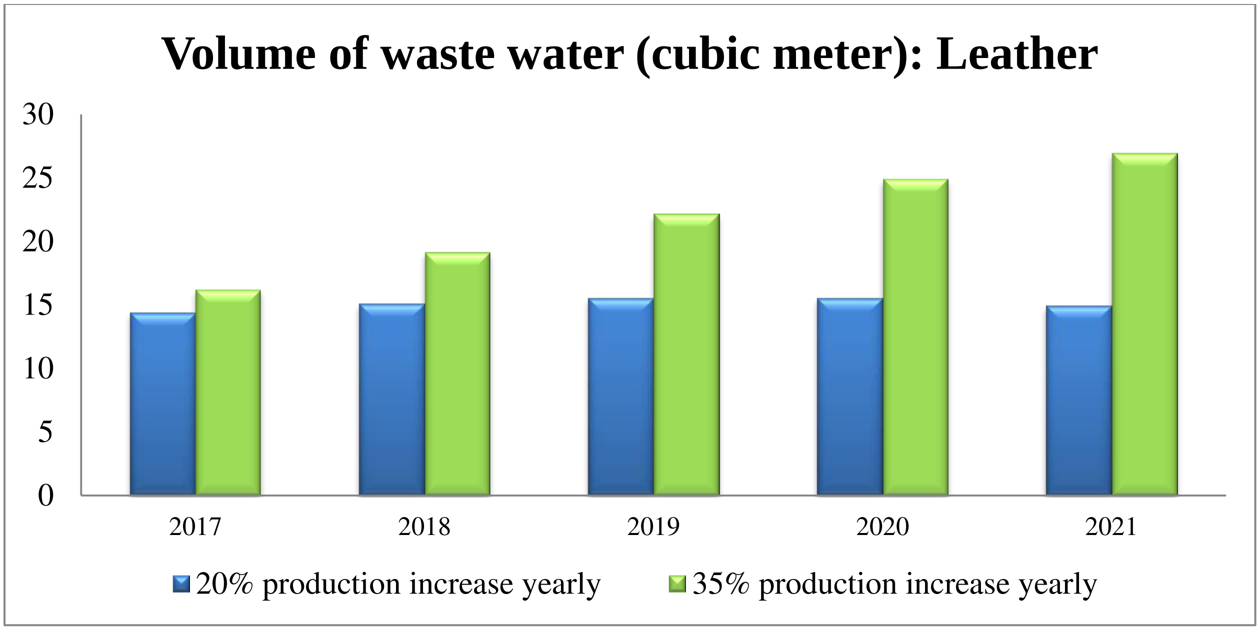


Figure 13: Projected wastewater volume generated by tannery industries for improved KPI (year 2017-2021)

The above figures give graphical representation of the leather production and volume of wastewater generation associated with it. If the annual production growth rate remains the same as now in the next 5 years, which is 20%, then the total production by 2021 will be 746,496 ton of leather. This production will generate about 30 million m^3 wastewater for conventional tanning process (40 m^3/ton). Again, if the annual growth rate increases to 35%, then the total production at 2021 will be 1,345,210 metric ton of leather (Table 14). This will generate about 54 million m^3 wastewater for conventional tanning process. This volume is 1.8 times higher than the wastewater volume of 2016.

Implementation of cleaner production options and developed water efficient technologies will improve the KPI. As a result the wastewater generation in 2021 will be reduced to 15 million m^3 for 20% production growth rate and 37 million m^3 for 35% production growth rate which is 50%

less than the volume of wastewater with conventional technology. The liner interpolations shows that the pollution loads will also be reduced by 50% by 2021 if the developed technologies are adapted.

Table 15-17 represent the pollution loads of tannery industries (2011-2021) which were calculated using the effluent parameters presented in Table 9. Pollution loads projection from 2017 to 2021 was also calculated for both conventional and improved technology which is presented in Table 16 and 17. These results are graphically represented in Figure 14 and 15.

Table 15: Pollution load analysis (metric ton) for tannery industries for 2011-2016.

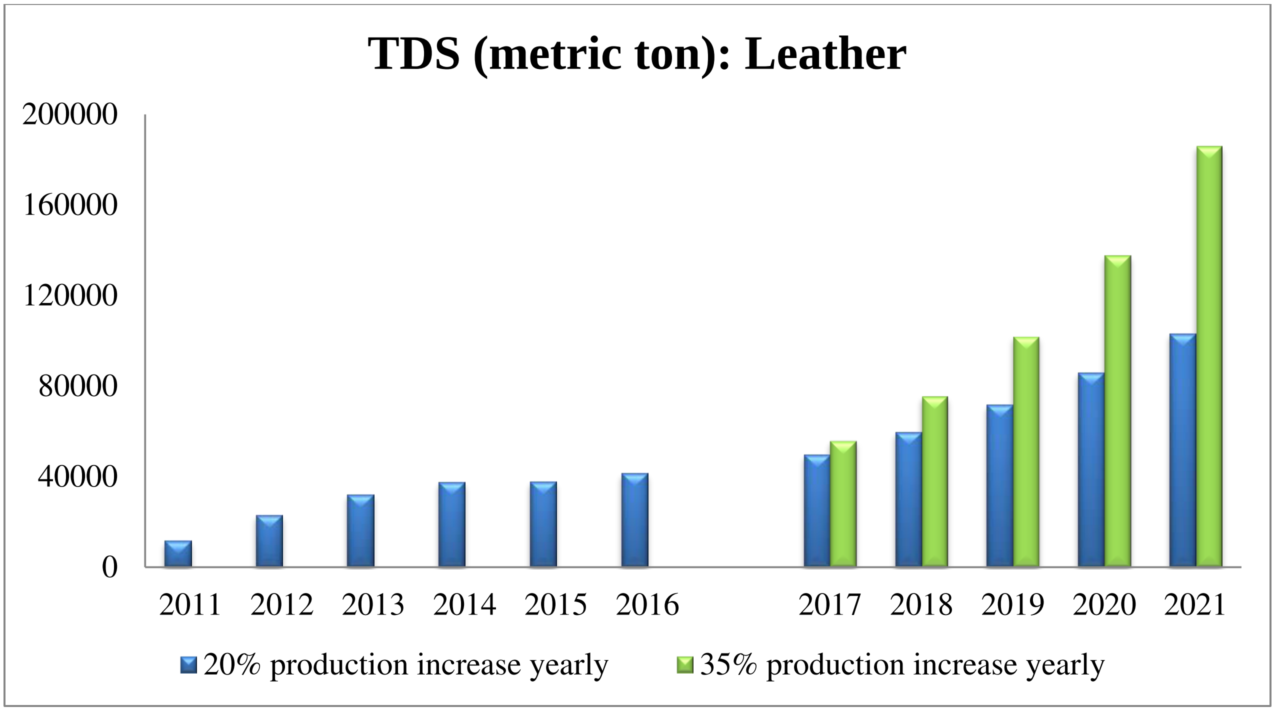
Year	TDS	TSS	BOD	COD
2011	11,543	5521	1807	4851
2012	23,086	11,041	3613	9703
2013	32,064	15,335	5019	13,476
2014	37,545	17,956	5877	15,780
2015	37,757	18,058	5910	15,869
2016	41,400	19,800	6480	17,400

Table 16: Future pollution load analysis for tannery industries with 20% annual production growth rate (2017-2021).

Year	Tannery industries in conventional practice(metric ton)				Tannery industries in improved practice(metric ton)			
	TDS	TSS	BOD	COD	TDS	TSS	BOD	COD
2017	49,680	23,760	7776	20,880	49,680	23,760	7776	20,880
2018	59,616	28,512	9331	25,056	52,164	24,948	8165	21,924
2019	71,539	34,214	11,197	30,067	53,654	25,661	8398	22,550
2020	85,847	41,057	13,437	36,081	53,654	25,661	8398	22,550
2021	103,016	49,269	16,124	43,297	51,508	24,634	8062	21,648

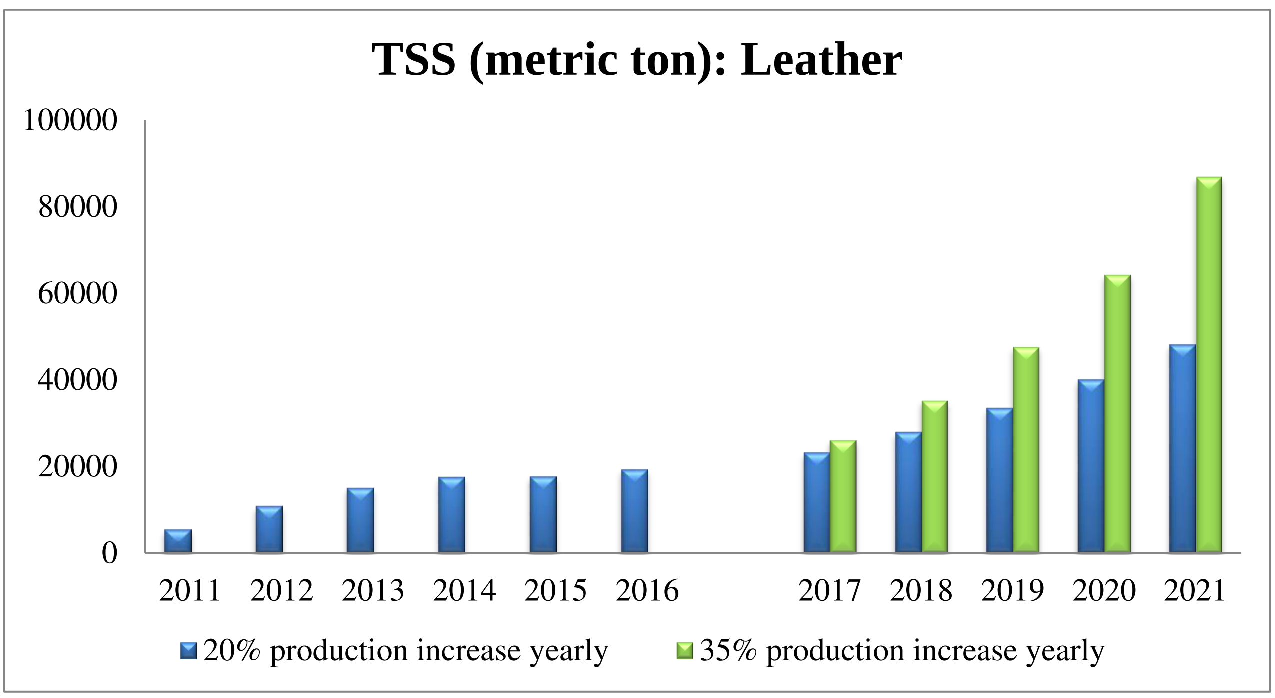
Table 17: Future pollution load analysis for tannery industries with 35% annual production growth rate (2017-2021).

Year	Tannery industries in conventional practice(metric ton)				Tannery industries in improved practice(metric ton)			
	TDS	TSS	BOD	COD	TDS	TSS	BOD	COD
2017	55,890	26,730	8748	23,490	55,890	26,730	8748	23,490
2018	75,452	36,086	11,810	31,712	66,020	31,575	10,334	27,748
2019	101,860	48,715	15,943	42,811	76,395	36,537	11,957	32,108
2020	137,510	65,766	21,523	57,794	85,944	41,104	13,452	36,121
2021	185,639	88,784	29,057	78,022	92,819	44,392	14,528	39,011



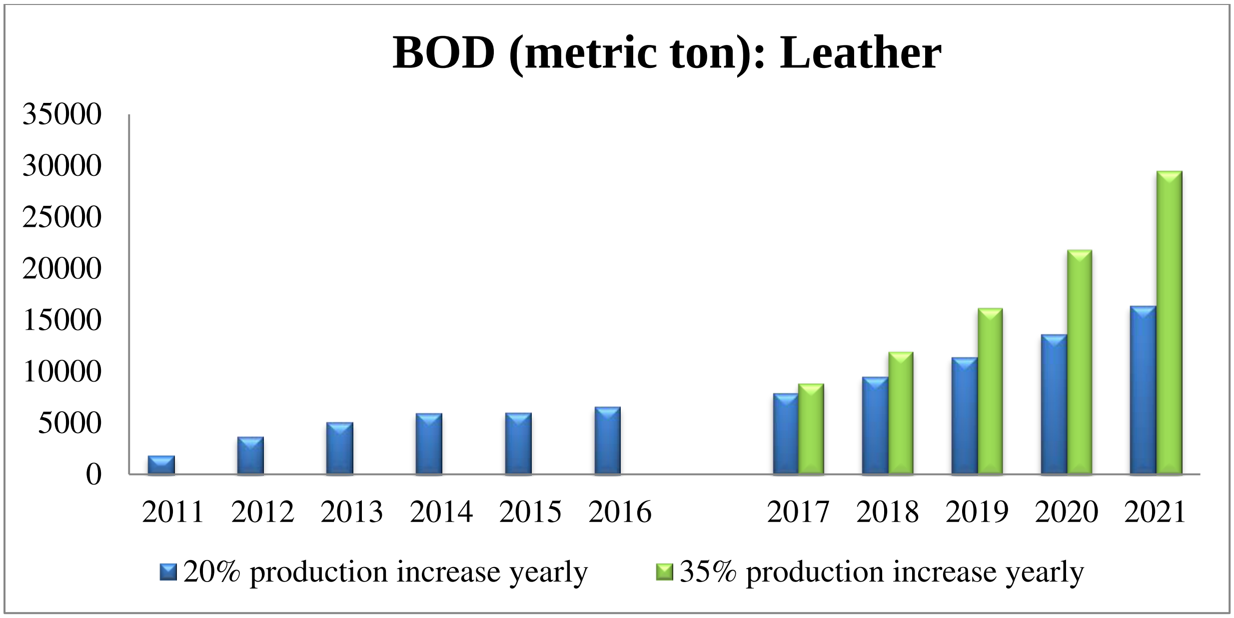
TDS (metric ton): Leather
200000
160000
120000
80000
40000
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
20% production increase yearly
35% production increase yearly

(a)

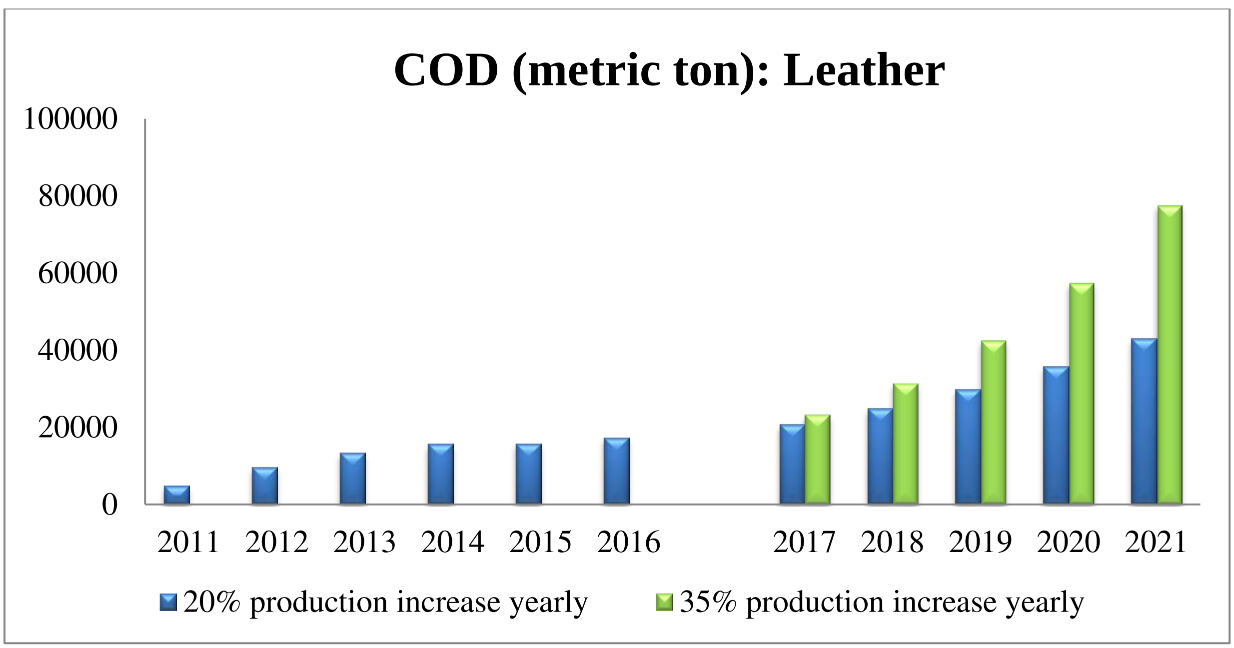


TSS (metric ton): Leather
100000
80000
60000
40000
20000
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
20% production increase yearly
35% production increase yearly

(b)

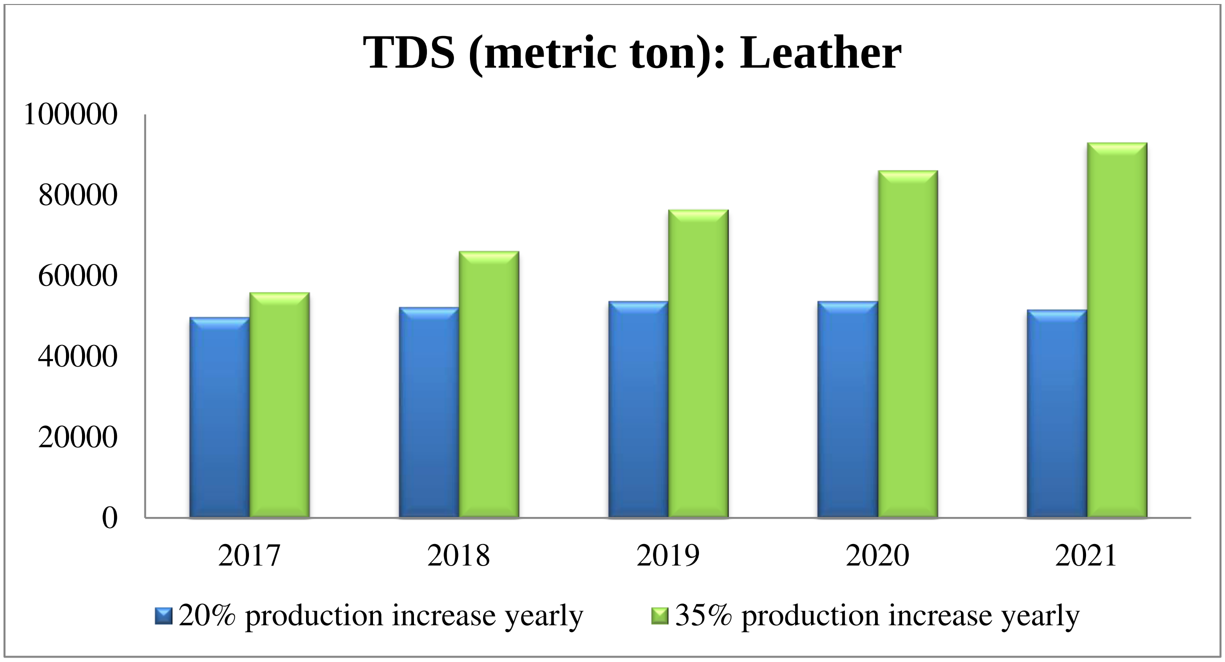


(c)

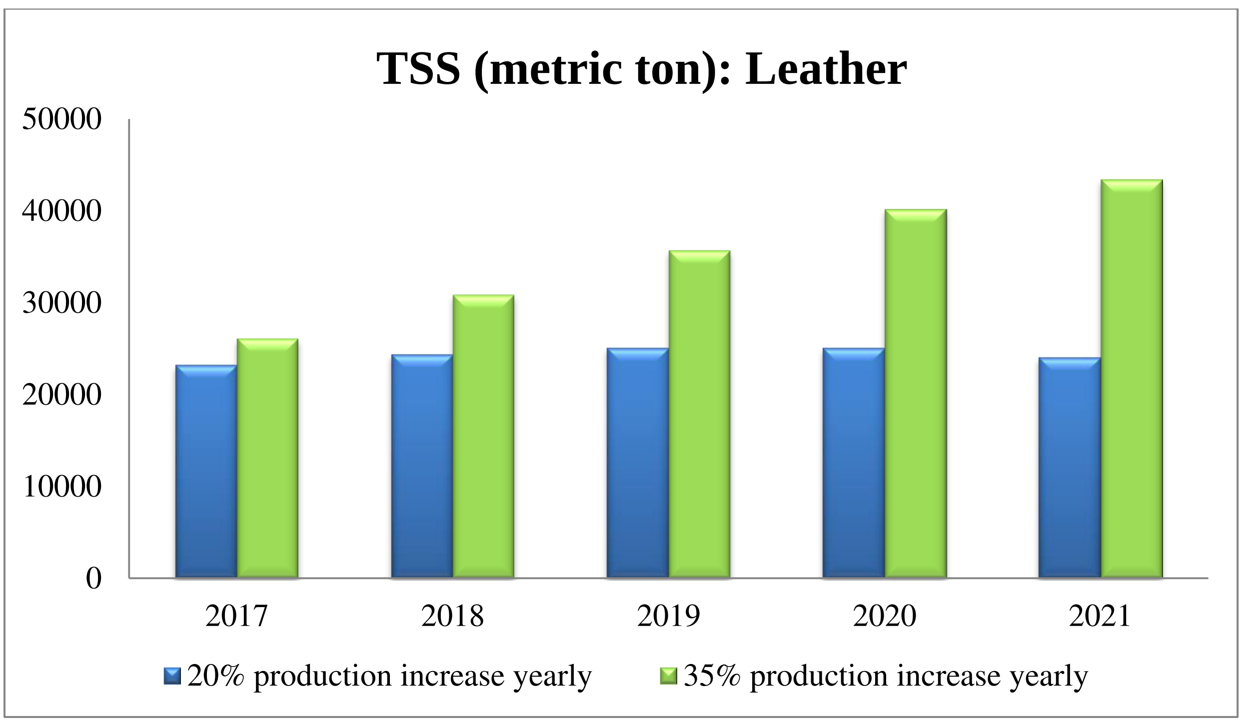


(d)

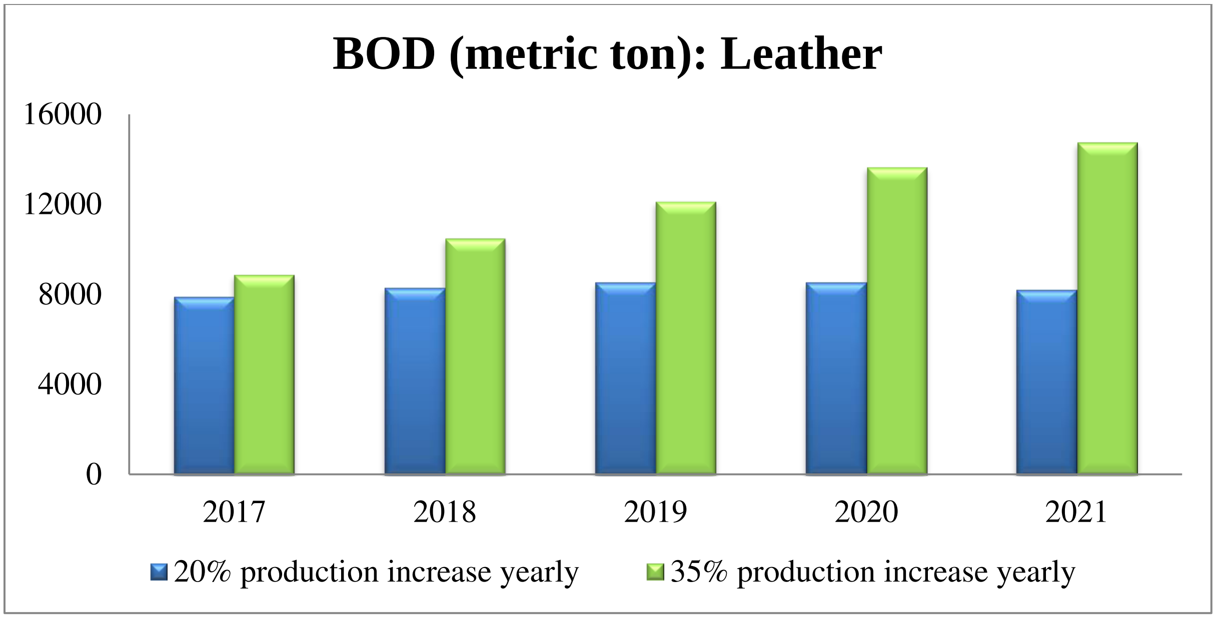
Figure 34: Annual pollution loads caused by tannery industries following conventional practice; (a) TDS, (b) TSS, (c) BOD, (d) COD.


TDS (metric ton): Leather
100000
80000
60000
40000
20000
0
2017
2018
2019
2020
2021
20% production increase yearly
35% production increase yearly

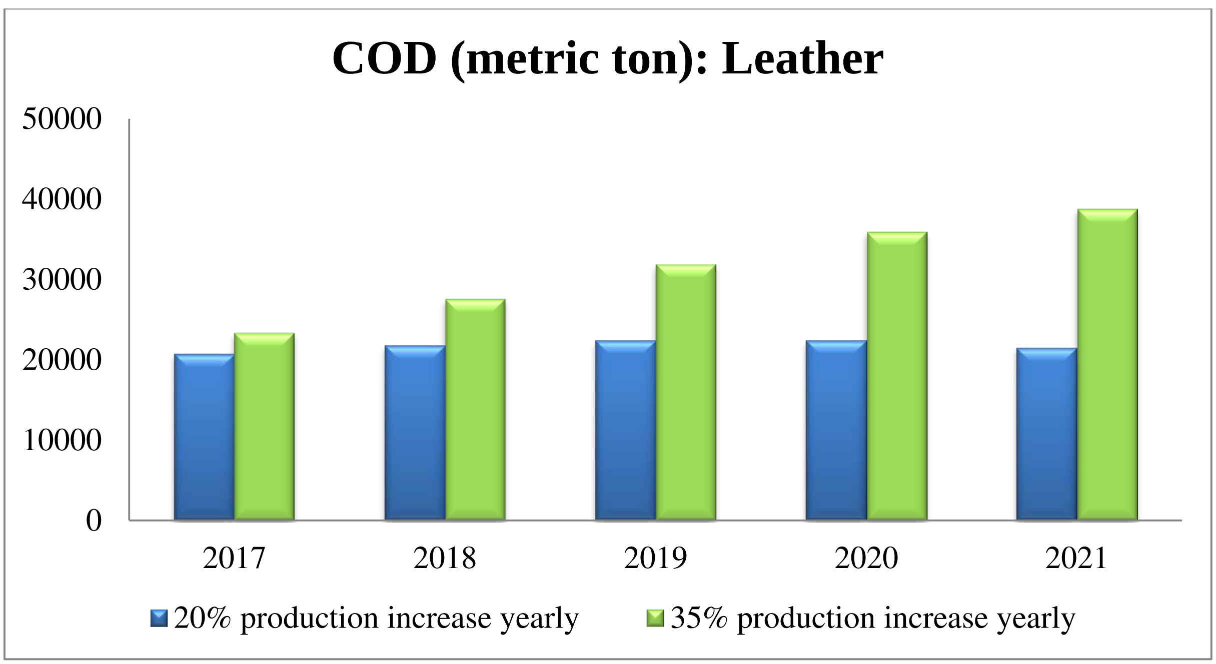
(a)


TSS (metric ton): Leather
50000
40000
30000
20000
10000
0
2017
2018
2019
2020
2021
20% production increase yearly
35% production increase yearly

(b)



(c)



(d)

Figure 45: Annual pollution loads caused by tannery industries adapting improved practice; (a) TDS, (b) TSS, (c) BOD, (d) COD.

Acids, alkalis, chromium salts, tannins, solvents, sulfides, dyes, auxiliaries, and many others compounds which are used in the transformation of raw or semi-pickled skins into commercial goods, are not completely fixed by skins and remain in the effluent. For instance the present commercial chrome tanning method gives rise to only about 50–70% chromium uptake (Islam et al., 2014). Table 15 and graph 14ashow that the amount of calculated Total Dissolved Solids (TDS) in 2016 produced by the tannery industries is 41,400 metric ton. At an annual production growth rate of 20%, the TDS amount in 2021 is projected to be 103,016 and 51,508 metric ton for conventional and improved technology respectively. Again, for 35% annual growth rate the projected amount for 2021 is 185,639 and 92,819 metric ton for conventional and improved technology respectively (Table 16 and 17, Figure 14a and 15a).

The composition of solids present in tannery effluent mainly depends upon the nature and quality of hides and skins processed in the tannery. High level of total suspended solids present in the tannery effluent could be attributed to their accumulation during the processing of finished leather. Presence of total suspended solids in water leads to turbidity resulting in poor photosynthetic activity in the aquatic system (Trivedy and Goel, 1984) and clogging of gills and respiratory surfaces of fishes (Alabaster and Lloyd, 2013). In 2016, the amount of Total Suspended Solids (TSS) generated by the tannery effluent was 19,800 metric ton (Table 15, Figure 14b). It is projected that in 2021, for 20% annual production growth rate the TSS amount from tannery effluent will be 49,269 and 24,634 metric ton for conventional and improved technology respectively.At 35% annual production growth rate the projected TSS value will be 88,784 and 44,392 for conventional and improved technology respectively (Table 16 and 17, Figure 14b and 15b).

The Biological Oxygen Demand (BOD) produced by tannery effluent in 2016 is calculated as 6,480 metric ton (Table 15, Figure 14c). In 2021 for annual production growth rate of 20%, the projected BOD value from tannery effluent is 16,124 and 8,062 metric ton for conventional and improved technology respectively. At 35% annual production growth rate, the projected value is 29,057 and 14,528 metric ton respectively(Table 16 and 17, Figure 14c and 15c).

In 2016, Chemical Oxygen Demand (COD) produced by tannery effluent was 17,400 metric ton (Table 15, Figure 14d), whereas, in 2021, the values will be 43,297 and 21,648 metric for conventional and improved KPI respectively for 20% annual production growth rate. Again, for 35% annual production growth rate, the projected COD value in 2021 will be 78,022 and 39,011 metric ton for conventional and improved KPI respectively(Table 16 and 17, Figure 14d and 15d). The combined water pollution impact for textile and leather industries are presented in Table 18-19 and Figure 16-17.

Table 18: Textile and leather combined wastewater volume and pollution load (with conventional technology)

Year	Combined Wastewater volume (million m^3)	Combined Pollution load (metric ton)			
		TDS	TSS	BOD	COD
2011	149	606,607	37,802	74,169	219,647
2012	156	648,816	44,954	78,581	231,952
2013	187	776,000	55,652	94,081	277,491
2014	197	811,677	59,920	98,902	291,631
2015	212	883,442	63,880	106,849	315,016
2016	229	953,931	69,242	115,298	339,870
2017	255	1,059,675	81,116	128,447	378,207
2018	284	1,179,615	95,910	143,479	421,901
2019	318	1,316,439	114,523	160,779	472,018
2020	357	1,473,548	138,154	180,843	529,923
2021	403	1,655,280	168,411	204,308	597,364

For annual production growth of 10% for textile and 35% for leather

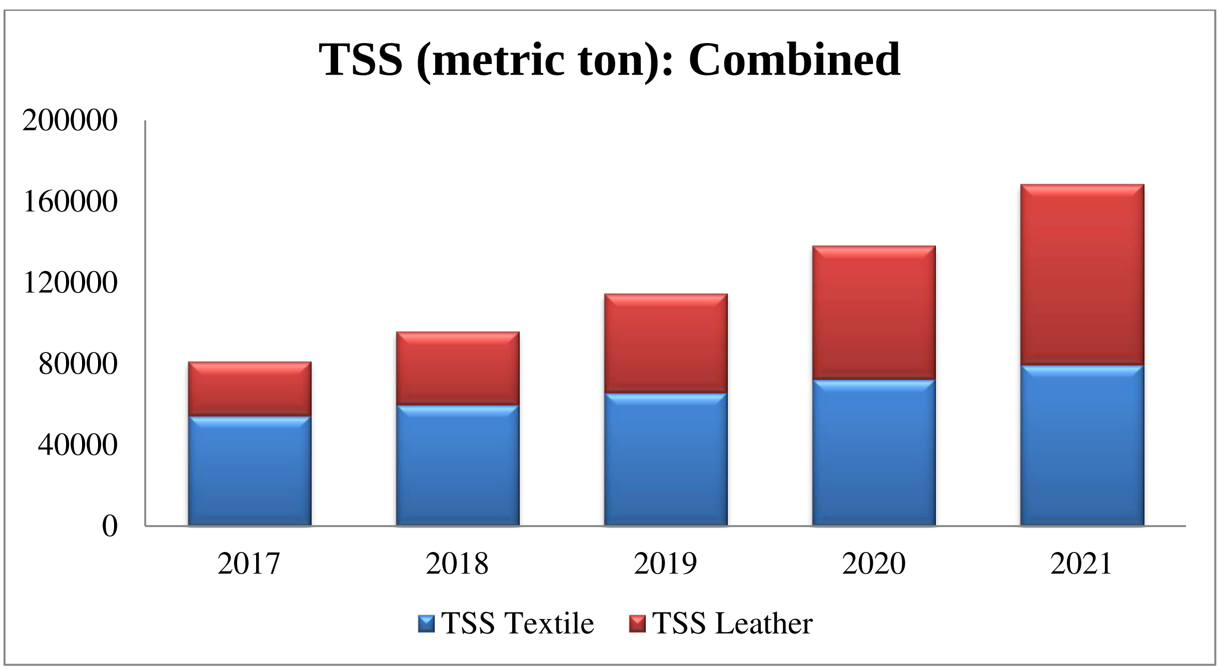
Table 19: Textile and leather combined wastewater volume and pollution load (with developed technology)

Year	Combined Wastewater volume (million m^3)	Combined Pollution load (metric ton)			
		TDS	TSS	BOD	COD
2017	243	1,009,485	78,397	122,462	360,471
2018	256	1,052,397	80,722	127,580	375,636
2019	269	1,097,240	83,151	132,927	391,482
2020	283	1,144,101	85,690	138,515	408,042
2021	297	1,193,070	88,344	144,354	425,347

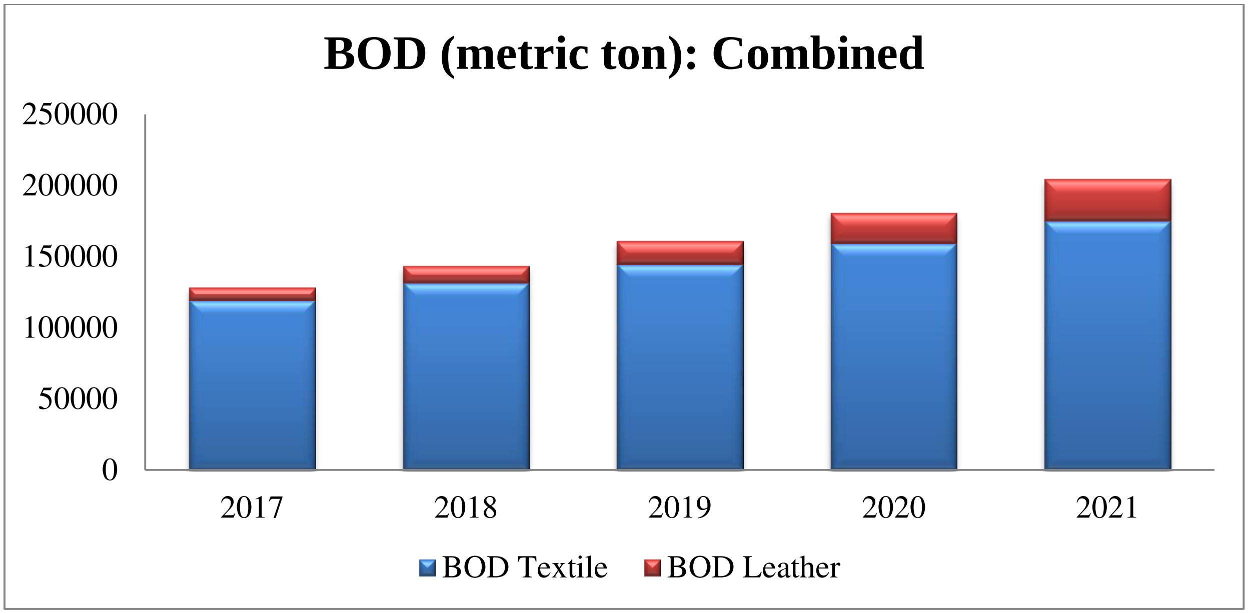
For annual production growth of 10% for textile and 35% for leather


TDS (metric ton): Combined
2000000
1600000
1200000
800000
400000
0
2017
2018
2019
2020
2021
TDS Textile
TDS Leather

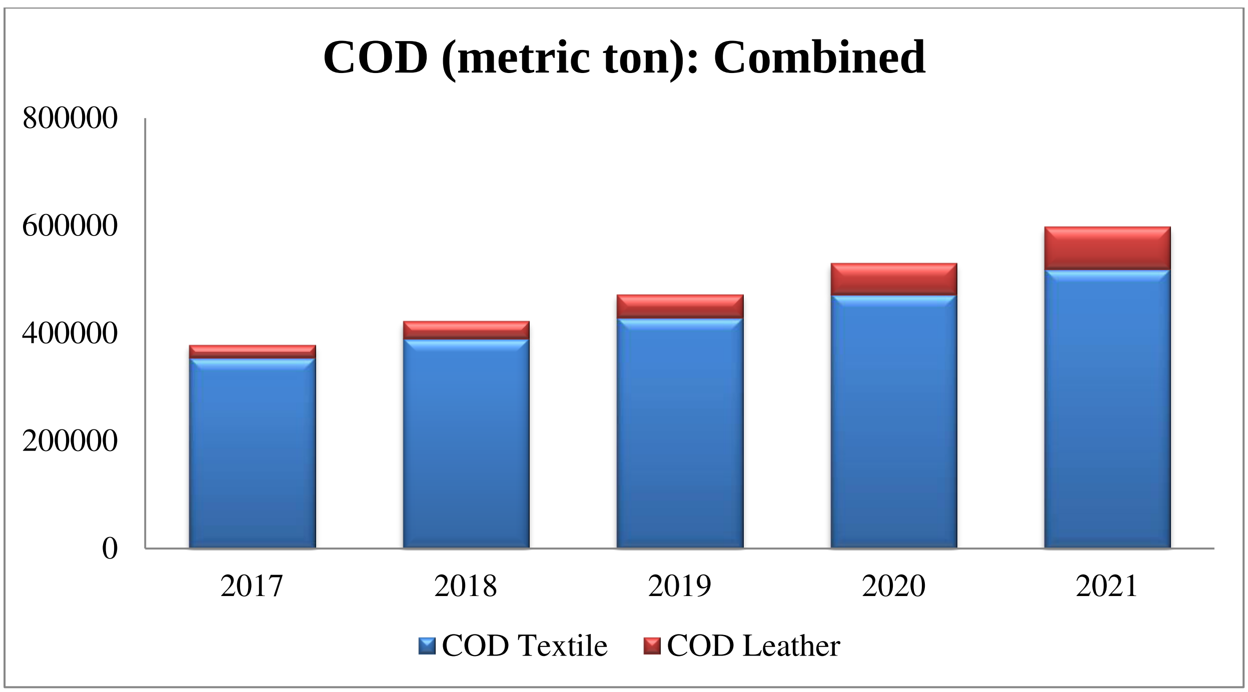
(a)


TSS (metric ton): Combined
200000
160000
120000
80000
40000
0
2017
2018
2019
2020
2021
TSS Textile
TSS Leather

(b)

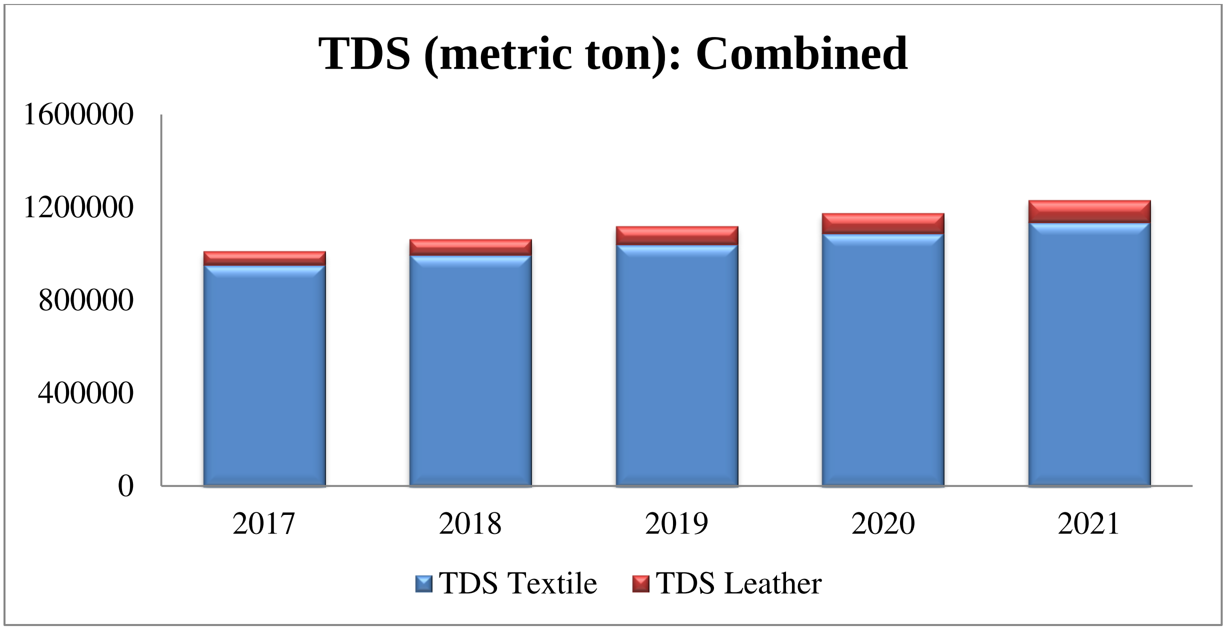


(c)

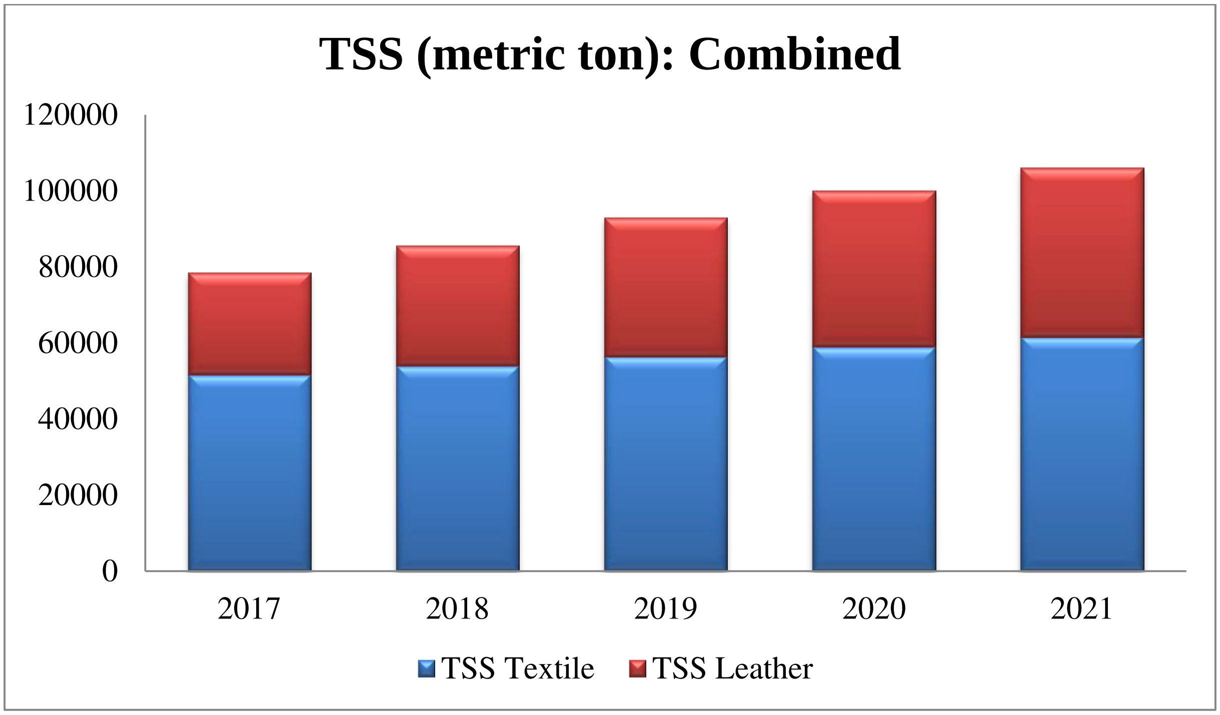


(d)

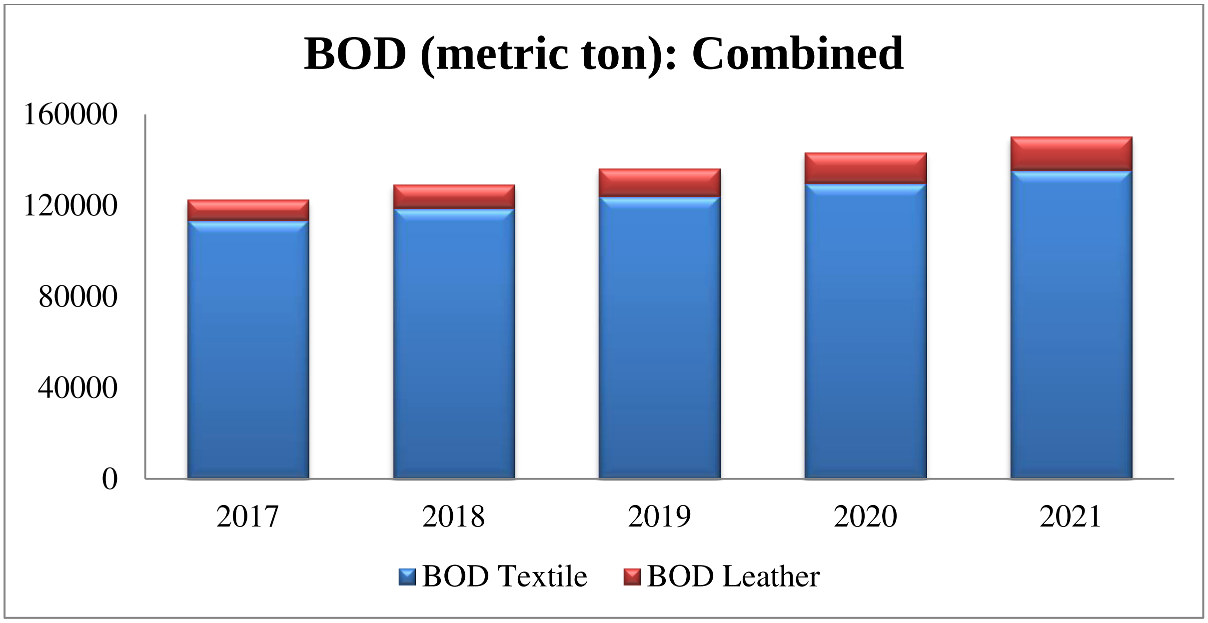
Figure 56: Combined pollution loads caused by textile and tannery industries with conventional technologies (2017-2021); (a) TDS (b) TSS (c) BOD (d) COD


TDS (metric ton): Combined
1600000
1200000
800000
400000
0
2017
2018
2019
2020
2021
TDS Textile
TDS Leather

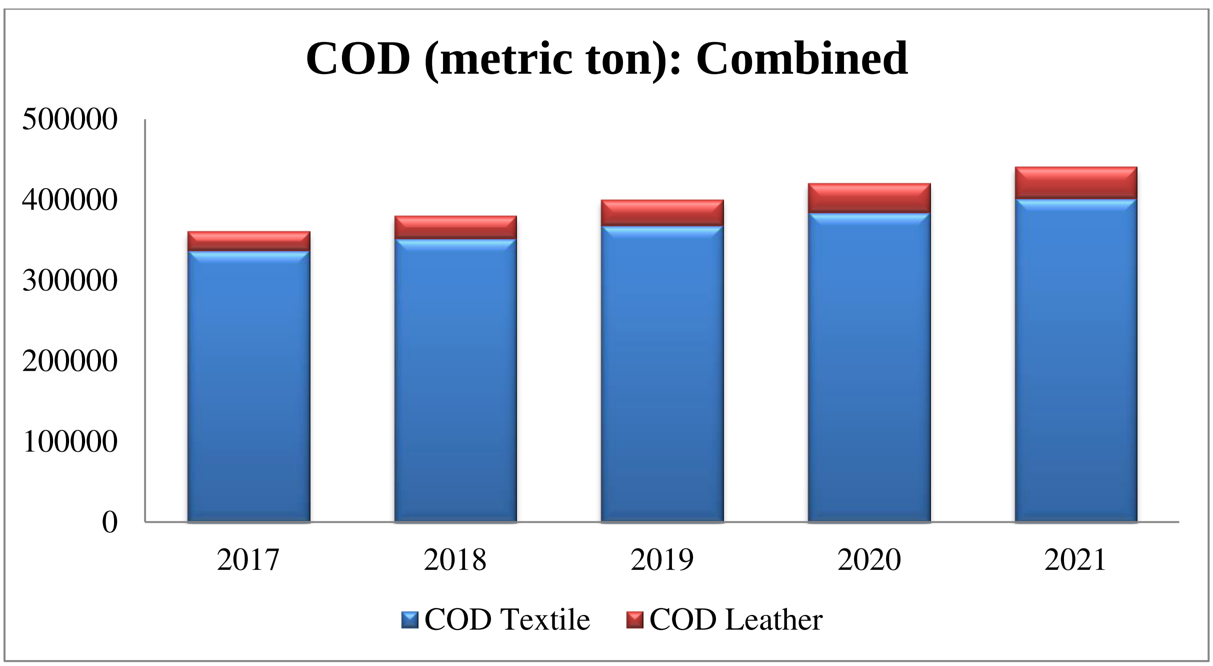
(a)


TSS (metric ton): Combined
120000
100000
80000
60000
40000
20000
0
2017
2018
2019
2020
2021
TSS Textile
TSS Leather

(b)



(c)



(d)

Figure 67: Combined pollution loads caused by textile and tannery industries with developed technologies (2017-2021); (a) TDS (b) TSS (c) BOD (d) COD

4.3 Environmental Impact, Climate Change and Possible Health Effects

The rivers and water bodies near to the industrial zones in Bangladesh (such as Dhaka, Narayanganj and Gazipur) are the major receivers of the untreated effluents coming from textile and leather industries. Increasing wastewater volume results in increasing water footprint (both blue and grey water footprint) and lowers the level of water table. Textile and leather industries consume high volume of water to process per unit fabric and hide respectively, which may deplete groundwater level. It has been reported that in Dhaka city, groundwater levels dropped more than 200 feet over the last 50 years and these levels continue to decline at a high rate (Roberts,2016). Groundwater helps supporting overlying rock and soil; once the water table drops, there might be a gradual settling of the land, a phenomenon known as land subsidence (Sah,2001). Since 2011 to 2016, wastewater volume increased around 54%, TSS and TDS in effluents increased around 85% and 53% respectively and BOD and COD increased around 55% (Table 18). From trend analysis, it can be extrapolated that by 2021 these industries will produce 2.7 times more effluent than that of 2011 (Table 18). Adaptation of improved technology and cleaner production options will reduce water consumption and effluent volume for improved industries, however, the cumulative wastewater volume and pollution impacts caused by the textile and leather sector will still be high enough for the country to manage growing pollution load.

Industrial effluents pollute the groundwater too. Farmers depending on groundwater find their useful plants are dying because of groundwater pollution. These crop failures mean local production cannot meet the demand, transporting produce from faraway increases carbon footprint, thus affecting the climate by producing greenhouse gas which leads to global warming. Excessive groundwater extraction and global warming caused by increasing carbon footprint may contribute in rising sea level.In Bangladesh, projected sea level rise could flood the residences of millions of people by destroying 17.5% of total land area of the country (Wassmann, Hien et al.,2004; Stern,2006; Cruz, Harasawa et al.,2007).

High concentration of BOD and COD reduces the dissolved oxygen concentration in water body which may result in fish mortality, and changes in species composition in long run (Akpor and Muchie, 2011). Untreated wastewater may also cause bioaccumulation of contaminants, which is the gradual accumulation of organic or inorganic contaminants into the living tissues of plant and animals from their environment. Bioaccumulation occurs when a contaminant is taken up by organisms faster than their bodies can break it down or eliminate it. Polluted water may also cause biomagnification of contaminants (Chambers and Mill, 1996).

Industrial toxic and chemical wastes that are disposed into water bodies are responsible for thousands of illness and premature deaths across the globe. For instance, exposure to inorganic arsenic causes tumors to form (Terrible Effects of Industrial Pollution).The presence of dyes in surface and subsurface water causes many water borne diseases, viz. nausea, hemorrhage, ulceration of skin and mucous membrane, dermatitis, perforation of nasal septum and severe irritation of respiratory tract (Usha, 1989; Islam, Mahmud et al., 2011). A large number of villages at Gazipur and D.N.D (Dhaka-Narayanganj-Demra) Embankment are now being threatened by the environmental degradation caused by the effluent (Islam, Mahmud et al.,2011).

5. Conclusion

Textile and leather sectors are the largest manufacturing sectors in Bangladesh. The growth in these sectors, and other small and medium scale enterprises, undoubtedly has a positive effect on national economic development but there are also environmental concerns. Effluent from textile dyeing and tannery industries is a major source of environmental pollution. In this study, the past trend (2011-2016) and future projection (2017-2021) of pollution impacts associated with BD textile dyeing and tannery industries is developed analyzing yearly export data, production growth rate, and pollution load of the effluents. This study will be highly useful for the Government, funding agencies, industry management and technologists to analyze wastewater impact with increased textile and leather production and to develop environment friendly dyeing and tanning practice and technologies. This research will also provide the baseline for other relevant studies to measure overall industrial pollution load.

6. Recommendations for Future Study

In this study, for wastewater parameter analysis samples were tested for each type of effluents and the method of wastewater collection was grab sampling. The pollution parameters of textile dyeing and leather tanning effluents vary a lot. To get more authentic average effluent parameters, it is suggested to follow composite sampling method. Also, only four major parameters (TDS, TSS, BOD, and COD) were considered for pollution load analysis. During a more extensive research in future on this subject, other categories of water quality like nutrients (nitrogen, phosphorus) and physical properties (pH, color, odor, temperature, turbidity) can also be taken into account.

The pollution load has been calculated based on the process effluents without any treatment. However, many industries now have effluent treatment plants (ETP) and the effluents discharged to environment from these factories have lower pollution load. If those are considered, the total pollution load will vary from this study results.

Based on some assumptions, production data in weight basis were calculated from the export data and yearly production growth percentage. If the exact production data can be obtained in weight basis, the calculated wastewater volume data will be more authentic. Again, the water KPI used to calculate the wastewater volume is assumed as per the current process conditions practiced in Bangladesh. However, industries are gradually moving towards upgraded water flow metering system. So in future studies more accurate water KPI can be used if these tracked water data can be collected.

7. References

1. Ahmed, A. and S. M. Tareq (2008). "Textile industries in Bangladesh: A rising environmental degradation down the drains." Bangladesh textile today.
2. Akpor, O. and B. Muchie (2011). "Environmental and public health implications of wastewater quality." African Journal of Biotechnology 10(13): 2379-2387.
3. Alabaster, J. S. and R. S. Lloyd (2013). Water quality criteria for freshwater fish, Elsevier.
4. Arumai Dhas, J. P. (2008). Removal of Cod and Colour from Textile Wastewater Using Limestone and Activated Carbon, Universiti Sains Malaysia.
5. Augsburger, N. D. (1980). Envrionmental Control Handbook for Poultry and Livestock, ACME Engineering & Manufacturing Corporation.
6. Bangladesh Garment Manufacturers and Exporters Association. (2017, 2017-03-12). "Comparative Statement on Export of RMG and Total Export of Bangladesh." Retrieved March 18, 2017, from http://www.bgmea.com.bd/home/pages/TradeInformation.
7. Bangladesh Garment Manufacturers and Exporters Association. (2017). "Value of Total Apparel Export." Retrieved March 2, 2017, from http://www.bgmea.com.bd/home/pages/TradeInformation.
8. Business for Social Responsibility (2010). Water Quality Guidelines**:** 3.
9. Chambers, P. A. and T. Mill (1996). Dissolved oxygen conditions and fish requirements in the Athabasca, Peace and Slave rivers: assessment of present conditions and future trends, Northern River Basins Study.

10. Charoenlarp, K. and W. Choyphan (2009). "Reuse of dye wastewater through colour removal with electrocoagulation process." Asian Journal on Energy and Environment 10(4): 250-60.

11. Department of Environment (2008). Guide for Assessment of Effluent Treatment Plants.

12. Dey, S. and A. Islam (2015). "A review on textile wastewater characterization in Bangladesh." Resources and Environment 5(1): 15-44.

13. Dhanabalan, V., Sukanya, Lokesh, K.V. (2015). "Air-Dyeing Technology: A Review." Retrieved March 20, 2017, from http://www.textiletoday.com.bd/air-dyeing-technology-a-review/.

14. Environmental Conservation Rules (1997). "Department of Environment." Ministry of Environment and Forest. People's Republic of Bangladesh.

15. Farah Maria Drumond Chequer, G. A. R. d. O., Elisa Raquel Anastácio Ferraz, Juliano Carvalho Cardoso, Maria Valnice Boldrin Zanoni and Danielle Palma de Oliveira (2013). Textile Dyes: Dyeing Process and Environmental Impact. M. Günay.

16. Ferdous, N. Z.-A. (2011). "12 factories adapt Ceaner Production." Retrieved March 19, 2017, from https://bangladesheconomy.wordpress.com/2011/12/19/12-factories-adapt-cleaner-production/.

17. Gregory, P. (1993). "Dyes and dye intermediates." Kirk-Othmer Encyclopedia of Chemical Technology.

18. Hasan, K. F., M. S. Mia, (2016). "Role of Textile and Clothing Industries in the Growth and Development of Trade & Business Strategies of Bangladesh in the Global Economy." International Journal of Textile Science 5(3).

19. Hoque, A. and A. Clarke (2013). "Greening of industries in Bangladesh: pollution prevention practices." Journal of Cleaner Production 51: 47-56.
20. Huq, M. (2003). "A Compilation of Environment Laws Administrated By the Department of Environment." Department of Environment and Bangladesh Environmental Management Project (BEMP), Dhaka.
21. Hussain, M. and T. P. Rao (2013). "Effect of Industrial Effluents on Surface Water Quality–A Case Study of Patancheru, Andhra Pradesh, India." Current World Environment 8(3): 445-454.
22. International Textile Manufacturers Federation (2014). Country Statements 2013.
23. Islam, M. M., A. M. Khan (2013). "Textile industries in Bangladesh and challenges of growth." Research Journal of Engineering Sciences, *ISSN*2278: 9472.
24. Islam, M. M., K. Mahmud (2011). Assessment of environmental impacts for textile dyeing industries in Bangladesh. Green Technology and Environmental Conservation (GTEC 2011), 2011 International Conference on, IEEE.
25. Joseph, E. I. (2007). "Wastewater Treatment in the Textile Industry " Pakistan Textile Journal: 60-66.
26. Kar, A., Keane, S.E, Greer, L. (2012). Best Practices for Textile Mills to Save Money and Reduce Pollution Bangladesh.
27. Khan, M. S., S. Selim (2011). Characterizing and Measuring Textile Effluent Pollution Using a Material Balance Approach: Bangladesh Case Study. 9th International Conference on Mechanical Engineering (ICME) 2011.
28. Kiron, M. I. (2015). "Ready Made Garments Industry of Bangladesh. Apparel Merchandiser.".

29. L.A.H.M. Verheijen, D. W., L.W. Hulshoff Pol (1996). Management of Waste from Animal Product Processing.

30. LFMEAB (2016). Investment Prospects in Bangladesh Leather Sector.

31. Mendham, J. (2006). Vogels textbook of quantitative chemical analysis, Pearson Education India.

32. Mirdha, R. U. (2015) "Leather sector's exports cross $1b for second year."

33. Moore, S. B. and L. W. Ausley (2004). "Systems thinking and green chemistry in the textile industry: concepts, technologies and benefits." Journal of Cleaner Production 12(6): 585-601.

34. Ockerman, H. W. and C. L. Hansen (1999). Animal by-product processing & utilization, CRC Press.

35. Partnership for Cleaner Textile. (2017). Retrieved March 20, 2017, from http://www.textilepact.net/about-us/what-is-pact.html.

36. Roberts, K. B. (2016). "Water crisis in Bangladesh: Overpumping in Dhaka may threaten regional groundwater resources outside the city." from https://phys.org/news/2016-09-crisis-bangladesh-overpumping-dhaka-threaten.html.

37. Rott, U. and R. Minke (1999). "Overview of wastewater treatment and recycling in the textile processing industry." Water Science and Technology 40(1): 137-144.

38. Rouf, M., M. Islam, Haq, Ahmed, Rabeya (2013). "Characterization of effluents of leather industries in Hazaribagh area of Dhaka city." Bangladesh Journal of Scientific and Industrial Research 48(3).

39. S.E.A.M Project (1999). Textile Sector Report: Cleaner Production Oppotunities (Egypt).

40. Sah, R. C. (2001). GROUNDWATER DEPLETION AND ITS IMPACT ON ENVIRONMET IN KATHMANDU VALLEY, Pro Public.
41. Sharif, M. and M. Hannan (1999). "Guide to the Environmental Conservation Act 1995 and Rules 1997." Bangladesh Centre for Advanced Studies (BCAS), Dhaka, Bangladesh.
42. Shi, H., S. Peng, (2008). "Barriers to the implementation of cleaner production in Chinese SMEs: government, industry and expert stakeholders' perspectives." Journal of Cleaner Production 16(7): 842-852.
43. Srinath T, V. T., Ramteke PW and Garg SK (2002). "Chromium (VI) biosorption and bioaccumulation by chromate resistant bacteria." *Chemosphere*48 (4): 427-35.
44. Stern, N. (2006). The Stern Review on the Economics of Climate Change. Cambridge, UK, Cambridge University.
45. Suresh, V., M. Kanthimathi (2001). "An improved product-process for cleaner chrome tanning in leather processing." Journal of Cleaner Production 9(6): 483-491.
46. Trivedy, R. and P. Goel (1984). Chemical and biological methods for water pollution studies, Environmental publications.
47. Usha, M. (1989). "Impact analysis of industries in Sanganer." PG Diploma Field Study Report.
48. Vaishali, P. and P. Punita (2013). "Assessment of seasonal variation in water quality of River Mini, at Sindhrot, Vadodara." International journal of environmental sciences 3(5): 1424.
49. van den Berg, J. C. T. (1988). Dairy Technology in the Tropics and Subtropics, Pudoc.
50. Yusuff, R. and J. Sonibare (2004). "Characterization of textile industries’ effluents in Kaduna, Nigeria and pollution implications." Global Nest: Int. J 6(3): 212-221.

51. Zollinger, H. (2003). Color chemistry: syntheses, properties, and applications of organic dyes and pigments, John Wiley & Sons.

Appendix I: Textile Dyeing Process

The dyeing process is one of the key factors in the successful trading of textile products. In addition to the design and beautiful color, the consumer usually looks for some basic product characteristics, such as good fixation with respect to light, perspiration and washing, both initially and after prolonged use. To ensure these properties, the substances that give color to the fiber must show high affinity, uniform color, resistance to fading, and be economically feasible.

Modern dyeing technology consists of several steps selected according to the nature of the fiber and properties of the dyes and pigments for use in fabrics, such as chemical structure, classification, commercial availability, fixing properties compatible with the target material to be dyed, economic considerations and many others.

Dyeing methods have not changed much with time. Basically water is used to clean, dye and apply auxiliary chemicals to the fabrics, and also to rinse the treated fibres or fabrics. The dyeing process involves three steps: preparation, dyeing and finishing, as follows:

Preparation is the step in which unwanted impurities are removed from the fabrics before dyeing. This can be carried out by cleaning with aqueous alkaline substances and detergents or by applying enzymes. Many fabrics are bleached with hydrogen peroxide or chlorine-containing compounds in order to remove their natural color, and if the fabric is to be sold white and not dyed, optical brightening agents are added.

Dyeing is the aqueous application of color to the textile substrates, mainly using synthetic organic dyes and frequently at elevated temperatures and pressures in some of the steps. It is important to point out that there is no dye which dyes all existing fibres and no fiber which can be dyed by all known dyes. During this step, the dyes and chemical aids such as surfactants, acids, alkali/bases, electrolytes, carriers, leveling agents, promoting agents, chelating agents, emulsifying oils, softening agents etc. (applied to the textile to get a uniform depth of color with the color fastness properties suitable for the end use of the fabric). This process includes diffusion of the dye into the liquid phase followed by adsorption onto the outer surface of the fibres, and finally diffusion and adsorption on the inner surface of the fibres. Depending on the expected end use of the fabrics, different fastness properties may be required. For instance, swimsuits must not bleed in water and automotive fabrics should not fade after prolonged exposure to sunlight. Different types of dyes and chemical additives are used to obtain these properties, which is carried out during the finishing step. Dyeing can also be accomplished by applying pigments (pigments differ from dyes by not showing chemical or physical affinity for the fibres) together with binders (polymers which fix the pigment to the fibres).

Finishing involves treatments with chemical compounds aimed at improving the quality of the fabric. Permanent press treatments, water proofing, softening, antistatic protection, soil resistance, stain release and microbial/fungal protection are all examples of fabric treatments applied in the finishing process.

Dyeing can be carried out as a continuous or batch process. The most appropriate process to use depends on several factors, such as type of material (fiber, yarn, fabric, fabric construction and garment), generic type of fiber, size of dye batch and quality requirements for the dyed fabric, but batch processes are more commonly used to dye textile materials..

In continuous processing, heat and steam are applied to long rolls of fabric as they pass through a series of concentrated chemical solutions. The fabric retains the greater part of the chemicals while rinsing removes most of the preparation chemicals. Each time a fabric is passed through a solution, an amount of water equivalent to the weight of the fabric must be used.

In batch processing, sometimes called exhaust dyeing, since the dye is gradually transferred from the dye bath to the material being dyed over a relatively long period of time, the dyeing occurs in the presence of dilute chemicals in a closed equipment such as a kier, kettle, beam, jet or beck. Unlike the continuous process, instead of being passed through various baths in a long series of equipment sections, in the batch process the fabric remains in a single piece of equipment, which is alternately filled with water and then drained, at each step of the process. Each time the fabric is exposed to a separate bath, it uses five to ten times its own weight in water.

Some batch dyeing machines only operate at temperatures up to 100ºC. However, the system can be pressurized, allowing for the use of temperatures above 100ºC. Cotton, rayon, nylon, wool and some other fibres dye well at temperatures of 100ºC or below. Polyester and some other synthetic fibres dye more easily at temperatures above 100ºC.

Since the degree of dye fixation depends on the nature of the fiber, it is important to consider this topic. The fibres used in the textile industry can be divided into two main groups denominated natural fibres and synthetic fibres. Natural fibres are derived from the environment (plants or animals), such as wool, cotton, flax, silk, jute, hemp and sisal, most of which are based on cellulose and proteins. On the other hand, synthetic fibres are organic polymers, mostly derived from petroleum sources, for example, polyester, polyamide, rayon, acetate and acrylic. The two most important textile fibres are cotton, the largest, and polyester. Cotton has been used for over 7000 years, and consists of mainly cellulose, natural waxes and proteins. The large number of hydroxyl groups on the cellulose provides a great water absorption capacity.

A brief description of the each step of fabric dyeing process is given below:

Sizing

Sizing of the warp yarn is essential to reduce breakage of the yarn and thus production stops on the weaving machine. On the weaving machine, the warp yarns are subjected to several types of actions i.e. cyclic strain, flexing, abrasion at various loom parts and inter yarn friction.With sizing, the strength of the yarn improves and the hairiness of yarn decreases. The degree of improvement of strength depends on adhesion force between fiber and size, size penetration as well as encapsulation of yarn. Different types of water soluble polymers called textile sizing agents/chemicals such as modified starch, polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC), and acrylates are used to protect the yarn. Also wax is added to reduce the abrasiveness of the warp yarns. The type of yarn material (e.g. cotton, polyester, linen), the thickness of the yarn, type of weaving machinery determine the sizing recipe.

Singeing

Singeing is the first step of dyeing. Singeing is important for a fabric to provide a smooth finish. Woven fabric goods usually contain protruding fibres from textile yarns. Singeing process is used to remove those protruding fibres from the surface of the fabric. The fabric is passed in to a flame and these protruding fibres are burned out. Sometime copper plate is used remove the fiber. For printing, singeing is most essential to improve the surface smoothness by eliminating the pilling and fibres.

Desizing

Desizing is the process of removing sizing materials from the fabric, which is applied in order to increase the strength of the yarn which can withstand with the friction of loom. Fabric which has not been desized is very stiff and causes difficulty in its treatment with different solution in subsequent processes.After singeing operation the sizing material is removed by making it water-soluble and washing it with warm water. Desizing can be done by either the hydrolytic method (rot steep, acid steep, enzymatic steep) or the oxidative method (chlorine, chloride, bromite, hydrogen peroxide). Depending on the sizing material that has been used, the cloth may be steeped in a dilute acid and then rinsed, or enzymes may be used to break down the sizing material. Enzymes are applied in the desizing process if starch is used as sizing materials. Carboxymethyl cellulose (CMC) and Poly vinyl alcohol (PVA) are often used as sizing materials.

Scouring

Scouring is one of the most important processes of textile fabric dyeing. All natural fibres contain natural oil and wax. Before dyeing, those oil and wax must be cleaned for smooth and proper dyeing. The scouring is a cleaning procedure that used to eliminate those oil, wax from fibres, yarns, or fabric by soaping. For scouring process alkaline solutions are typically used; however, solvent solution may be used in some cases. The parameters of scouring procedures like temperature, chemical composition, and time vary with the types of fabrics and fibres, materials, dirt, lubricants etc. Residual tints antistatic agents, water-soluble sizes, used for yarn verification.

Bleaching

Bleaching is a complex process. The most common bleaching agents include hydrogen peroxide, sulfur dioxide gas and sodium hypochlorite. All natural fibres contain a natural color which is harmful for dyeing shade matching. So it is important to remove the natural color from the fiber. Bleaching is used to eliminate the natural color from the fiber and prepare the fabric for further processing. Bleaching chemical selection is dependent on the types of fabric. Hydrogen peroxide is the most popular bleaching agent used for cotton and cotton blends.

Mercerizing

Mercerization is a treatment for cotton fabric and thread that gives fabric or yarns a lustrous appearance and strengthens them. The process is applied to cellulosic materials like cotton or hemp and it is not conducted in the knit dyeing process. A further possibility is mercerizing during which the fabric is treated with sodium hydroxide solution to cause swelling of the fibres. This results in improved lustre, strength and dye affinity. Cotton is mercerized under tension, and all alkali must be washed out before the tension is released or shrinkage will take place. Mercerizing can take place directly on greige cloth, or after bleaching.

Dyeing

Dyeing is the process of adding color to textile products like fibers, yarns, and fabrics. Dyeing is normally done in a special solution containing dyes and particular chemical material. After dyeing, dye molecules have uncut chemical bond with fiber molecules. The temperature and time controlling are two key factors in dyeing. There are mainly two classes of dye, natural and man-made. Suitable dyestuff, dyeing machine and dyes chemical is required for achieving proper dyeing shade.

Finishing

Textile finishing is a series of processes to which all bleached, dyed, printed and certain greige fabrics are subjected before they are put on the market. The object of textile finishing is to render textile goods fit for their purpose or end-use and/or improve serviceability of the fabric. Finishing on fabric is carried out for both aesthetic and functional purposes to improve the quality and look of a fabric. Fabric may receive considerable added value by applying one or more finishing processes.

Printing

Textile printing is referred as localized dyeing. It is the application of color in the form of a paste or ink to the surface of a fabric, in a predetermined pattern. Printing designs onto already dyed fabric is also possible. In properly printed fabrics the color is bonded with the fiber, so as to resist washing and friction. Textile printing is related to dyeing but, whereas in dyeing proper the whole fabric is uniformly covered with one color, in printing one or more colors are applied to it in certain parts only, and in sharply defined patterns. In printing, wooden blocks, stencils, engraved plates, rollers, or silk screens can be used to place colors on the fabric. Colorants used in printing contain dyes thickened to prevent the color from spreading by capillary attraction beyond the limits of the pattern or design.

Appendix II: Leather Tanning Process

Tanning is the process by which raw animal skins and hides are converted into leather. This process permanently alters the protein structure of the skin, preventing it from decomposing and turning it into a stable material. Tanning may be carried out using animal, plant, or mineral products. The tanning agents used include the plant product known as tannin (from which "tanning" gets its name), fish or animal oil, and salts of chromium. Once tanned, the leather becomes useful for a variety of products, including jackets, gloves, shoes, handbags, wallets, briefcases, and upholstery.

The chemicals traditionally used for tanning have been derived from plants, whereas the most common process nowadays is a combination of chrome salts (chrome tanning) and readily usable vegetable extracts (vegetable tanning). In most cases raw hides produced at slaughterhouses are preserved by pickling and drying for transport to tanneries and further treatment. In the very few cases that hides are instantly tanned there is no need for preservation. During the tanning process at least ±300 kg chemicals (lime, salt etc.) is added per ton of hides.

Pre-tanning (Beam house operations)

Soaking:

The preserved raw hides regain their normal water contents. Dirt, manure, blood, preservatives (sodiumchloride, bactericides) etc. are removed.

Fleshing and trimming:

Extraneous tissue is removed. Unhairing is done by chemical dissolution of the hair and epidermis with an alkaline medium of sulphide and lime. When after skinning at the slaughterhouse, the hide appears to contain excessive meat, fleshing usually precedes unhairing and liming.

Bating:

The unhaired, fleshed and alkaline hides are neutralized (deliming) with acid ammonium salts and treated with enzymes, similar to those found in the digestive system, to remove hair remnants and to degrade proteins. During this process hair roots and pigments are removed. The hides become somewhat softer by this enzyme treatment.

Pickling:

Pickling increases the acidity of the hide to a pH of 3 which enables chromium tannins to enter the hide. Salts are added to prevent the hide from swelling. For preservation purposes, 0.03 - 2 weight percent of fungicides and bactericides are applied.

Tanning:

There are two possible processes:

1. Chrome tanning:

After pickling, when the pH is low, chromium salts (Cr^{3+}) are added. To fixate the chromium, the pH is slowly increased through addition of a base. The process of chromium tanning is based on the cross-linkage of chromium ions with free carboxyl groups in the collagen. It makes the hide resistant to bacteria and high temperature. The chromium-tanned hide contains about 2-3 dry weight percent of Cr^{3+}. Wet blue, i.e. the raw hide after the chrome-tanning process, has about 40 percent of dry matter.

2. Vegetable tanning:

Vegetable tanning is usually accomplished in a series of vats (first the rocker-section vats in which the liquor is agitated and second the lay-away vats without agitation) with increasing concentrations of tanning liquor. Vegetable tannins are polyphenolic compounds of two types: hydrolysable tannins (i.e. chestnut and myrobalan) which are derivatives of pyrogallols and condensed tannins (i.e. hemlock and wattle) which are derivatives from catechol. Vegetable tanning probably results from hydrogen bonding of the tanning phenolic groups to the peptide bonds of the protein chains. In some cases as much as 50% by weight of tannin is incorporated into the hide.

Finishing:

Wet blue:

Chromium tanned hides are often retanned - during which process the desirable properties of more than one tanning agent are combined - and treated with dye and fat to obtain the proper filling, smoothness and color. Before actual drying is allowed to take place, the surplus water is removed to make the hides suitable for splitting and shaving. Splitting and shaving is done to obtain the desired thickness of the hide. The most common way of drying is vacuum drying. Cooling water used in this process is usually circulated and is not contaminated.

Crust:

The crust that results after retanning and drying, is subjected to a number of finishing operations. The purpose of these operations is to make the hide softer and to mask small mistakes. The hide is treated with an organic solvent or water based dye and varnish. The finished end product has between 66 and 85 weight percent of dry matter.