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A Material Balance Approach for Assessing Textile Chemical Consumption: A Case Study of Bangladesh Textile Sector

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Abstract: The textile and apparel industry around the world has developed greatly since the invention of cotton gin in the 18th century. It is an immense global market, worth USD 993.6 billion. Bangladesh is the second largest apparel exporter in the world. The textile industry of Bangladesh is the backward linkage industry of the country's $38.7 billion apparel sector. This industry manufactures and exports a wide range of ready-made garments (RMG). All these garments require a series of wet processing stages, in which different chemicals are consumed in large amounts. But there is no tool for assessing textile chemical consumption pattern in Bangladesh. This article introduces a mathematical tool to assess textile chemical consumption at national level by using a material balance approach from fiscal year (FY) 2007-08 to 2019-20. It had been estimated that Bangladesh produced textile products weighing about 2.38 million metric tons consuming almost 1.75 million metric tons of chemicals, worth around 2 billion USD. The market share was found to be around 3.85 % with respect to global textile market share. This novel study quantifies the chemicals consumed by the textile sector of Bangladesh in a fiscal year. It considers the type and nature of the chemicals used in different wet processing stages and the economic aspects of the consumed chemicals. Further analyses might provide ideas for sustainable management of textile chemicals. This study will also help policy makers, investors, and entrepreneurs to drive production of textile chemicals in Bangladesh, thus reducing the import costs and facilitating sustainable business.
Keywords: *textile chemical, annual production and consumption, material balance, sustainable chemical management*

1. Introduction

The textiles and garments industry forms an important element of global trade, particularly for developing and least developed countries. Bangladesh is one of the largest ready-made garment manufacturing countries of the world which has been driving the country's economy since 1990 and providing jobs for more than 50% of the total industrial workforce of the country(Khan, Brymer, & Koch, 2020; Project, 2020). The sector has experienced steady growth with the bulk order of value-added products of top-multinational apparel companies or brands during the last 30 years. This country is home to world's highest number of green factories and has been serving as a compliant sourcing hub for more than 150 countries(BGMEA, 2022). Bangladesh, being the world's second-largest Ready-Made Garment exporter after China, jumped by 15% to $38.76 billion in the fiscal year (FY) 2020-21, after the sector took a roughly $6 billion hit and came down to $27.94 billion in the FY 2019-20 due to the outbreak of COVID-19 pandemic[20, 21] . Bangladesh apparel sector reached up to 81 percent value addition threshold relying on the strong backwardly linked dyeing and finishing facilities, reaching a new height of exports despite the hurdles faced [1, 5, 30] . Major exporting partners of Bangladesh ready-made-garments are :Germany United Kingdom, Spain, France, Italy, Poland, Netherland, Denmark, Belgium and Sweden for the FY 2019-20[7].

Bangladesh textile dyeing industries are arguably the largest chemical consumers within the country, both in terms of commodity and functionality. Commodity chemicals are consumed in gross volumes (such as salts, alkali) and the functionality chemicals are used to accomplish specific purposes according to necessity[11, 23]. Hence, this industry involves thousands of chemicals of wide varieties with a specific purpose in processing and finishing operations[16,19]. A typical dyeing process consists of the following sequence of operations: sizing, de-sizing, scouring, bleaching, mercerization, enzyme treatment, dyeing, wash-off and finishing[3, 28]. Textile chemical consumption depends on several factors, such as fiber, yarn or fabric composition, color, or depth of the shade, dyeing machinery, dyeing procedure, liquor ratio, finishing type and finally consumer requirements[24].

Almost 90% of the required textile chemicals are imported and around 10% of the chemicals are sourced locally. There is no dedicated national database and audit tool for identifying the source, import volume and corresponding usage of these textile chemicals. Besides, the economic aspect of these chemicals is also not well understood or documented. In order to ensure and promote sustainable consumption of chemicals throughout the value chain, a comprehensive understanding of textile wet processing stages (dyeing, printing, finishing and washing) and associated chemical usage is needed for the qualitative and quantitative analysis of textile chemical consumption.

In this article, material balance approach has been used as an audit tool to assess annual chemical consumption in Bangladesh textile dyeing industries. Material balance technique for chemical consumption calculation is a fundamental technique for estimating annual textile production, in terms of textile article export value, weight per piece of garment and average price of per piece of garment. For this approach, representative factories have been selected with definite production processes (knit, woven, denim and yarn dyeing) and annual consumption of chemicals for those wet processing facilities have been calculated. Then those values were scaled up for obtaining the total volume of chemicals consumed in a fiscal year.

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This article generates a chemical consumption audit tool and a database for Bangladesh textile industries analyzing the consolidated prospects of its usage, growth and forecast in the world market. It also analyzes the economic aspects of textile chemicals consumed in Bangladesh. A database indicating the types, quantity, origin, transportation, storage, handling and usage of the textile chemicals can provide a clear understanding of the chemicals consumed in Bangladesh in a fiscal year. This audit tool may act as a backbone of implementing sustainable management of textile chemicals. This study presents a holistic approach towards preparing a database for textile chemicals that are consumed in Bangladesh. It might help textile industries to better monitor and maintain chemical inventory, explore and implement chemical safety and security options, phase out restricted chemicals and use eco-friendly options.

2. Textile Wet Processing in Bangladesh

Textile wet processing is a branch of applied chemistry in which different chemicals, dyestuffs and pigments are applied to textile materials for achieving a desired hue and design. It involves mechanical and chemical treatment to improve the aesthetic value of the fiber, yarn, fabric and garment[17, 29]. Textile finished product is a result of the long manufacturing chain, and the stages involved are – fiber, yarn, fabric, wet processing, and garments manufacturing. Textile wet processing practices in Bangladesh include knit dyeing, woven dyeing, yarn dyeing, denim dyeing, printing and garments washing. The application of coloration varies with different fabric construction, but the basic principle is similar for all kinds of textile articles. Figure 1 represents the general process sequence of fiber to end products in the textile industry and Figure 2 describes the textile chemical supply chain, from port to factory gate.

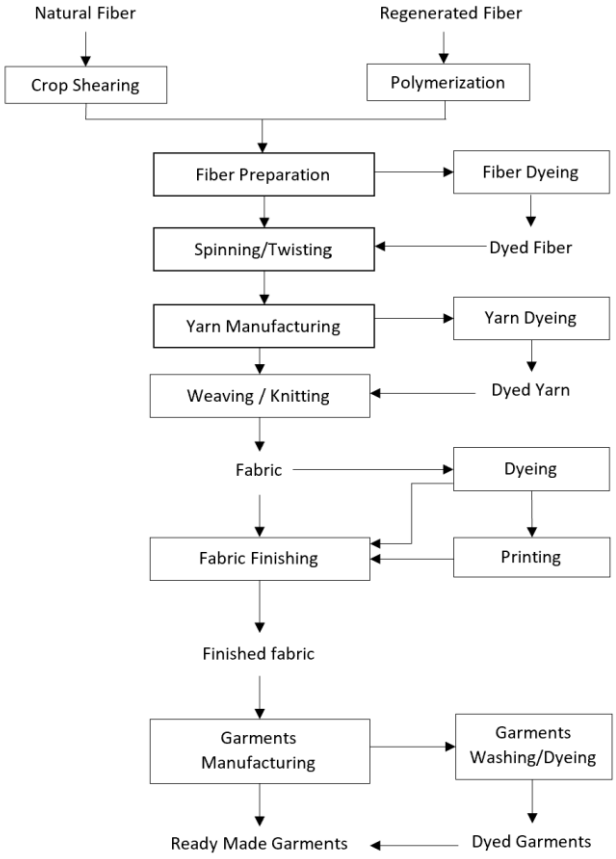

Figure 1: A typical textile manufacturing chain

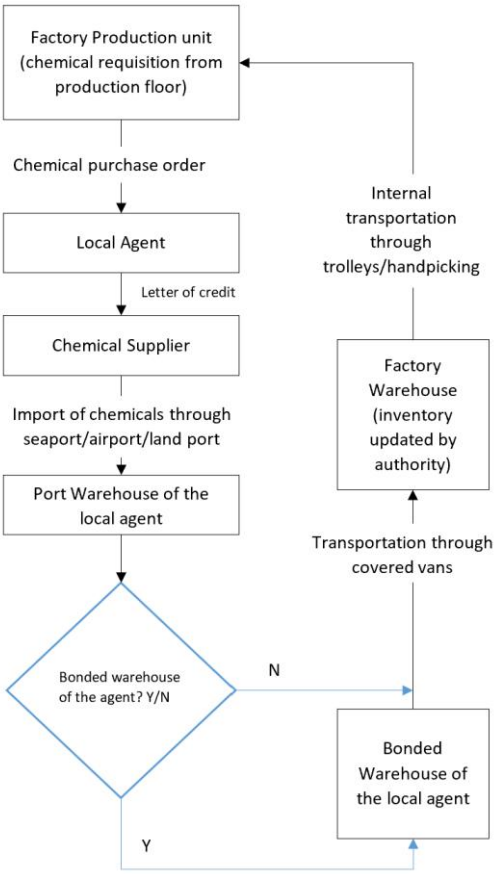

Figure 2: Textile chemical supply chain[10]

2.1 Knit dyeing

Knitting is the method of fabric formation by inter-looping of one or one set of yarns (Spencer, 2001).The batch or exhaust dyeing process is commonly practiced in Bangladesh for coloring of knitted textiles. The performance of dyeing depends on the quality of chemicals. Figures 3, 4 and 5 illustrate the type of chemicals consumed in different types of knit fabric processing units of Bangladesh. Basically, coloration of cotton fabric is done by reactive dyestuff, optical brightening agent is used for whitening of cotton fabric and disperse dyestuff is used for coloration of 100 % polyester fabric. Before finishing, final quality check (QC) is done to ensure that no extra chemicals are needed. If the fabric fails to meet the final QC, the shades are revised, and chemicals are adjusted according to need.

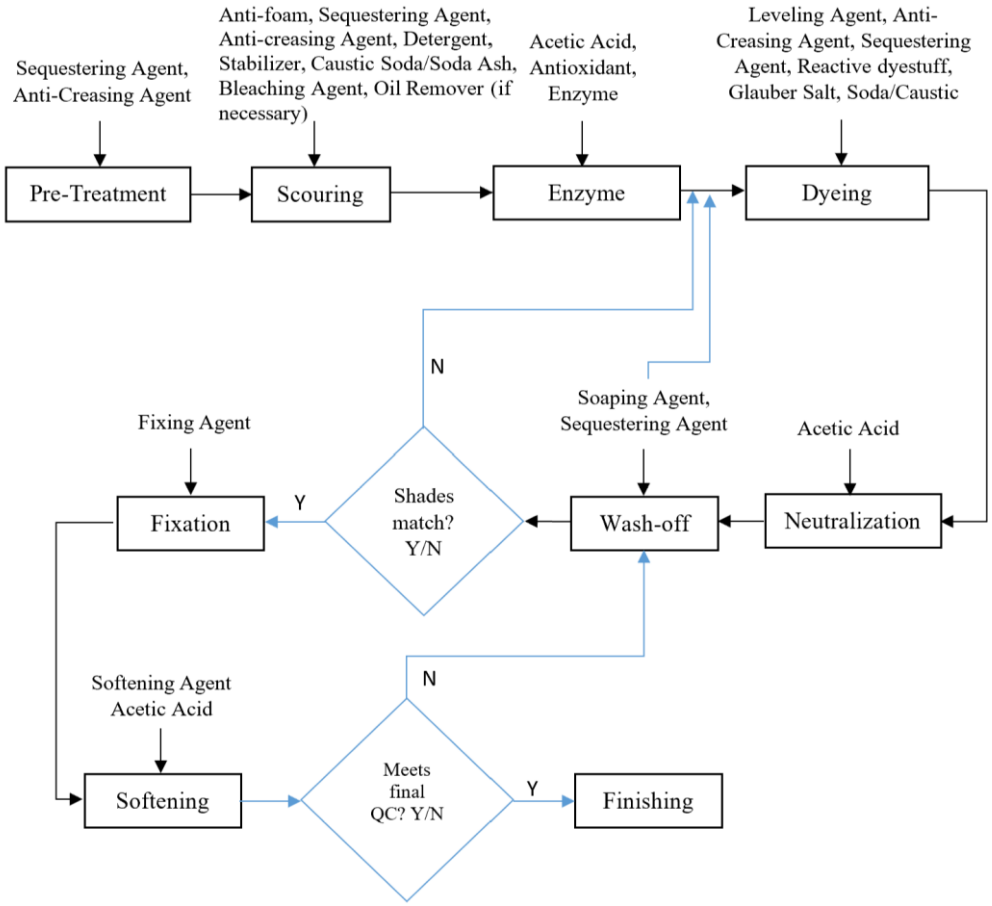

Figure 3: Process sequence and chemical use of cotton knit dyeing (Colored fabric)

Generally, cotton and polyester fabric are mostly dyed in Bangladesh dyeing industry. Reactive dye is a widely used dyestuff for cotton and disperse dye is the universal dyestuff for polyester in knit dyeing industry. Dyeing procedure of polyester fabric is much more complicated than dyeing of cotton fabric. In case of polyester dyeing, high temperature and pressure have to be maintained for good quality products [14].

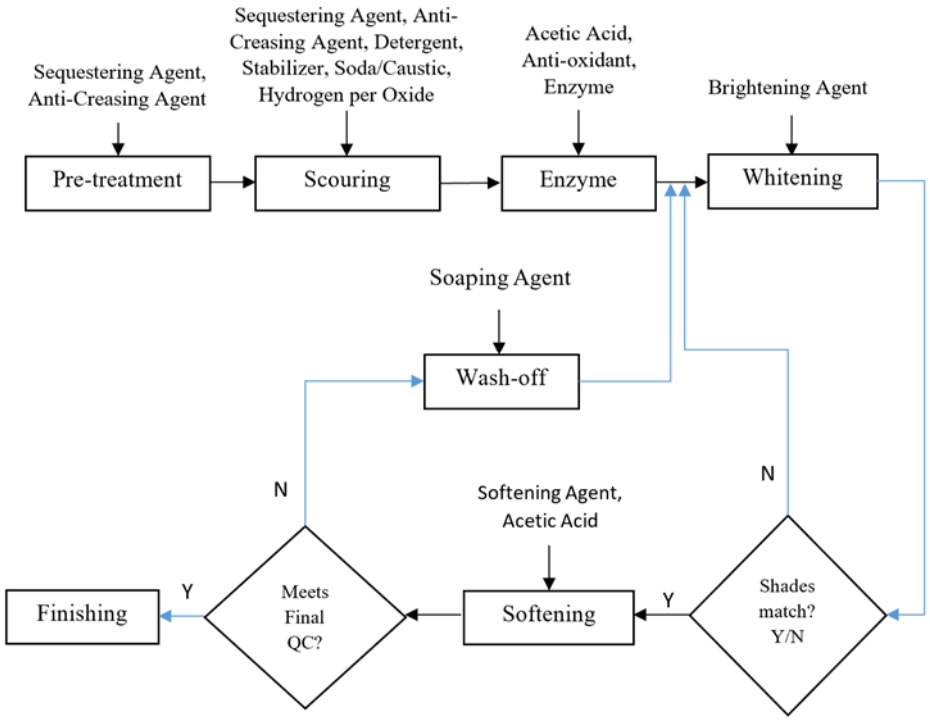

Figure 4: Process sequence and chemical use of cotton knit dyeing (White fabric)

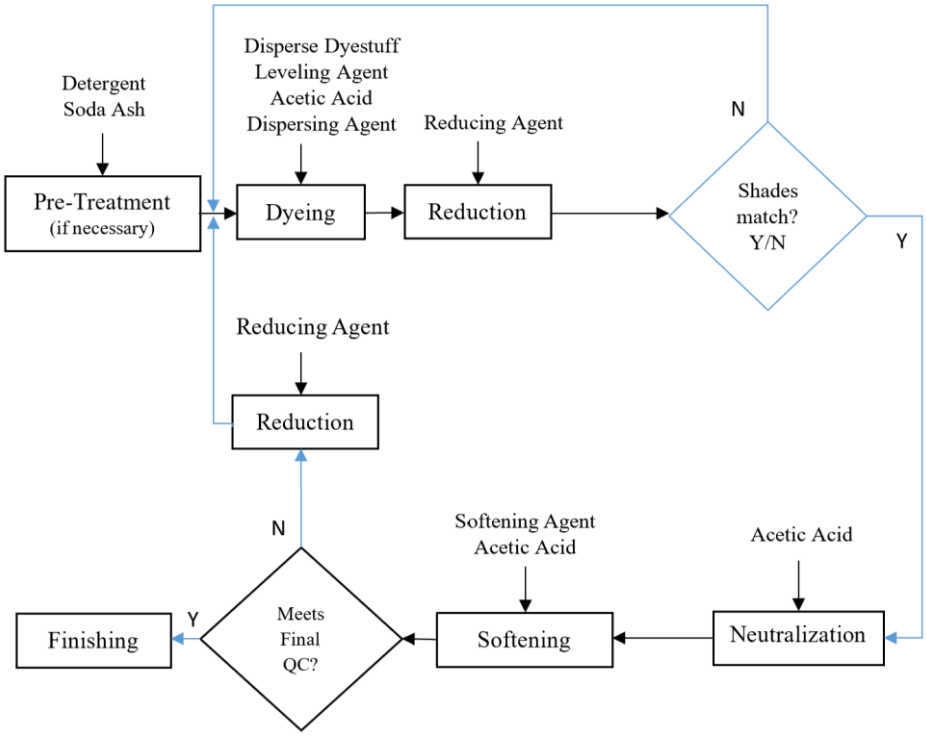

Figure 5: Process sequence and chemical use of 100% polyester knit dyeing

2.2 Woven dyeing

Weaving is a method of fabric formation by intersection or interlacement of two sets of yarns (warp and weft), which cross at right angles to each other[2]. The main technique or process used in woven dyeing fabric is the continuous dyeing process. Color retention of woven fabric may be processed by pad dyeing [22], jigger dyeing or jet dyeing[18,22]. Generally, mercerization of woven fabric depends on the buyer requirements. Liquor-ratio, temperature and dwell time are the fundamental factors of uniform woven dyeing. At present, a diverse range of design and structure-oriented woven fabrics are produced in Bangladesh. Figure 6 illustrates the chemicals involved in each stage of woven textile processing units (coloration of cotton fabric with reactive dyestuff of Bangladesh.

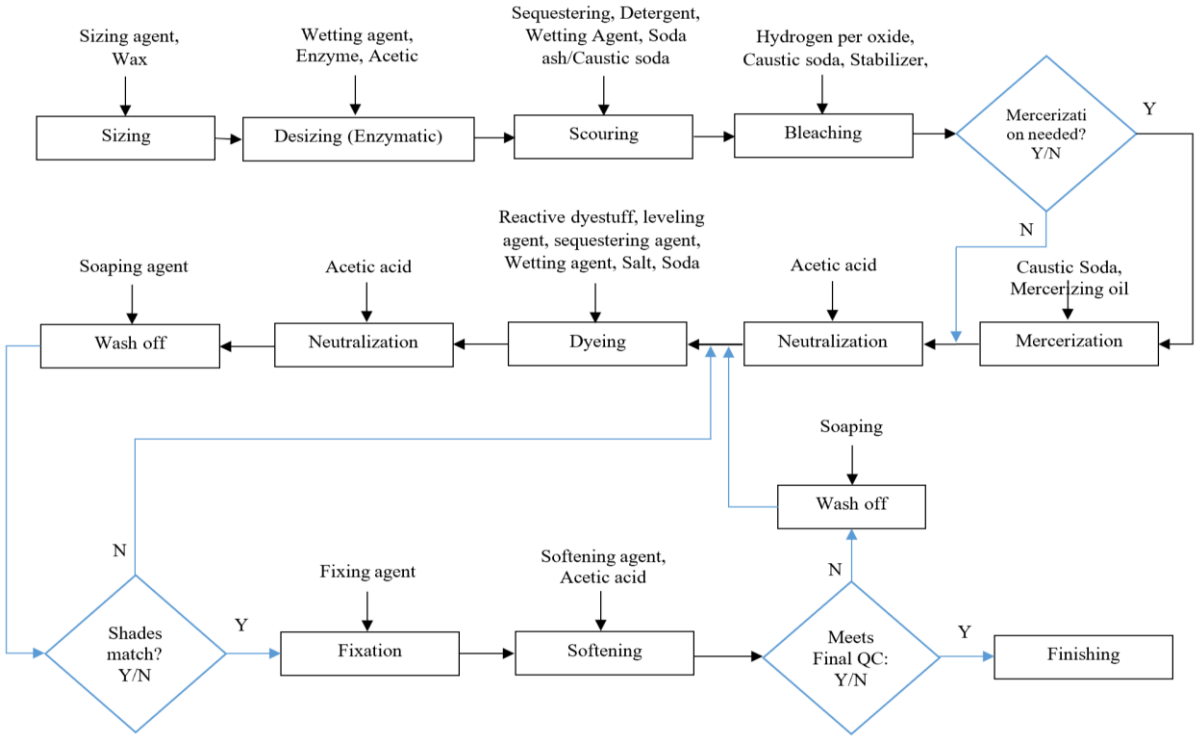

Figure 6. Process sequence and chemical use of cotton woven dyeing (color)

2.3 Denim dyeing

Denim is a stable, durable fabric constructed in a twill weave in which the warp threads are dyed while the weft thread is left undyed[4, 27]. There are different alternative dyeing methods that are used to obtain specific fabric appearance or performance. In Bangladesh denim industry, most of the denim fabrics are produced with 100% cotton and cotton-based blends with polyester or tencel, lycra and nylon etc. Figures 7 and 8 illustrate the nature of chemicals used in each stage in denim processing units (coloration for cotton yarn with indigo and sulfur dyestuff of Bangladesh. There are basically three types of denim warp dyeing in the continuous form: rope form, slasher and loop[25]. In Bangladesh, slasher and rope dyeing forms are used to manufacture denim products. The rope dyeing method is more suitable than slasher dyeing for a higher production rate with better quality dyeing, better wash fastness property, less breakage of ends and better shade consistency. But in contrast, more handling of yarn is needed to open ropes before sizing [8]. Denim washing is one of the most widely used finishing treatments in denim industry. Currently denim washing is done into two ways – mechanical washes (stone wash and sand wash) and chemical washes (acid wash, bleach wash, caustic wash, enzyme wash and pigment wash [4].

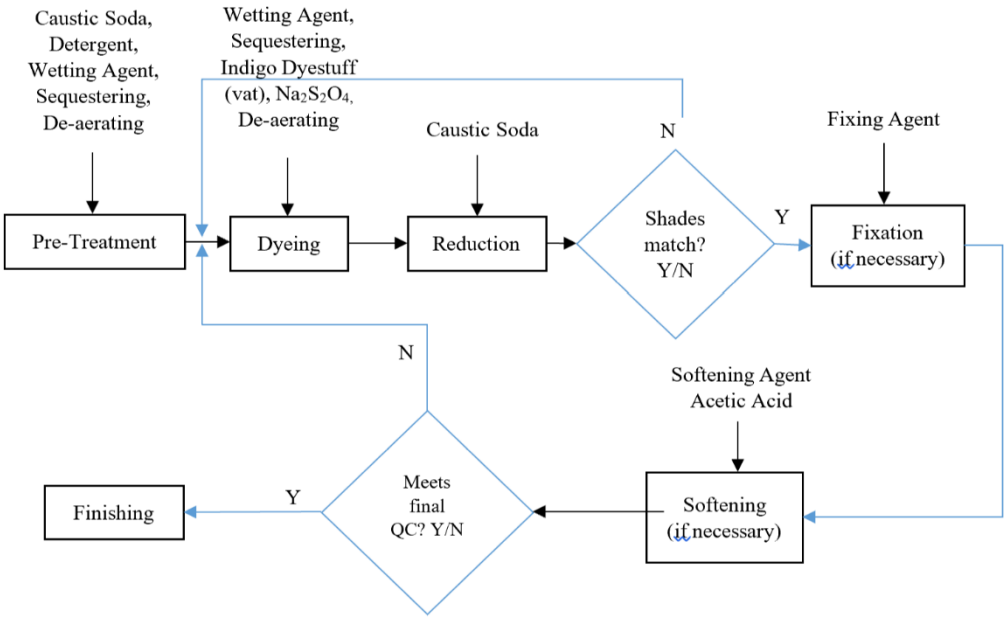

Figure 7. Process sequence and chemical use of denim indigo dyeing (Rope form)

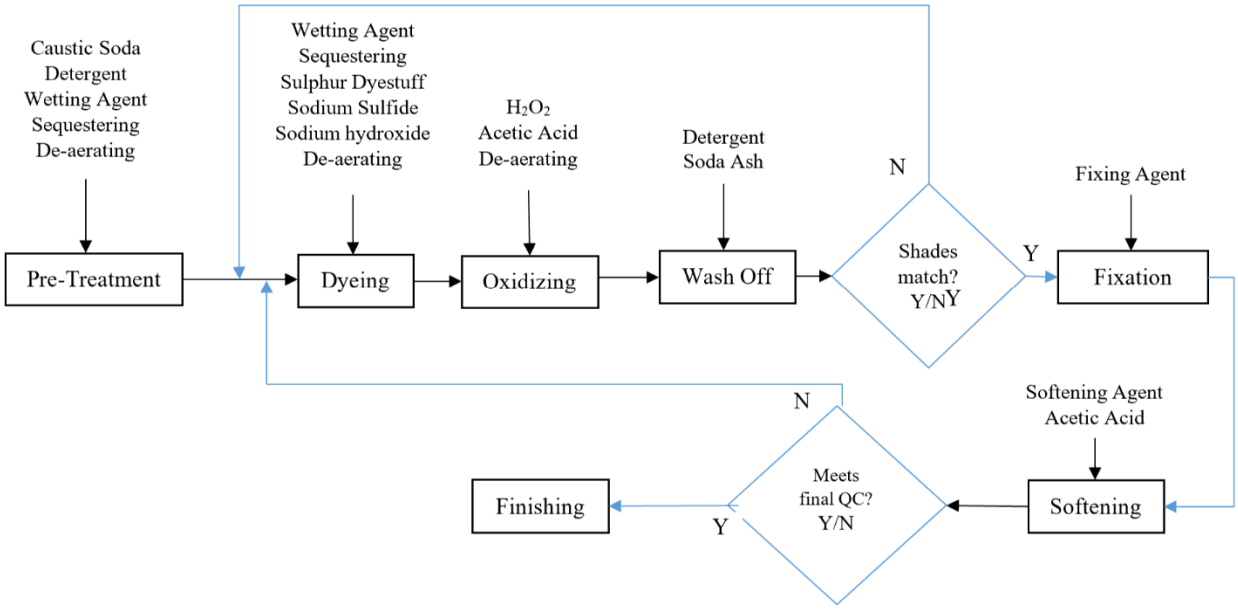

Figure 8. Process sequence and chemical use of denim sulphur dyeing (Rope form)

2.4 Yarn dyeing

Yarn dyeing is a method of coloration in which the yarns are dyed before they have been knitted or woven into fabrics. The main concern in dye selection for yarn dyeing is always the profitable production of a level dyeing with appropriate fastness properties[12]. At present, there are several forms of yarn dyeing methods in practice in the Bangladesh textile industry, namely – skin or hank dyeing, package dyeing, warp-beam dyeing, and space dyeing. The main purpose of yarn dyeing is to penetrate the dyestuff into the fibers, in the core of the yarn. The process sequence of applying color on yarn is alike the knit dyeing process.

2.5 Printing

Textile printing is a localized application of different dyes or pigments and chemicals by different methods (block, roller, screen, ink-jet, direct, resist, discharge, transfer, pigment, burn-out) to different specific areas on the face of a fabric according to predetermined color design[7, 15]. This is commonly attained by applying thickened pastes containing dyes or pigments onto a fabric surface according to the required design[7]. It is a technique of adding color to textile fabric to make decorative patterns. Figure 9 shows the chemicals involved in each stage in printing processing units of Bangladesh. After conducting surveys in several textile manufacturing units, it was estimated that around 40% of woven fabric and 30% of knit fabric were annually printed in Bangladesh textile industry.

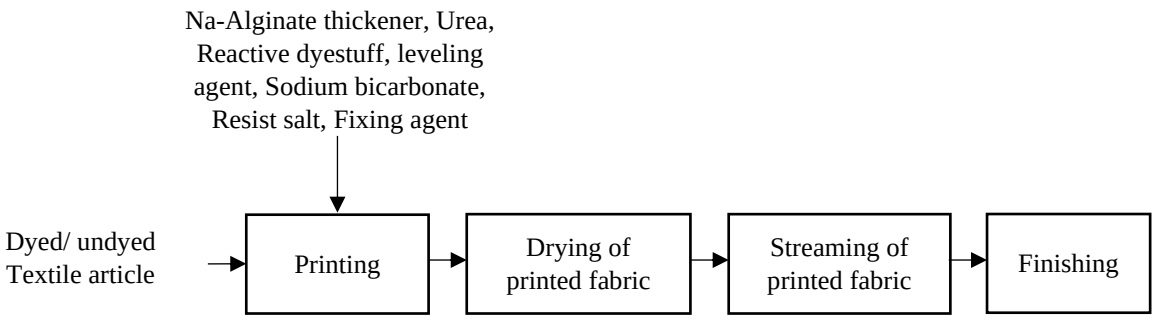

Figure 9. Process sequence and chemical use of printing (Cotton)

2.6 Garment dyeing

Garment dyeing industry, known as the "garments washing industry" is the process of dyeing assembled garment[9]. It is a method of coloration of fully fashioned garments (after stitching) The technique involved in garments dyeing is similar to the standard batch dyeing procedure, where garments are already prepared from either greige or scoured fabrics. The types of garment products such as sweaters, hosiery, T-shirts, socks and trouser are mostly in non-tailored forms. There are various methods used for garment-dyeing, such as cold dyeing, dip dyeing, over-dyeing, reverse dyeing, tie-dyeing, top dyeing, and normal wash.

3. Textile Chemical Consumption by Material Balance Approach

In this study, shirts, trousers, jackets and relevant items were considered as woven fabric, t-shirts and relevant items were considered as knit fabric, and sweaters and relevant items were considered as yarn dyed fabric by consulting with factory personnel. Export value of woven and knit fabric was sourced from online resources shared by the Bangladesh Garment Manufacturers' and Exporters' Association (BGMEA). Average export price and weight for per piece woven and knit fabric were assumed by contacting relevant factory personnel and buying-house merchandizers and from web resources. Apparel items exported from Bangladesh, prices of those items and market share have been enlisted in Appendix A1. An average of item wise product weight (textile products for men, women, and children), average weight of each of those products and their export price in USD has been shown in Appendix A2.

Total fabric production calculation (in million metric ton) was based on the following formula,

Total fabric production

$$= \frac{\Sigma\left(\textbf{Product Export value} \times \frac{\textbf{Weight}}{\textbf{piece}}\right)}{\textbf{Avg.Price per piece} \times 1000 \times 1000} \times \textbf{Manufacturing Wastage } 20\% \quad (1)$$

For identification of chemical consumption per kg of knit, yarn, woven and denim products, firstly representative factories were selected for each type of product and then their dyeing processes were evaluated. Appendix A4 depicts the data for process wise monthly production and chemical consumption report of textile dyeing industries for the fiscal year 2019-20. The annual production and chemical consumption data were evaluated based on monthly production and chemical consumption report obtained from textile industries through visits, interviews and inspections. The data has been shown in Appendix A4. Amount of chemical required on an average to produce per kg fabric was based on the following formula:

Chemical Consumption

$$= \frac{\textbf{Amount of Annual Chemical consumption per year in kg}}{\textbf{Amount of Annual Production in kg}} \times 1000 \quad (2)$$

If amount of chemicals required to produce per kg fabric is known, total volume of chemicals consumed in the textile sector can be evaluated by multiplying with total production capacity of all the RMG factories in Bangladesh. Table A5 in Appendix A5 enlists the average amount of chemicals needed to produce per kg of fabric. Total chemical consumption in million metric ton of textile industry in FY: 2019 – 2020 had been calculated by multiplying total fabric production with chemical required to produce per kg of fabric. Finally, total amount of textile basic and auxiliary chemical consumption (in kilo ton) that were consumed in Bangladesh textile sector in the year of FY 2019-2020 was calculated by the following formula:

$$\textbf{Chemical consumption of textile industry (in kilo ton)} = \frac{\Sigma\ (\textbf{Annual Production} \times \textbf{Chemical Consumed per kg fabric} \times \textbf{Consumption percentage based on Annual Production})}{\textbf{1000} \times \textbf{1000} \times \textbf{1000}} \quad (3)$$

The total annual chemical requirement (in kilo ton) is the summation of chemical consumption data of knit, woven and denim dyeing industries of Bangladesh. By conducting factory visits, textile chemical market surveys, and by interviewing senior merchandizers and chemical responsible executives from ten (10) textile dyeing industries of Bangladesh, the average retail values of per kg chemicals (in USD) were identified. Multiplying the total annual chemical requirement with the average retail values of chemicals estimates the annual chemical market value in USD. Appendix A6 represents the breakdown of annual textile chemical consumption and market value analysis.

$$\textbf{Total Annual Chemical Requirement (in kilo ton)} = \Sigma\ (\boldsymbol{Chemical\ Consumption(\ knit, woven\ and\ denim\ dyeing\ industries})} \quad (4)$$

Annual chemical market value in million USD = ***Total Annual Chemical Requirement (in kilo ton)*** $\times$ ***Average Price of Chemicals per kg in USD)*** (5)

3.1 Textile Fabric Production

Generally, the apparel items for export can be categorized into two major categories- woven and knit apparel. These two categories broadly classify various types of garments, such as shirts, trousers, jackets, t-shirts, and sweaters, which constitute the major production share. Other items are also produced like lingerie, socks, swimwear, sports item, functional fabric etc. In FY: 2019-20, export earnings from Bangladesh ready-made garments were $ 14.04 billion from woven garments and $ 13.90 billion for knit garments according to a report from Export Promotion Bureau (EPB), which contributes about 83 % of the total export.
Table 1 and 2 represent the parameters and the calculation of knit and woven fabric production in Bangladesh.

Table 1. Knit Fabric Production Calculation (FY: 2019-2020)[5]

Parameter	Knit dyeing		Yarn dyeing
	T-Shirt/Single Jersey	OTHERS	Sweater/Pullovers /Cardigans
Product Export Value in Million USD, ***PEV***	5614.00	4696.32	3597.68
Weight/Piece in gm, ***W***	180	160	300
Average Price/piece in USD, ***AP***	2.50	1.75	3.75

$$\text{Annual knit dyed fabric production} = \frac{\Sigma(\boldsymbol{PEV} \times \boldsymbol{W})}{\boldsymbol{AP} \times 1000 \times 1000} \times (\text{Wastage } 20\%)$$
$$= \left(\frac{5614.00 \times 180}{2.50} + \frac{4696.32 \times 160}{1.75}\right) \times \frac{1.20}{1000 \times 1000}$$
$$= 1.000 \text{ million metric ton}$$

In fiscal year 2019-2020, it had been estimated by stakeholder consultation that yarn dyed apparels contributed to about 12.87 % of the overall readymade garment exports in Bangladesh. For calculation, it was assumed that all yarn dyed garments were produced from yarn dyeing industries in Bangladesh.
Hence, annual yarn dyeing production accounted up to 0.409 million metric tons in FY 2019-2020. ($\frac{3597.68 \times 300}{3.75} \times \frac{1.20}{1000 \times 1000}$). Total knit dyed (exported) fabric production in FY 2019-2020 was 1.346 million metric tons **(**1.00 million metric ton + 0.345 million metric ton)

Table 2. Woven Fabric Production Calculation (FY 2019-2020)[5]

Parameter	Woven dyeing				Denim dyeing
	Shirt	Trouser	Jacket	Other's	Denim
Product export value in million USD, ***PEV***	1783.1	5447.13	3514.21	1135.41	2161.30
Weight/Piece (gm), ***W***	250	300	400	200	300
Average Price/piece (USD), ***AP***	3.25	3.50	3.75	1.75	3.50

Annual woven fabric production $= \frac{\Sigma(PEV \times W)}{AP \times 1000 \times 1000} \times$ (Wastage 20%)

$$= \left(\frac{1783.14 \times 250}{3.25} + \frac{5447.13 \times 300}{3.50} + \frac{3514.21 \times 400}{3.75} + \frac{1135.41 \times 200}{2.00}\right) \times \frac{1.20}{1000 \times 1000}$$

= 1.628 million metric ton

After conducting a survey with 10 top textile manufacturers and accumulating extensive information, it was found that around 40% of woven apparels and 75% of denim apparels were imported. If 40 % woven apparels were imported, then annual woven dyed fabric production was 0.977 million metric tons and annual denim dyed fabric production accounted up to 0.228 million metric tons.

$$\left(\frac{2161.30 \times 250}{3.25} \times \frac{1.20}{1000 \times 1000}\right)$$

If 75 % denim apparels were imported, then annual denim dyed fabric production was 0.057 million metric tons. Hence, woven apparel exported in FY 2019-2020 was 1.856 million metric tons (1.628 million metric tons+ 0.228 million metric ton). Therefore, total woven dyed fabric production in FY 2019 – 2020 was 1.034 million metric tons (0.977 million metric tons + 0.057 million metric tons). From these calculations, it can be derived that the volume of apparel exported in FY 2019-2020 was 3.202 million metric tons (1.346 million metric tons + 1.856 million metric tons) and among these, the volume of fabric that was manufactured in the dyeing facilities of Bangladesh textile sector was 2.38 million metric ton (1.346 million metric ton + 1.034 million metric ton). Figure 10 represents the apparel export volume in million metric tons from 2007 to 2020

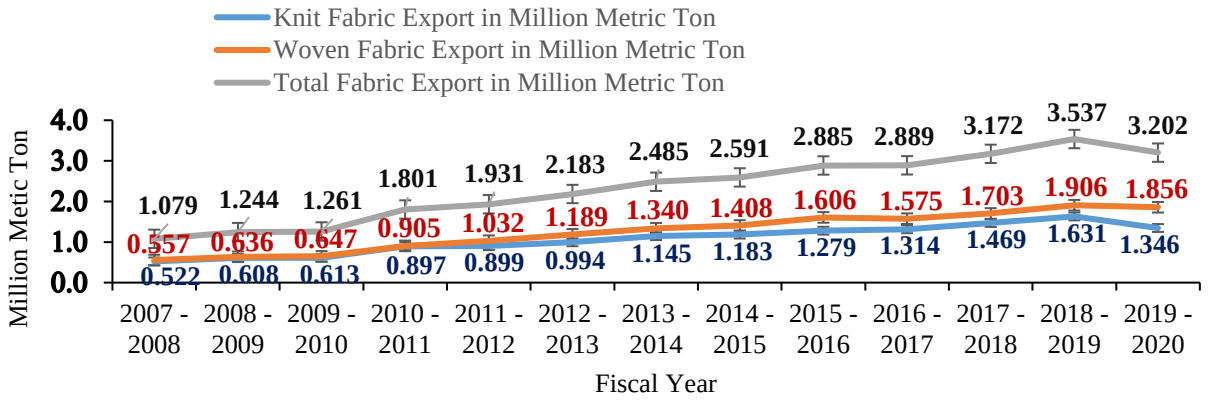

Figure 10. Annual apparel (knit and woven) export trend in Bangladesh (July 2007 – July 2020)

3.2 Textile Chemical Consumption

Bangladesh textile industry consumes vast quantities of basic and auxiliary textile chemicals. The basic chemicals include mainly caustic soda, sulphuric acid, hydrogen peroxide, calcium chloro-hypochlorite or bleaching powder, hydrochloric acid, etc. The auxiliary chemicals include different kinds of complex organic chemicals such as detergents, wetting agents, sequestering agents, anti-creasing agents, levelling agents, post-dyeing treatment chemicals - like soaping and softeners to improve product quality. Besides, fundamental, and auxiliary chemicals such as decolor ants, polymers, coagulants, salts and acids are used in Effluent Treatment Plants (ETP). The chemical consumption varies depending upon yarn count, fabric width, fabric gram per square meter (gsm), product aesthetic design or color, machine efficiency i.e., liquor ratio used in the dyeing machine. The consumption of dyestuffs and chemicals vary from industry to industry depending on the types of fabrics they manufacture.

Woven and denim dyeing processes require 10%-20% of additional chemicals with respect to knit dyeing process. The textile dyeing industry uses a wide range of chemicals, each intended to attain a specific purpose in wet processing. The type of chemicals, their functionality and usage in terms of per unit apparel (per kg of fabric) in wet processing sectors are represented in Table 3.

Table 3: Chemical wise breakdown of textile chemical consumption to produce per kg fabric

Sl No.	Type of Chemical	Functionality	Knit dyeing (gram/kg)	Woven dyeing (gram/kg)	Denim dyeing (gram/kg)	Yarn dyeing (gram/kg)
1.	Sizing agent	Increasing yarn strength	n/a	16-20	16-20	n/a
2.	Wax		n/a	0.75 - 1	0.75-1	n/a
3.	Wetting agent	Reduce surface tension, influence rate of absorption	n/a	30-40	35-40	6-10

4.	Anti-foaming agent	Prevent foam formation	0-8	3-6	3-6	0-10
5.	Anti-creasing agent	Prevent crease mark formation on fabric	6-48	n/a	n/a	n/a
6.	Detergent	Remove suspended materials	3-7	2-4	0.3–1	6-10
7.	Sequestering/Demineralizing agent	Demineralize scouring/dyeing bath, removes hardness, deactivate metal ions	6-30	15-25	1.5-2.5	8-16
8.	De-aerating agent		n/a	n/a	20-25	6-10
9.	Tri-sodium phosphate			0.7-1.2	n/a	n/a
10.	Stabilizer		0.7-7	2–6	n/a	n/a
11.	Sodium sulfate			3-6	n/a	n/a
12.	Enzyme (for enzymatic de-sizing)	Remove protruding fibres from surface		10-15	n/a	n/a
	Enzyme		1-5	n/a	n/a	n/a
	Caustic soda		6-18			10-14
	Caustic soda (with mercerizing)	Maintains color depth depending on fabric thickness	n/a	220-300	n/a	n/a
13.	Caustic soda (for sulphur rope dyeing)		n/a	n/a	180-250	n/a
	Caustic soda (for indigo dyeing)		n/a	n/a	150-220	n/a
	Hydrogen per oxide	Remove natural color of cotton fabric and for better absorption of dyes.	6-45	25-30		20-28
14.	Hydrogen per oxide (For sulphur rope dyeing)		n/a	n/a	12-18	n/a
15.	Brightening agent	Brighten white fabric	1-9	1-9		1-9
16.	Soda ash	Accelerate exhaustion process	30-100	60-100	0.2-0.4	70-120
17.	Glauber salt		100-500	150-250	n/a	250-450
	Acetic acid	Neutralization at different stages of dye bath	5-20	8-15	n/a	10-18
18.	Acetic acid (for sulphur rope dyeing)		n/a	n/a	15-25	n/a
	Acetic acid (for indigo dyeing)		n/a	n/a	8-15	n/a
19.	Hydrose	Use as reducing agent	6-18	n/a	25-30	8-24
20.	Hydrogen peroxide killing agent (Oxidizing agent)	Remove excess peroxide from dye bath	1-3	n/a	n/a	n/a
21.	Levelling agent (Cotton)	Ensure level dyeing	6-12	4-8	4-8	10-24
22.	Soaping agent	Remove unfixed dye from fabric surface	1-10	0.5-2.5	n/a	8-16
23.	Fixing agent	Fix unfixed dye on fabric	3-6	3-6	25-30	n/a
24.	Dispersing agent	Aggregate dispersed dyestuff	6-12	6-12	6-12	8-24
25.	Reducing agent	Strip dye from fabric	6-18	0.8-1.2	n/a	n/a
26.	Softening agent	Soften the fabric surface and make fabric more comfortable to wear.	5-10	6-12	15-18	n/a

3.3 Annual Textile Chemical Consumption

Material balance analysis was conducted to calculate annual textile chemical consumption based on product wise total textile chemical consumption of the dyeing industries. The calculations were carried out based on certain specific assumptions, such as printing process has been 30% of the annual knit fabric production, 40% of annual woven fabric production and Garment washing was 8% of annual knit fabric production. From the calculations it was found that the annual chemical consumption in the textile sector of Bangladesh in FY 2019-2020 was 1.757 million metric tons. Table 4 represents annual textile fabric production and chemical consumption in Bangladesh for FY 2019-2020.

Table 4. Annual Textile Fabric Production and Chemical Consumption in Bangladesh (FY 2019-20)

Parameter	Fabric Production in Million Metric ton	Fabric colored in Million Metric ton (P)	Chemical Consumed to produce per kg fabric in kg (C)	Total Annual Chemical Consumption in Million Metric ton, [T = P x C]
Knit Dyeing	1.000	1.345	0.500	0.500
Yarn Dyeing/Sweater	0.345		0.575	0.199
Woven Dyeing	0.977	1.034	0.875	0.855
Denim Dyeing	0.057		0.370	0.021
Printing (30% of Knit Fabric Production)		0.300		0.075
Printing (40% of woven Production)	n/a	0.391	0.250	0.098
Garments Washing (8% of Knit Production)		0.080	0.125	0.010
Total	2.379			1.757

Figure 11. depicts textile annual production and chemical consumption trend in textile industries from 2007 to 2020, derived from Eqn 1, 2 and 3. The graph indicates the increasing demand of textile chemicals, although the volume decreased in FY 2019-20 due to nationwide lockdown imposed since the outbreak of COVID-19 pandemic. Local chemical industries of Bangladesh produce basic chemicals which are consumed by the textile industries. But for dyestuff, auxiliaries and other chemicals, this sector is still largely dependent on chemical import.

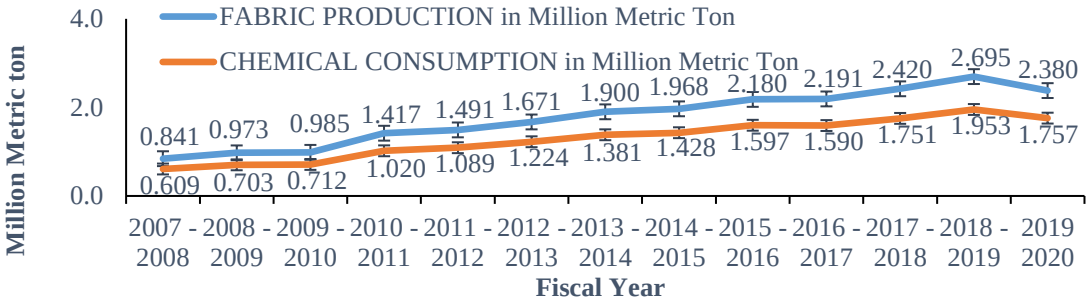

Figure 11. Textile chemical consumption trend with respect to annual production in Bangladesh (July 2007 – July 2020)

4. Economic aspects of textile chemical consumption

Sustainable chemical consumption the key to growth and competitiveness of Bangladesh textile dyeing sector. The competitiveness of Bangladesh's textile sector is impacted by an inadequate domestic supply of textile chemicals. Implementation of sustainable options in the textile production play key roles in continuous economic growth of the sector. The idea of resource efficiency regarding textile chemical production is a fundamental element of sustainable consumption. It can reduce the import dependency of basic and auxiliary chemicals. Figure 12 represents the textile chemical market value trend in Bangladesh from 2007 to 2020. These values were estimated using Eqn. 5.

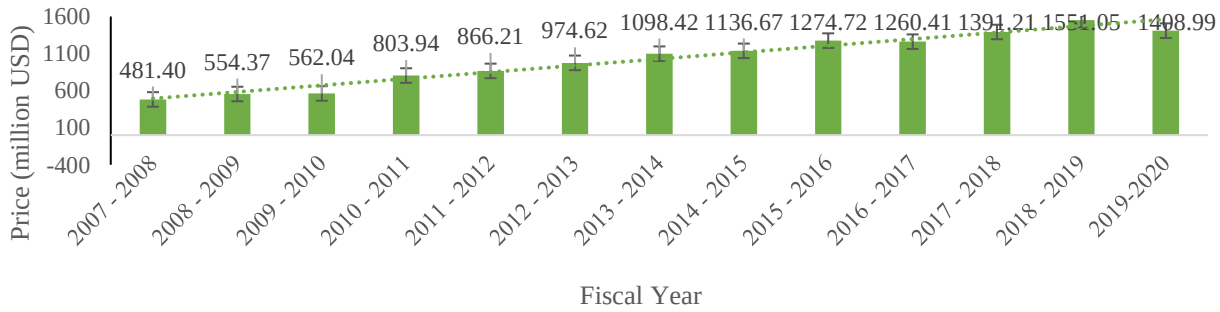

Figure 12. Textile chemical market value trend in Bangladesh (FY: July 2007 – July 2020)

Textile chemical consumption in Bangladesh had been estimated at around 1408.99 million USD in fiscal year 2019-2020. It is evident that the consumption decreased in FY2019-20 due to COVID-19 outbreak, but the trend of chemical market value presented in figure 12 indicates that the demand for textile chemicals will keep increasing in the future. At present, a limited number of the manufacturers produce chemicals in Bangladesh. These are mainly bleaching powder, caustic soda, hydrochloric acid, hydrogen peroxide, liquid chlorine, paraffin wax, sodium hypochlorite, and sulphuric acid. Among these, only caustic soda, hydrogen per oxide and sulphuric acid are used in textile dyeing industries. Figure 13 represents market value trend of mostly used textile chemicals in Bangladesh from July 2015 – July 2020.

	Glauber salt	Caustic soda	Sequestering agent	Wetting agent	Soda ash	Anti-creasing agent	Thickener	Enzyme	Acetic acid	Hydrogen per oxide
2015-2016	72.71	64.53	43.75	44.14	40.60	35.98	31.41	23.45	19.44	14.47
2016-2017	74.00	63.28	44.47	44.24	41.33	33.48	29.85	22.50	19.77	14.57
2017-2018	81.38	68.61	48.50	46.92	44.88	41.27	34.38	25.08	21.55	15.93
2018-2019	90.67	76.71	54.13	52.68	50.13	45.18	38.09	27.95	24.04	17.77
2019-2020	78.59	73.65	47.77	50.63	44.49	36.97	34.20	26.21	21.34	15.90

Figure 13: Market value of top ten textile chemicals consumed in Bangladesh (FY: July 2015 – July 2020)

Considering the huge volume of chemicals consumed in a fiscal year, manufacturing textile chemicals can be a futuristic business tool for Bangladesh. It may also empower sustainable textile production by improving the overall business ecosystem. Figure 14 depicts the quantity of top ten textile chemicals based on demand that has been consumed in Bangladesh textile sector in FY 2019-20.

	Glauber salt	Caustic soda	Soda ash	Hydrogen per oxide	Thickener	Sequestering agent	Wetting agent	Acetic acid	Anti-creasing agent	Enzyme
2015-2016	427.70	129.07	116.01	36.17	34.91	33.65	22.07	19.44	16.35	9.02
2016-2017	435.28	126.55	118.08	36.43	33.17	34.21	22.12	19.77	15.22	8.66
2017-2018	478.70	137.21	128.22	39.81	38.21	37.31	23.46	21.55	18.76	9.65
2018-2019	533.37	153.55	143.23	44.44	42.33	41.64	26.34	24.04	20.54	10.75
2019-2020	462.28	147.31	127.11	39.76	38.00	36.75	25.32	21.34	16.81	10.08

Figure 14: Quantity wise of top ten textile chemical requirement in Bangladesh (FY: July 2015 – July 2020)

5. Conclusion

This study demonstrates the amount of chemicals consumed in Bangladesh textile sector in a fiscal year. It had been calculated that 1.75 million metric ton of chemicals have been consumed to produce 2.38 million metric fabrics in FY 2019-20. More than 90% of the chemicals that are being used in the wet processing units of textile industries are imported. Hence, this bears a noteworthy impact on the economy of Bangladesh. The yearly expenses of chemical import are on the rise. In the post COVID-19 time, the price hike of chemicals is imminent. Therefore, it is important for Bangladesh to look for alternative options of chemical import. One option of substituting chemical import is formulation of chemicals within the country. But the local capacity is not yet developed. Moreover, the recent drive for sustainability involving chemical safety and security has been instigating changes in the chemical management system of the textile industries. This methodological study can help factory management to maintain chemical traceability starting from procurement to disposal. This article can also contribute to explore advanced traceability options and address live inventory management systems by helping factories to calculate their annual chemical consumption using the material balance audit tool. This will also help to identify the total life cycle of the chemicals used in wet processing. This study may also help the sectoral

stakeholders to identify the amount of chemicals consumed and procured in textile industries in a fiscal year, analyze the market of regularly consumed textile chemicals within the country and plan for formulation of chemicals within the country by enhancing local capacity. In addition, the mathematical tool used in this study may be implicated to prepare relevant databases of chemical consuming industries of Bangladesh.

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Supplementary Material

Appendix A1: Apparel Items Exported from Bangladesh

Table A1. Apparel Items Exported from Bangladesh (FY: 2019-2020)

Items	Price (Million US$)	Percentage (%)
Shirts	1,783.14	6.38
Trousers	5,447.13	19.49
Jackets	3,514.21	12.57
T-Shirt	5,614.00	20.09
Sweater	3,597.68	12.87
Estimated Denim	2,161.30	7.73
Knit apparel (others)	4,696.32	16.80
Woven apparel (others)	1,135.41	4.06
Total Apparel	**27,949.19**	**100.00**

Appendix A2: Item wise average product weight and export price in USD

Table A2. Average item wise product weight and export price in USD

Product Items	Child's + Men's + Women's per piece product weight		Average weight of per piece product	Export Price in USD		Average Price in USD
	Minimum	Maximum		Minimum	Maximum	
T-Shirt	130	230	180	1.50	3.50	2.50
Sweater	220	380	300	2.50	5.00	3.75
Shirt	180	320	250	1.50	5.00	3.25
Trouser (Knit + Woven)	250	350	300	2.00	5.00	3.50
Denim	200	400	300	1.50	5.00	3.25
Jacket/Coat	300	500	400	2.50	5.00	3.75
Knit Other's Product Item						
Sock's	50	150	100	0.40	1.00	0.70
Knit women's suit's	180	360	270	2.20	4.50	3.35
Outfit	180	360	270	2.20	4.50	3.35
Underpants	60	150	105	0.40	1.20	0.80
Leggings	150	220	185	1.50	3.50	2.50
Hat (knit)	120	220	170	1.00	2.00	1.50
Gloves	60	220	140	0.50	2.00	1.25
Knit Babies garments	100	300	200	1.50	3.20	2.35
Swimming suit	60	120	90	0.60	1.50	1.05
Lingerie	40	100	70	0.50	0.80	0.65
Average per piece other's knit item product weight			160	Average per piece other's knit item product price		1.75
Woven Other's Product Item						
Gabardine	200	360	280	1.75	3.50	2.63
Shorts	80	200	140	0.50	1.75	1.13
Outfits	150	360	255	2.00	3.50	2.75
Anoraks	130	320	225	1.50	3.00	2.25
Tops & Lingerie	60	180	120	0.50	0.80	0.65
Skirt	200	350	275	2.00	2.50	2.25
Brassieres	50	160	105	0.50	0.75	0.63
Average per piece other's woven item product weight			200	Average per piece other's woven item product price		1.75

Appendix A3:

Table A3. Apparel items exported from Bangladesh textile industry [5]

Year	Type of Apparel: Knit (Export value in million USD)			Total Knit Apparel Export value in million USD	Type of Apparel: Woven (Export value in million USD)					Total woven Apparel Export value in million USD
	T-Shirt	Others	Sweater		Shirts	Trousers	Jackets	Others	Denim	
2006-2007	2208.90	1096.61	1248.09	4553.60	943.44	2201.32	1005.06	132.81	375.00	4657.63
2007-2008	2765.56	1292.87	1474.09	5532.52	915.60	2512.74	1181.52	200.00	300.00	5167.28
2008-2009	3065.86	1504.78	1858.62	6429.26	1000.16	3007.29	1299.74	200.00	300.00	5918.51
2009-2010	3145.52	1542.38	1795.39	6483.29	993.41	3035.35	1350.43	159.24	475.00	6013.43
2010-2011	4696.57	2297.30	2488.19	9482.06	1566.42	4164.16	1887.50	200.00	300.00	8432.40
2011-2012	4713.11	2432.94	2340.34	9486.39	1733.54	4686.39	2231.16	202.25	750.00	9603.34
2012-2013	5143.22	2711.93	2620.73	10475.88	1972.89	5185.48	2634.28	247.20	1000.00	11039.85
2013-2014	5863.81	3253.06	2932.94	12049.81	2173.73	5690.78	2973.16	238.95	1365.45	12442.07
2014-2015	6064.13	3533.50	2829.16	12426.79	2271.43	5697.83	3183.17	235.73	1676.45	13064.61
2015-2016	6118.53	4054.42	3182.47	13355.42	2317.09	6319.00	3774.08	588.84	1739.73	14738.74
2016-2017	5861.98	3639.81	3361.53	13757.25	2108.38	6026.69	3546.88	817.11	1893.53	14392.59
2017-2018	6292.25	5221.56	3674.70	15188.51	2063.57	6389.38	3978.47	1439.48	1986.94	15426.25
2018-2019	7011.26	5621.37	4255.91	16888.54	2324.85	6939.61	4384.81	1379.07	2216.39	17244.73
2019-2020	5614.00	4696.32	3597.68	13908.00	1783.14	5447.13	3514.21	1135.41	2161.30	14041.19

Here, Knit apparel export value (others) = Total knit apparel export value: (T-Shirt + Sweater) and, other Woven apparel export value = Total woven apparel export value: (Shirt + Trouser + Jacket + Denim).

Appendix A4

Table A4. Process wise Monthly Production and Chemical Consumption Report of Textile dyeing factory [Fiscal Year 2019–2020]

Month	Knit dyeing industries annual report			Yarn dyeing industries annual report		
	Knit dyeing production (kg)	Total dyestuff + chemical consumption (kg)	Average chemical consumption in kg/kg	Yarn dyeing production (kg)	Total dyestuff + chemical (kg)	Average chemical consumption in kg/kg
July	229617	120286.262	0.524	349509	213134.339	0.610
August	301001	164640.803	0.547	339796	196113.654	0.577
September	230277	119887.949	0.521	319727	181476.871	0.568
October	300615	136596.281	0.454	358417	193395.127	0.540
November	350759	145352.503	0.414	398575	221971.301	0.557
December	318448	139926.945	0.439	384179	218608.657	0.569
January	267977	142885.157	0.533	332769	183896.751	0.553
February	247515	135652.815	0.548	328881	176920.516	0.538
March	328588	151581.053	0.461	376136	208674.652	0.555
April	351912	171951.303	0.489	389293	225199.985	0.578
May	438068	233082.079	0.532	399667	257218.293	0.644
June	274452	146835.142	0.535	364615	224571.442	0.616
Average Chemical Required in kg to produce per kg knit fabric			**0.500**	**Average Chemical Required in kg to produce per kg knit fabric**		**0.575**
Information for Knit dyeing industry: Liquor to fabric weight ratio: 1:6 (Normally varies 1:6~8); Dyeing capacity: The average per day dyeing capacity of the industry is 12 ~ 14 tons of knit fabric.				Information for yarn dyeing industry: Liquor to fabric weight ratio: 1:8. Dyeing capacity: The average per day dyeing capacity of the industry is 13 ~ 14.5 tons of yarn dyed fabric.		
Month	**Woven Dyeing Industries Annual Report**			**Denim Dyeing Industries Annual Report**		
	Production (kg)	**Total Dyestuff + Chemical Consumption (kg)**	**Average Chemical Consumption in kg/kg**	**Production (kg)**	**Total Dyestuff + Chemical Consumption (kg)**	**Average Chemical Consumption in kg/kg**
July	122763.344	121879.805	0.993	897217.2274	344968.061	0.384
August	120838.646	110159.144	0.912	816495.218	297974.305	0.365
September	129136.573	101513.942	0.786	699732.1341	249134.332	0.356
October	146833.821	138068.693	0.940	692815.771	241967.350	0.349
November	158654.606	127603.187	0.804	746408.6652	269356.125	0.361
December	183119.799	144576.547	0.790	693195.3893	259622.690	0.375
January	192852.104	147631.702	0.766	677792.863	264125.805	0.390
February	131346.131	125106.500	0.952	642979.2652	247151.772	0.384
March	121600.227	138749.776	1.141	670794.437	258926.653	0.386
April	175862.437	146701.107	0.834	717724.9223	264563.540	0.369
May	192701.777	144411.604	0.749	780576.4079	286471.542	0.367

June	105648.792	87412.597	0.827	1012340.713	356776.300	0.352
Average Chemical Required in kg to produce per kg woven fabric			**0.875**	**Average Chemical Required in kg to produce per kg denim fabric**		**0.370**
Information woven and denim dyeing industry: Monthly production of woven and denim industry generally stands at yard, so the values were converted to kg using following formula. **Production Meter to Kg conversion formula:** Production (kg) = [Production(meter) x GSM x Dia. (meter)] /1000 Assumption: GSM of woven = 250 and dia. Of woven fabric = 1.5 meter and GSM of denim fabric = 250 (generally lies between 4 ~ 15 ounce) and denim fabric dia. = 1.46 meter. Dyeing capacity: The average per day dyeing capacity of the woven industry is 5.5 ~ 7 tons of and denim industry is 28 ~ 30 tons.						
Month	**Print (Knit + woven) Dyeing Industries Annual Report**			**Garments Washing Industries Annual Report**		
	Production (kg)	**Total Dyestuff + Chemical Consumption (kg)**	**Average Chemical Consumption in kg/kg**	**Production (kg)**	**Total Dyestuff + Chemical Consumption (kg)**	**Average Chemical Consumption in kg/kg**
July	77665	17917.761	0.231	4937	584	0.118
August	93024	21277.222	0.229	3596	494	0.137
September	117679	33490.983	0.285	4800	587	0.122
October	163129	38237.847	0.234	5334	621	0.116
November	204650	50838.342	0.248	4798	579	0.121
December	199111	51987.222	0.261	3850	535	0.139
January	187679	47098.985	0.251	3996	544	0.136
February	133129	38287.817	0.288	4929	617	0.125
March	173129	42267.347	0.244	4992	585	0.117
April	154650	40838.162	0.264	5584	593	0.106
May	194650	37838.142	0.194	4636	549	0.118
June	173764	47917.761	0.276	4121	566	0.137
Average Chemical Required in kg to produce per kg printed fabric			0.250	**Average Chemical Required in kg to produce per kg garments washing fabric**		0.125
Information for printing and garments washing industry: The average per day printed capacity of the industry is 5.5-6.5 tons and garments washing industry is 175-200 kg of fabric						

Appendix A5

Table A5. Process wise average chemical consumption to produce per kg fabric

Types of dyed fabric		Average chemical consumption (gram)
Knit dyed fabric (basic)		**500**
Knit dyed fabric	White Color	50-150
	Light Color	150-450
	Medium/Dark Color	450-650
	Extra Dark Color	650-800
	Black Color	400-750
	Double Part	300-800
	100 % Polyester	80-200
Yarn dyed fabric		**575**
Woven dyed fabric		**875**
Denim dyed fabric		**370**
Printed dyed fabric		**250**
Garments washed fabric		**125**

Appendix A6: Annual textile chemical consumption and market value analysis: July 2019 – July, 2020)

Here, Total fabric production in million metric ton (P) = Knit dyed (P_k) = 1.223, woven dyed (P_w) = 1.007, denim dyed (P_d) = 0.057, yarn dyed (P_y) = 0.408, knit printed (P_k) = 0.366, woven printed (P_w) = 0.402, garments washing (P_g) = 0.097..

Table A6: Breakdown of annual textile chemical consumption and market value analysis

Sl No.	Chemicals	Average Chemical Consumed for per kg fabric in gram Q	Average Per Kg Chemical Price in USD, f	Chemical Consumption Percentage (based on annual Production), W	Chemical Consumption of knit dyeing industries in kilo ton, a= (P_k ×Q×W)	Chemical Consumption of woven dyeing industries in kilo ton, b = (P_w×Q×W)	Chemical Consumption of denim dyeing industries in kilo ton, c= (P_d×Q×W)	Chemical Consumption of yarn dyeing industries in kilo ton, d= (P_y×Q×W)	Total annual chemical consumption in kilo ton, (s = a+b+c+d)	Annual Chemical Market Value in million USD. (f × s)
1.	Sizing Agent	18	0.90	45%		7.91	0.46		8.38	7.54
2.	Wax	0.875	0.70			0.38	0.02	-	0.41	0.29
3.	Anti-foaming Agent	4.5	3.25	10%	0.45	0.44	0.03	0.16	1.07	3.48
4.	Anti-Creasing Agent	24	2.20	70%	16.81				16.81	36.97
5.	Wetting Agent	32	2.00	70%		21.89			25.32	50.63
		37.5					1.50			
		8						1.93		
6.	Detergent	3	1.80	75%	2.25	2.20			6.55	11.79
		8						2.07		
	Detergent (Sulphur rope dyeing)	0.65					0.03			
7.	Sequestering agent	18	1.30	80%	14.40				36.75	47.77
		20				15.63				
		24						6.63		
		2		70%			0.08			
8.		8	1.00	75%				2.07	2.52	2.52

	De-Aerating agent	22.5		35%			0.45			
9.	Tri-sodium phosphate	0.95	0.40	70%		0.65			0.65	0.26
10.	Stabilizer	2.25	1.50	80%	1.80				7.66	11.49
		4				5.86				
11.	Sodium Sulfate	4.5	0.01	75%		3.30			3.30	0.03
12.	Enzyme	2.5	3.2	75%	1.88				10.08	32.25
	Enzyme (with enzymatic de-sizing)	14		60%		8.21				
13.	Caustic soda	9	0.50	85%	7.65				147.31	73.65
		12						3.52		
	Caustic soda (with mercerizing)	260		50%		127.01				
	Caustic soda (sulphur rope dyeing)	215		40%			4.90			
	Caustic soda (indigo dyeing)	185					4.22			
14.	Hydrogen per oxide	18	0.40	75%	13.50				39.76	15.90
		27.5				20.15				
		24		70%				5.80		
	Hydrogen per oxide (sulphur rope dyeing)	15		35%			0.30			
15.	Brightening Agent	5	2.75	10%	0.50	0.49		0.17	1.16	3.19

16.	Acetic acid	10	1.00	80%	8.00				21.34	21.34
		11.5				8.99		.		
		14		75%				3.63		
	Acetic acid (Sulphur rope dyeing)	20		40%			0.46			
	Acetic acid (Indigo dyeing)	11.5					0.26			
17.	H_2O_2 killing agent	1.5	1.00	80%	1.20				1.20	1.20
18.	Levelling agent - cotton	9	1.40	75%	6.75			2.33	13.74	19.23
		6				4.40	0.26			
19.	Levelling agent – polyester	6	2.20	10%	0.60	0.59	0.03	0.21	1.43	3.14
20.	Soda ash	65	0.35	70%	45.51				127.11	44.49
		80		75%		58.62				
		95		70%				22.97		
		0.3		65%			0.01			
21.	Glauber salt	300	0.17	75%	225.07				462.28	78.59
		200				146.55				
		350						90.66		
22.	Sodium sulfide	2	0.35	65%			0.07		0.07	0.03
23.	Soaping agent	5.5	1.90	65%	3.58				7.37	14.00
		1.5		75%		1.10				
		12		65%				2.69		
24.	Reducing agent	12	2.25	5%	0.60				0.70	1.57
		1		10%		0.10				
25.	Fixing agent - color (Cotton)	4.5	2.00	50%	2.25	2.20			4.92	9.84
		27.5		30%			0.47			
26.	Fixing Agent -	4.5		10%	0.45	0.44			0.89	1.78

	white (Cotton)									
27.	Fixing Agent - Color (Polyester)	3.5		8%	0.28	0.27		0.10	0.88	1.76
		40		10%			0.23			
28.	Softener – Color (Cotton)	7.5	1.60	55%	4.13			1.42	10.62	16.99
		9				4.84				
		13.5		30%			0.23			
29.	Softener - White (Cotton)	7.5		10%	0.75			0.26	1.94	3.10
		9				0.88	0.05			
30.	Dispersing agent	16	1.50	10%				0.55	2.33	3.50
		9			0.90	0.88				
31.	Hydrose	27.5	1.20	60%			0.94		3.73	4.47
		12		10%	1.20	1.17		0.41		
32.	* Others (dyestuff + auxiliaries and ETP chemicals)	-	1.2		139.64	409.75	6.09	50.99	606.48	727.77
Total (knit + woven + denim + yarn)					500.15	854.90	21.09	198.59	1574.73	1244.54
34	Thickener (Printing)	100	0.90	55%	16.50	21.49			38.00	34.20
35	* Printing others (Chemical + dyestuff + pigment)				58.52	76.21			134.73	121.25
Total (printing)					75.02	97.70			172.73	155.45
Garments washing (other)			0.75		10.00				10.00	9.00
Total (knit + woven + denim + yarn + print + washing)									1757.46	1408.99