

RESEARCH ARTICLE

Water and chemical consumption in the textile processing industry of Bangladesh

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Abstract

The textile wet processing industry is considered a notorious polluter due to its widespread use of natural resources without proper replenishment. Bangladesh is one of the largest producers of textile products in the World, and therefore, it is vulnerable to environmental degradation. Bangladesh is predominantly a cotton processing country; therefore, reactive dyes are commonly used, and the dye combination is very water and chemical-intensive. There is a scarcity of information on the consumption of water, textile dyes and the generation of wastewater in the textile sector. Thus, this study aimed to estimate the amount of water use, wastewater generation, and chemical use in textile wet processing units. Therefore, a face-to-face in-depth questionnaire-based survey was conducted in 18 textile wet processing factories, including knit composite, knit dyeing, yarn dyeing, denim dyeing, and knit and yarn dyeing. The average specific groundwater consumption to process 1 Kg of textile materials was 164 L/Kg (SD ~ 81.8); dyehouse water was 136 L/Kg (SD ~ 70.6), while corresponding wastewater was 119 L/Kg (SD ~ 73.0). This high consumption of groundwater is directly linked to the depletion of groundwater in the region, where textile industries are situated and also, causes water pollution through wastewater generation. The water used in the dyehouse water was usually soft water and found to be in a range of 68% to 100% that of groundwater extracted. For chemical use, a factory used 449 g of chemicals to process 1 Kg of textile materials, in which the most widely used chemicals were inorganic and basic chemical in nature. However, the chemical use varied from 152 g/Kg to 705 g/Kg of textile production. The total chemical consumption ranged from 954 tons to 4,525 tons a year. More than 50% of the wastewater treatment plants were biological, a quarter of combination and physico-chemical and biological, and the rest were chemical treatment plants in this study. Even though this study may not represent the whole textile wet processing industry of Bangladesh, however, This study provides baseline information on water and chemical consumption and wastewater generation. Our findings would be helpful for policy makers and researchers to identify transformative challenges required at the national level.

OPEN ACCESS

Citation: Uddin MA, Begum MS, Ashraf M, Azad AK, Adhikary AC, Hossain MS (2023) Water and chemical consumption in the textile processing industry of Bangladesh. *PLOS Sustain Transform* 2(7): e0000072. <https://doi.org/10.1371/journal.pstr.0000072>

Editor: Musa Manga, The University of North Carolina at Chapel Hill Gillings School of Global Public Health, UNITED STATES

Received: December 31, 2022

Accepted: June 23, 2023

Published: July 31, 2023

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: <https://doi.org/10.1371/journal.pstr.0000072>

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Data Availability Statement: Aggregated outputs necessary to replicate the study's findings are publicly available in the paper while questionnaire

is available as a [Supporting Information file](#).

Individual factory level data are not publicly available because of restrictions imposed by the authors' agreement with participating factories. Our agreement with factories restricts us from sharing individual factory data. The following people may be contacted with any questions: Mr. Nazmul Karim (nazmul.karim@uwe.ac.uk), Mr. Md Anwarul Islam, PhD candidate, The university of Adelaide in Chemical Engineering, (anwaruldhk@gmail.com), Mr. Abul Kalam Azad, Lecturer, Bangladesh University of Textiles, (abulkalam.azad@dce.butex.edu.bd).

Funding: Field level data collection was funded by Independent University, Bangladesh (IUB), grant number IUB/DEM/18, awarded to MSH. The funders had no role in study design, data collection and analysis, the decision to publish, or preparation of the manuscript. No authors received a salary or honorarium from any of the funders for the study.

Competing interests: The authors have declared that no competing interests exist.

Author summary

With a second position in the global apparel export market, Bangladesh also bears the environmental burden due to extensive resource usage—water, energy, and chemical, followed by the generation of wastewater. To tackle this issue, our study tried to establish a baseline of water and chemical use in textile wet processing, as there are few references available. We surveyed 18 factories in-depth and found that, on average, 164 L of water and 449 g of chemicals are consumed to dye 1 kg of textile material, which is very similar to global peers. However, due to sheer volume of factories and associated production, along with high reprocessing, made the industry unsustainable in the longer term. Excessive water use contributes to rapid groundwater depletion and high amounts of wastewater. On the other hand, excess chemical use contributes to unnecessary chemical costs and pollution load. We expect this study will help stakeholders and policymakers address the issue systematically.

Introduction

The textile, apparel, and fashion industry is a USD 1.7 trillion clothing industry growing at a rate of 6–7.5% per annum that employs more than 300 million people along the textile value chain [1,2]. In the last two decades, apparel production has approximately doubled due to the growing global population, with more per capita income in developed and developing economies [3].

The textile industry is typically fragmented, and, in some cases, this could be a complex production system involving the production of yarn, fabric, colouration, printing, apparel for consumers, home furnishing, and industrial goods. A substantial number of inputs is needed in each segment, including raw materials, water, chemicals, and energy. Consequently, high waste emissions in terms of wastewater and greenhouse gases put pressure on the environment and significant risks to public health [4]. The impact is particularly severe for developing countries, mostly Asians, as they are considered the manufacturing hubs of textiles. To illustrate this fact, China, Bangladesh, India, Pakistan, and Vietnam produced the most textiles and apparel for Western countries [5].

The textile industry has received much criticism due to its environmental impact during the production and end use of fashion products [5]. The negative impacts of textile wet processing on the environment are extensive water consumption and wastewater discharge, characterized by excessive organic chemicals and [colouring agents](#), low [biodegradability](#), and high salinity [6]. Among all industrial sectors, textile dyeing, printing, finishing, and washing, combined with the Textile wet processing industry, uses 85% of the total water and 65% of the total chemical used in the textile supply chain [7]. As a result, this industry is considered one of the most polluting industries for producing and discharging wastewater and the chemical it carries [8,9]. It was also reported that the textile and apparel industry exceeded the combined emission from international aviation and maritime transport. If the same trend continues, it could account for one-fourth of the World's carbon emissions by 2050 [3,10].

During wet processing, the chemicals are added at various stages, particularly depending on the amount of water used. After completion, warm or hot water carrying various types and amounts of chemicals is discharged as wastewater. The wastewater is a complex mixture and is contaminated with unexhausted or unfixed dyes, diluents of dyes, various auxiliaries, bleaches,

detergents, optical brighteners, and many other chemicals, including carcinogenic heavy metals used during textile processing [6].

Water used in textile wet processing factories can be categorized into three: raw water extracted usually from underground, which is then treated to remove water hardness to produce soft water, and wastewater generated after treatment in textile wet processing. Soft water is used in the boiler to produce steam and in treatment steps such as dyeing/finishing. A part of this soft water is also used inside the dyehouse cleaning, laboratory, pilot processing, etc. Some factories use 100% water as soft water, a resource loss and economic loss. The ratio of groundwater to soft water is usually more than 70%, which is typical as the remaining amount is supposed to be used for other domestic purposes [11].

After wet processing, the residual auxiliaries and their degradation products are supplied to the Wastewater Treatment Plant (WWTP), which is then discharged to the sewage system or directly to water sources such as rivers or canals. The textile industry wastewater load is usually chemically heavy and depends on the number of processing steps and the corresponding application process [12]. Typical characteristics of textile wastewater also include a wide range of pH values, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Content (TOC), Total Dissolved Solids (TDS), and heavy metals [13]. The electrical conductivity of wastewater is usually high due to the use of electrolytes such as NaCl and Na₂SO₄ in the dyeing process [3].

Bangladesh is a lower-a-middle-income country with a population of nearly 170 million. The Textile and apparel industry is the largest and most important industry for Bangladesh's economy in terms of output, export, foreign exchange earnings, and employment. This industry contributes 9.25% to the country's GDP and more than 81.82% to the country's export, with USD 42.6 billion in FY2021-22 [14]. Bangladesh holds more than 6% share in the global apparel market and has positioned itself as the second largest garment exporting country after China [2]. The apparel industry is also the second largest employment-generating industry, after agriculture, with direct employment of 4.5 million people. With forward and backward linkage, the industry is trying to become the go-to destination for the textile and apparel business; however, with no more indigenous popular textile raw materials, the challenge is to produce products cheaply where the environmental concern is largely neglected.

When it comes to water consumption in the dyehouse and subsequent generation of wastewater for Bangladesh, there are few references available [15–19]. However, many articles are based on estimates or available historical data. For example, Sustainable Industrial Water Projection (SIWP) tool was developed based on a single factory [18] where the material balance approach is used to calculate from a factory [16]. The modification of the projection tool to calculate pollution load for various industry were extrapolated from two previously published articles [17]; the water footprint assessment of different products was based on historical data [15], and the estimation relied on the garment export value [20]. The most comprehensive project that can be considered reliable from the International Finance Corporation (IFC) Partnership of Cleaner Textile (PaCT) [19] estimates that the textile wet processing industry in Bangladesh consumes around 1500 billion litres of water consumption annually to process 5 million tons of fabric (300 L/Kg of fabric). Although it is estimated that 1700 wet processing units (washing, dyeing, and finishing) are operated, the evidence suggests the number would be around 500 to 700, including single-alone garment washing units [21]. Out of these, it was found that only 61% of facilities are equipped with effluent treatment plants (ETPs), of which 29% were found to be compliant, and some 11 to 51% were either poorly designed or operated [21]. However, the same study also predicted that specific water consumption for textile processing ranges from 80 to 300 L to produce 1 Kg of textile. This range of assumption has a huge gap considering the calculation was based on the maximum amount of water required to

process per kg of textile water. Again, the number of wet processing units is dubious. Those studies also did not calculate or assume the amount of chemicals required to process the textile materials.

With this background, in this study, we aim to estimate the amount of water use, wastewater generation, and chemical use in textile wet processing units.

Materials and methods

Study setting

The major industrial textile cluster in Bangladesh is clustered around Dhaka city (Gazipur, Tongi, Savar, Narayanganj); therefore, water pollution hotspots are the same [22]. IFC PaCT did a water footprint assessment in the Konabari cluster of the Gazipur region, which houses 33 Washing, Dyeing, and Finishing (WDF) units and consumes approximately 13 billion liters of fresh water per year, the biggest source of water pollution [23]. The rivers around these textile clusters around Dhaka City (Buriganga, Shitalakhya, Balu, and Turag) are highly polluted with heavy metals and organic pollutants [24]. Therefore, this study was centred around Gazipur and Narayanganj (Fig 1).

Research instrument: Study questionnaire

A team of experts, including textile engineers, environmental specialists, industry owners and statisticians, developed the questionnaire. The study questionnaire was carefully designed to extract information on the factory profile, production capacity, and monthly production for a year in white/wash, light/medium, deep colour, water consumption, wastewater generation, and chemical use for a year. The questionnaire was piloted in two factories and finalized before data collection.

Sampling

Selecting factories in a randomized fashion representing the textile industry in Bangladesh requires a complete list of the factories, access to those factories, and willingness to provide the comprehensive data that we require. Therefore, we follow a special sampling technique relevant to this situation, named snowball sampling [25,26]. First, we approached a few factories familiar with the research team and requested comprehensive data. The interviewees (who agreed to participate in this study) were asked to provide clues about other potential factories. In the next stage, the research team contacted these referred factories to increase the sample size further and collect more data and referrals. Following this sampling technique, we approached 50 factories, and 18 of them provided data for this study.

Data collection and analysis

A team of 15 data collectors (undergraduate and postgraduate students from the textile engineering discipline) were recruited and trained. Data confidentiality was explained as this is linked to the reputation of the participant industries. Five three-member teams were assigned for industry-level face-to-face data collection. Groundwater data has been collected from the Head, or representative of the Utility, dyehouse water and chemical data from the Head of Production and wastewater data from the Head of the wastewater treatment plant. Some factories provided all the data that was requested. In contrast, some factories provided partial data, possibly due to the non-availability or sensitivity of data.

Data were managed and stored using REDCap electronic data capture tool hosted at Biomedical Research Foundation (BRF) for further processing (<https://redcap.brfd.org/>).

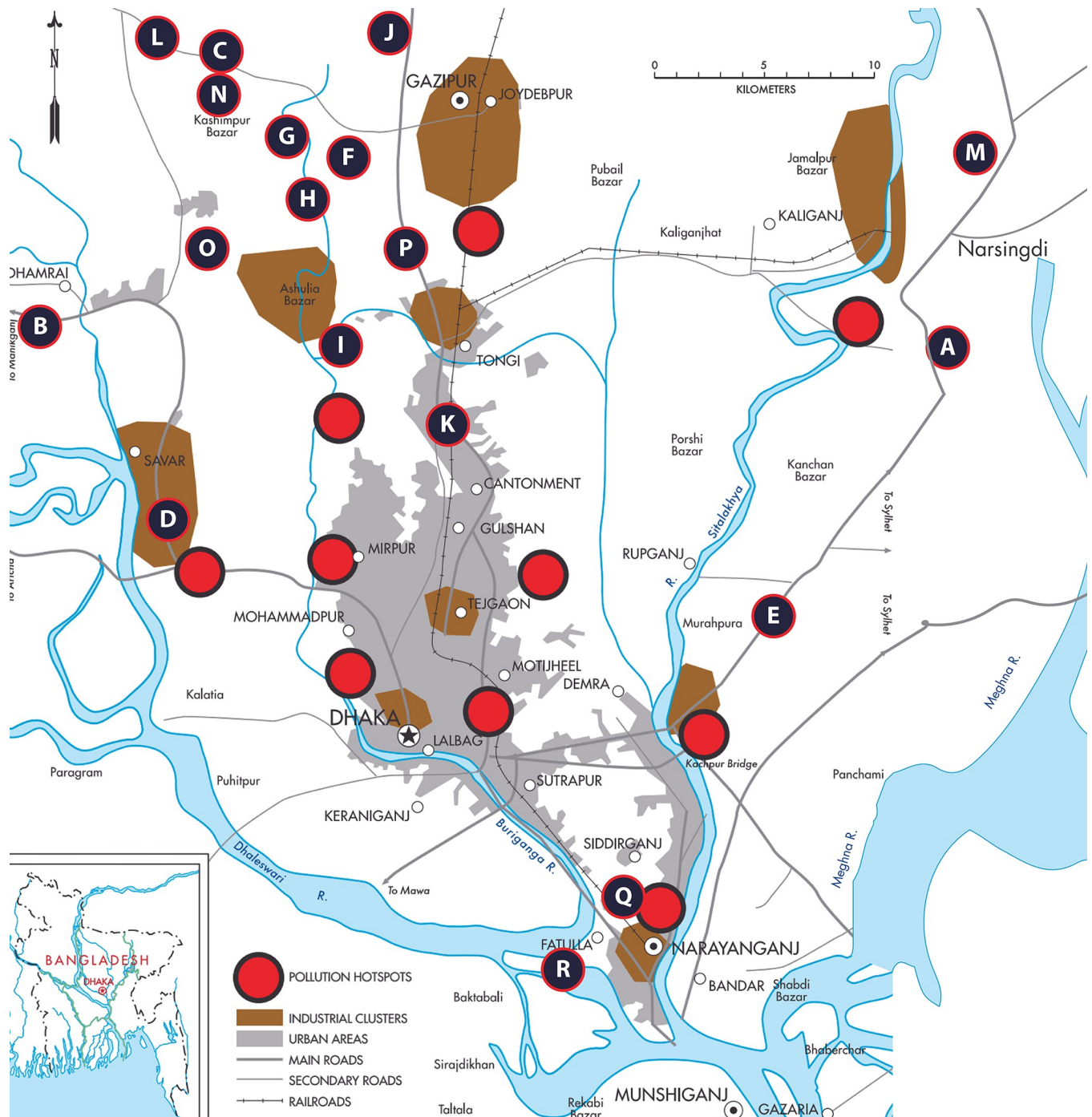


Fig 1. Location of textile factories studied in this study along with water pollution hotspots (from [27]). The English Alphabets refer to the factory locations of this study. The base layer of the map was adapted from the World Bank and can be accessed at <https://documents1.worldbank.org/curated/en/903711495006283196/pdf/115071-WP-The-Bangladesh-Responsible-Sourcing-Initiative-A-NEW-MODEL-FOR-GREEN-GROWTH-PUBLIC.pdf>.

<https://doi.org/10.1371/journal.pstr.0000072.g001>

Descriptive statistical procedures were used to analyze the data. Categorical variables were presented using counts and percentages, and continuous variables were summarized using means and standard deviations.

Results

Table 1 represents the basic information about investigated factories. It comprised nine knit composite (including knitting, dyeing, and garment units), five stand-alone knit dyeing, one knit and yarn, two yarn dyeing, and one denim dyeing. The wastewater treatment plants were mostly biological (10), some were combined physico-chemical and biological (6), and two factories used chemical-based wastewater treatment plants. The number of employees varied widely, from 46 from a single dyeing unit to 1290 personnel for a knit composite factory with various units. The factory sizes varied from a small company with a production capacity of ~1,812 tons to 18,000 tons annually, which means the factory can process that amount in a 24-hour shift and 25 working days.

Fibre type and machine

Table 2 summarises the various fibres processed by the factories, the machine type, and their loading capacity to dye fabric. Fibres that were processed were mostly cotton-based and cotton blend with few rayons. On average, approximately 47% of dyed fabric represents deep shade, approximately 27% of colour refers to medium shade, while white and light represent around 26% of the total material dyed. In industry, below 1% shade refers to white or light, 1 to 3% depth refers to medium shade, and over 3% depth represents deep colour materials.

Fig 2 represents the most used machine brands in textile wet processing factories in the study. All the machines are of international origin, mostly from China, Turkey, Greece and Germany. The machine size varied between 120 kg to 1,880 kg per batch, along with some sample machines, usually less than 50 kg per batch.

Water use and wastewater generated

Fig 3 provides the groundwater extraction, specific water consumption in the dyehouse for textile processing, and corresponding wastewater generated for the individual units, while **Fig 4**

Table 1. Details of the factories from where data is collected.

Factory	Type	Production limit (tons/month)	WW treatment type	WWTP Capacity (m ³ /day)
A	Knit composite	2,911	Biological	3,600
B	Knit composite	4,670	Biological	2,000
C	Knit composite	2,565	Physico-chemical and biological	2,400
D	Knit composite	3,169	Physico-chemical and biological	2,530
E	Knit and Yarn dyeing	12,148	Biological	2,000
F	Knit composite	2,209	Biological	960
G	Knit composite	2,700	Chemical	N/A
H	Yarn dyeing	18,000	Biological	6,500
I	Knit dyeing	2,919	Physico-chemical and biological	1,200
J	Knit composite	6,677	Biological	1,440
K	Knit dyeing	4,109	Biological	1,920
L	Yarn dyeing	3,600	Physico-chemical and biological	960
M	Denim dyeing	4,986	Biological	9,300
N	Knit composite	7,200	Biological	3,000
O	Knit composite	2,640	Central ETP	-
P	Knit dyeing	4,823	Physico-chemical and biological	4,000
Q	Knit dyeing	7,930	Physico-chemical and biological	2,400
R	Knit composite	1,812	Biological	2,080

<https://doi.org/10.1371/journal.pstr.0000072.t001>

Table 2. Major fibre dyed along with a share of various colour depth.

Factory Code	Major fiber type	Depth of colour (%)		
		White/light (%)	Medium (%)	Deep (%)
A	Cotton, Polyester, Viscose blend, PC	28	9	63
B	Cotton, Viscose, Cotton/Modal, PC	38	42	20
C	Cotton, Viscose, CVC, PC	28	0	72
D	Cotton, Cotton Spandex, CVC, PC	23	23	54
E	Cotton, Polyester, Viscose, CVC, PC	N/A	N/A	N/A
F	Cotton, Polyester, Viscose, Modal, CVC, PC	20	35	45
G	Cotton, Polyester, Viscose, PC, CVC	0	59	41
H	Cotton, Polyester, Viscose, Lyocell	N/A	N/A	N/A
I	Cotton, Polyester, Viscose	32	30	38
J	Cotton, Polyester, Viscose	28	30	42
K	Cotton, Viscose, PC, CVC	30	30	40
L	Cotton, Polyester, CVC	20	30	50
M	Cotton, Polyester	5	30	65
N	Cotton, Polyester, Viscose, PC, CVC	25	33	42
O	Cotton, Polyester, Blend	N/A	N/A	N/A
P	Cotton, Polyester, Viscose, Modal, Blend	46	26	28
Q	Cotton, Polyester, PC, CVC	N/A	N/A	N/A
R	Cotton, Polyester, Viscose	45	0	55
Average		26%	27%	47%

<https://doi.org/10.1371/journal.pstr.0000072.t002>

summarises specific water consumption and wastewater generated. Dyehouse water was usually soft water, treated in a water-softening plant, and found to be in a range of 68% to 100% that of groundwater extracted. The specific water consumption to process 1 Kg of textile

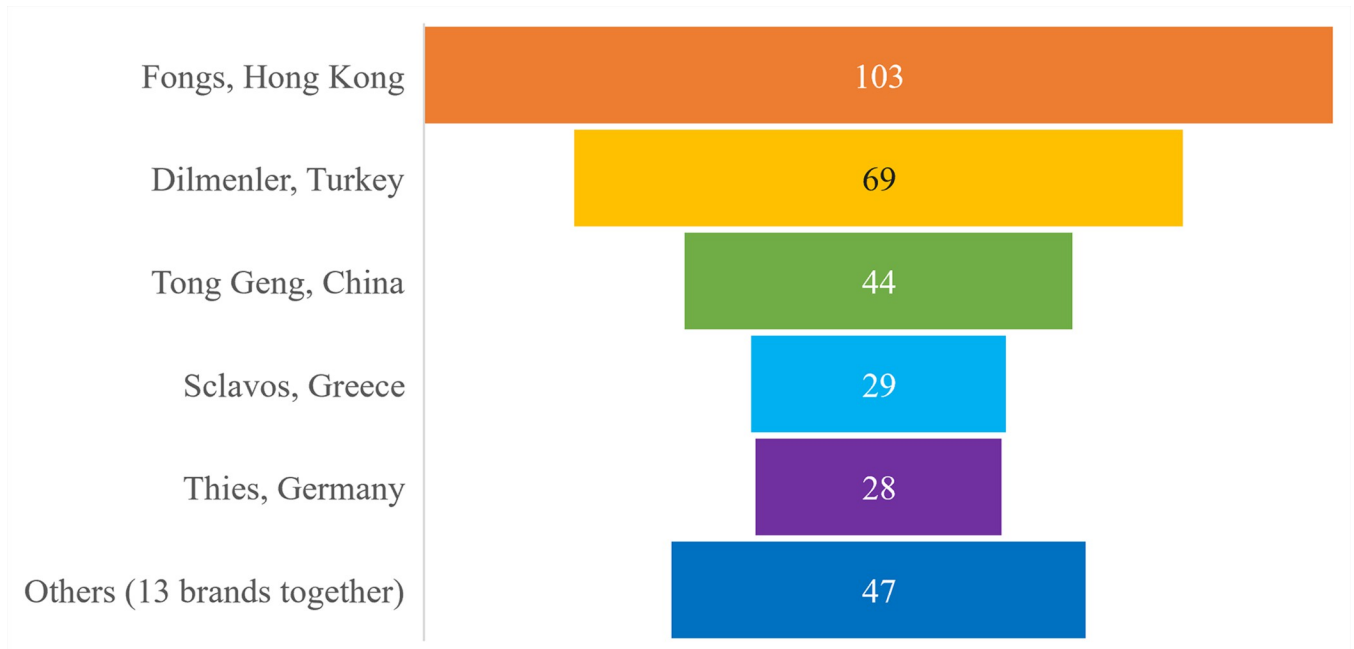


Fig 2. Top brands of textile dyeing machines used in factories.

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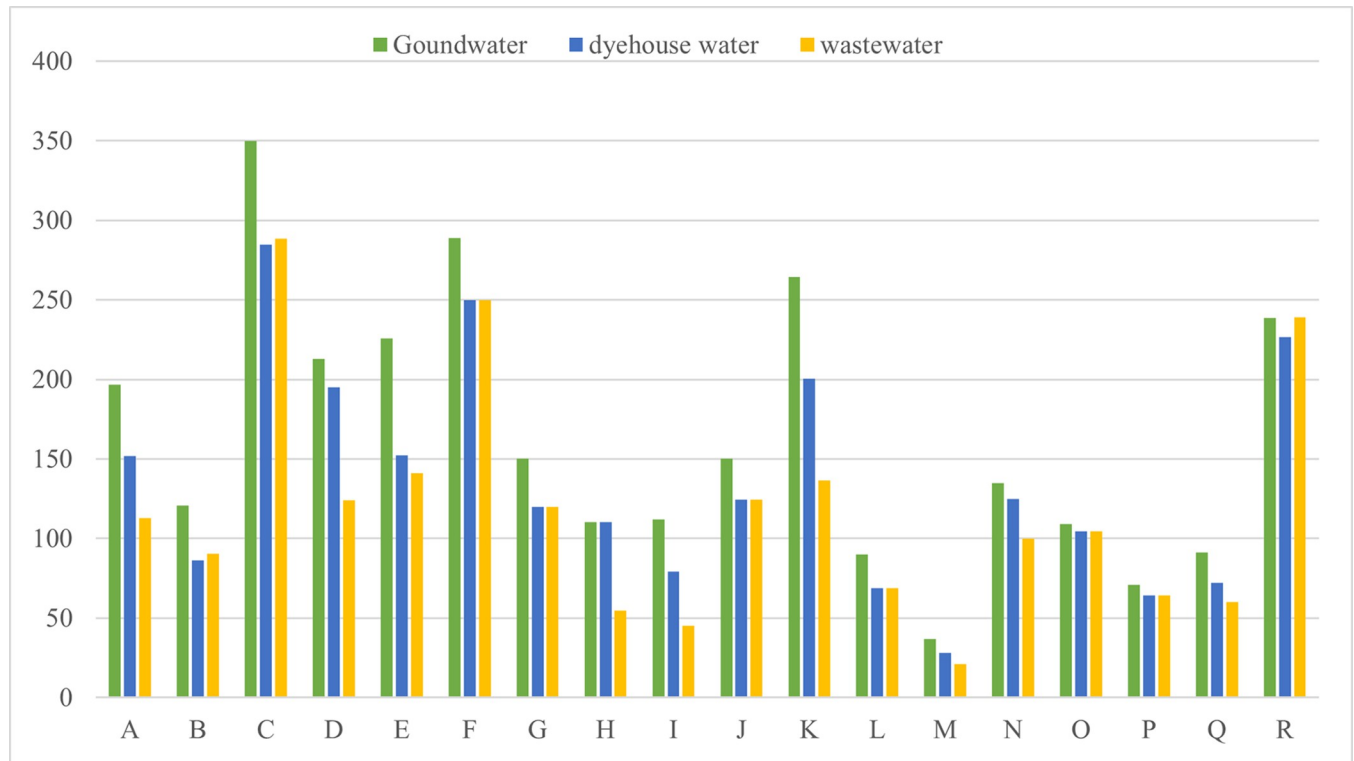


Fig 3. Specific water consumption from groundwater, usage in dyehouse and corresponding wastewater generated. Units (L/Kg) amount of water required to process 1 Kg of textile materials.

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materials was 28 L/Kgs for denim dyeing to as high as 285 L/Kg for a knit composite factory. The average groundwater consumption was 164 L/Kg; dyehouse water was 136 L/Kg, while the corresponding wastewater generated was 119 L/Kg.

Fig 4 shows the minimum, 25th quantile, 50th quantile (median), 75th quantile, and maximum water consumption data found in those factories. Significant variation in consumption has been observed in all three cases—Groundwater, dyehouse water and wastewater generated. In all three cases, outliers were also identified.

Chemical use

Fig 5 shows that, on average, a factory used 449 g of chemicals to process 1 Kg of textile materials ranging from 152 g/Kg to 705 g/Kg. The lowest value of 152 g/Kg is unreal, given the size of the factory (i.e., annual production ~2730 tons), and a deeper look showed that four of the chemical uses were not provided. The total chemical consumption had been in the range of 954 tons to 4,525 tons a year.

Fig 6 identified the top 10 chemicals used in wet textile processing and consumed in a year. Out of the top 10, seven were basic chemicals, including salt, soda, acid, and bleaching agents. Mostly reactive dyes came out at the top for textile-specific chemicals, which is particularly essential for cotton-based textile products.

Discussion

In this study, we have calculated the water consumption, generation of wastewater and chemical consumption in textile industries.

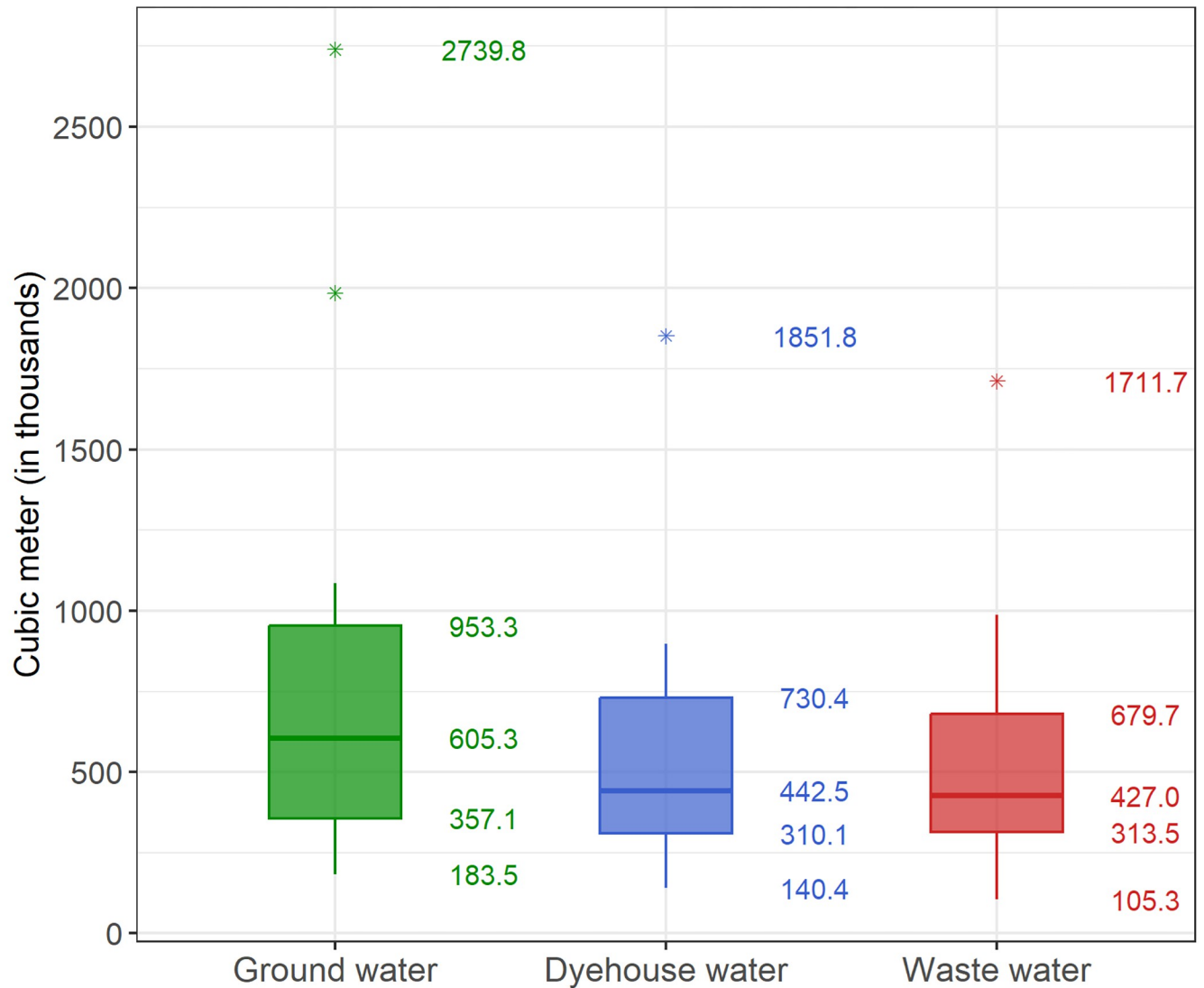


Fig 4. Distribution of consumed and discharged water to process 1 Kg of textile materials.

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Water consumption

We found that the specific water consumption in the textile factories varied between 28 L/Kg to 285 L/Kg. The depth of dyeing also directly relates to water consumption since the deep colour requires more water for processing and more steps of washing and rinsing. Although it is unacceptable; however, it is understandable the high amount of water consumption for factory C is 285 L/Kg with a deep shade of around 72% in our study.

Although the variation of water consumption is very high, however, our finding is similar to other studies reported elsewhere in the World, from 45 L/Kg [27], 81 L/Kg [9], 100 L/Kg [28], 200 L/Kg [29] and between the ranges [30]. According to the Best Available Techniques (BAT) for the Textiles Industry, water consumption varies from 70 to 250 L/Kg fabric depending on the techniques applied. Studies from South Africa reported that the specific water intake for the textile industry varies from 95 to 400 L/Kg fabric depending on the type of processes

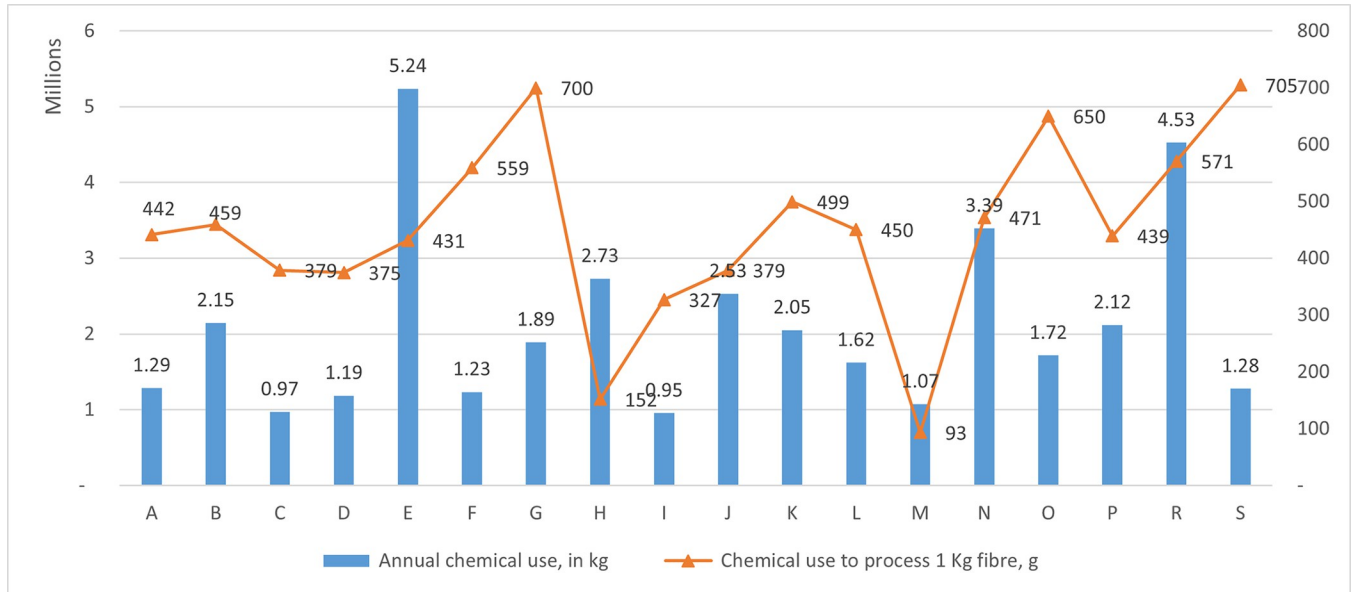


Fig 5. Annual Chemical consumption and chemical use (g/Kg) to process 1 kg of textiles by each factory.

<https://doi.org/10.1371/journal.pstr.0000072.g005>

used and water efficiency [31]. Therefore, it could be concluded that water consumption in textile wet processing in the present study is within the ranges of global peers. Still, the average seems skewed to a higher edge. Although the number of factories and their associated nature of response covered in this study is not adequate to conclude, it represents a reasonable state of

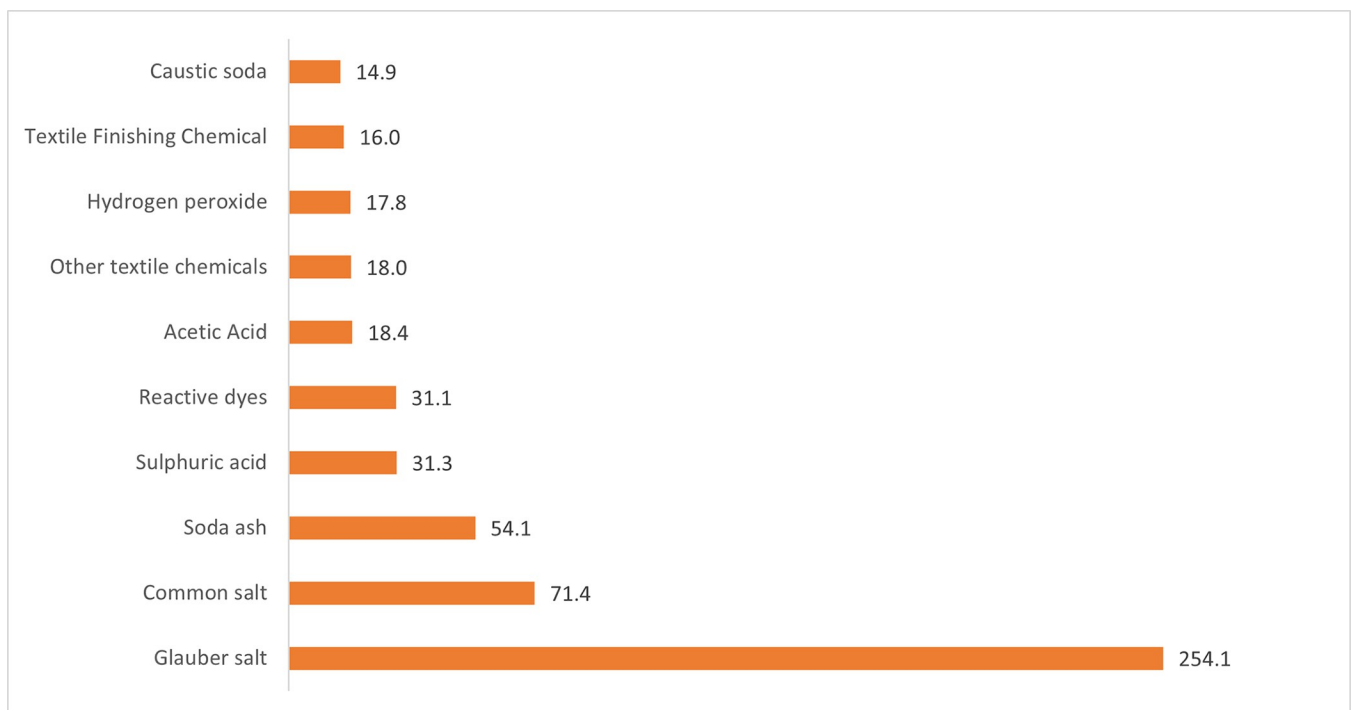


Fig 6. Major chemicals used in textile processing with specific individual chemical consumption in g to process 1 Kg of textile materials.

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Bangladesh's textile wet processing industry based on field-level data extracted from industries. The industry intakes an average of 164 L of groundwater to process 1 kg of fabric and eventually discharges 119 L of wastewater.

Water consumption could be varied on several factors, including lack of a proper management system, absence of measuring instruments, the absence of calibration, and the use of such measurement tools, if any, approach to free natural resources. This indicates that a significant amount of water is used, which can be saved if the right technology and process optimization can be applied. In this regard, washing/rinsing processes have significant potential to be optimized [32] as sometimes reducing the liquor ratio in material treatment steps might not be possible due to the limitation of the particular dyeing machine [11]. The practice of overflow washing/rinsing was common when the water consumption is high in textile processing, which could be replaced by batch-wise washing/rinsing (drop fill method) or counter washing and could result in savings of 45% [11] to 75% [30] of water use. A reduction in water use of 10 to 30 percent can usually be accomplished by taking fairly simple measures—water leaks, broken or missing valves, running water, defective toilets, and water coolers [11,32].

Water consumption in the textile industry and industrial water pollution goes hand in hand due to the generation of a substantial amount of wastewater, which is poorly treated. In Turkey, the textile industry is the second largest water consumer, responsible for 15% of total industrial water consumption (191.5 million m³ per day) and the third most energy-intensive sector [9]. On the other hand, in Bangladesh, it is estimated that the water consumption required by the textile sector was over 4 million litres per day in 2014, which in business-as-usual scenario cases, the industry would require an additional 6 million litre a day by 2030 to meet the targeted export [33]. Another study estimated that with 1.8 million metric tons of fabric produced in 2016, around 217 million m³ of wastewater is generated annually, projected to produce 349 million m³ by 2021 if the same practices and trend follow [20].

Considering the ongoing depletion of groundwater, scarcity of clean surface water, and associated geological concerns, such arbitrary water uptake is a concern in Bangladesh and elsewhere [34]. A study based on groundwater level data during 1980–2012 shows successive depletion in Dhaka and Gazipur, hosting major textile processing units, all other industries, and millions of residents. In Gazipur, the groundwater level was depleted from 5 m below the sea level to 21 m between 1980 and 2008 [35]. It also revealed a sharp fall in groundwater level after 2003 that may arguably coincide with the growth in textile set in the vicinity.

Although this study did not intend to find any statistical correlation between the above two circumstances, i.e., growth of apparel export [36] vs. groundwater depletion, it could be said there is a concern. While the recipients of groundwater are many, including population, agriculture, and industries, the textile value chain is leading. The progressive rate of depletion of groundwater level in general and the counter-progressive rate of water uptake by textile units are certainly forming grounds for severity in the ecosystem.

Chemical consumption

In cotton dyeing, various dyes and chemicals are used to promote interactions and uniform fixation of the dyes in a textile substrate. Typically, the total quantity of chemicals used in textile factories varies from 10% to over 100% of the weight of the fabric [31]. In our study, to process 1 Kg of textiles, the average consumption of Glauber salt and common salt was ~254 g and ~71 g, respectively. These findings are consistent with another study [37], 88.1 g/Kg of fabric [38], some 40.3% of total NaCl consumption. A substantial amount of salt is also used in water softening, as high as reported 59.7% of total NaCl [9]. Salts such as NaCl and/or Na₂SO₄ act as an electrolyte, assist in dye uptake of reactive dyeing and require as much as 80 g/L, used

for deep shade. The chemicals used in textiles are dyes, auxiliaries, surface active agents, textile finishes, bleaches, solvents, and lubricants. These chemicals are formulated so pretreatment, dyeing, and finishing can be carried out effectively and quickly. Auxiliary chemicals enhance the performance of the textile wet processes and are consumed little during the process. Traditional auxiliaries can be inorganic, such as electrolytes, oxidizing/reducing agents, and organic such as surfactants [39]. The use of dyestuffs, auxiliaries, and finishing agents varies with the type of fibre, dyes, required shade, fastness, quality and functional requirements. The textile industry uses over 8,000 chemicals to process 400 billion square meters of fabric annually worldwide [38]. The Colour Index International listed 27,000 individual products under 13,000 generic names [40]; many are toxic and persistent. On the other hand, 1000 chemicals are required to produce chemicals for consumer textiles, of which 900 are hazardous [41]. The epidemiological study showed that the use of toxic chemicals has a higher correlation between work conditions and the symptoms of otolaryngology, dermatitis, and ophthalmological among the workers [4].

Higher consumption of chemicals means apart from dyes and some finishes, most of the chemicals are discharged in their original or some other form into the wastewater. In the case of reactive dyeing, the residual reactive dyes could be in the range of 10 to 40% due to incomplete exhaustion and/or fixation [38,42,43,44]. The Restricted Substances List (RSL) and Manufacturing Restricted Substance Lists (MRSL) are constantly changing due to enhanced understanding of scientific information the chemicals by scientists and researchers. The Zero Discharge of Hazardous Chemicals (ZDHC) initiative to eradicate hazardous chemicals from the textile and footwear supply chain published a Manufacturing Restricted Substances List (ZDHC MRSL) [45]. These substances are banned from intentional use in facilities processing textile materials, leather, rubber, foam, adhesives, and trim parts in textiles, apparel, and footwear. Similarly, the RSL list was also published by American Apparel & Footwear Association (AAFA) [46], Bluesign System Substance List (BSSL) [47], Apparel & Footwear International Restricted Substances Management (AFIRM) Group [48], amongst many others. The list includes selected Arylamines, Alkylphenol (AP) and Alkylphenol Ethoxylates (APEOs), Chlorobenzenes and Chlorotoluenes, carcinogenic dyes such as direct, acid, basic, disperse, flame retardants, Perfluorinated and Polyfluorinated Chemicals (PFCs), heavy metals amongst others [45].

High electrolyte concentration in discharged effluent is undesirable but inevitable since current wastewater treatment technology without a membrane system cannot treat them; as a result, the increased salinity affects the delicate balance of flora and fauna [38]. The specific salt consumption could be minimized in various ways, particularly by reducing the liquor ratio during the dyeing process, in which electrolyte directly correlates with the water used [49]. It is also possible to use other technologies for cellulosic fibres, such as cold pad batch dyeing with no salt requirements, pre-cationized cellulosic fibres without or minimum salt [38], low-salt and/or low-temperature reactive dyeing [50], plasma-based pretreatment [38], and more recently Nano-Dyeing process [51]. However, such chemicals/technology/processes are often more expensive than traditional chemicals, and as water is cheap, it is difficult to change consumer behaviour.

There is a strong linkage between deep colour and the consumption of chemicals in textiles to the consumption of chemicals. The deep shade in cellulosic dyeing would require much more dyes, associated salts and alkalis, auxiliaries such as levelling agents, and more detergents in subsequent washing steps to wash off the unfixed dyes. Therefore, the factory with a higher percentage of deep shade (~ 60%) is supposed to consume more chemicals than other factories with more light to medium shade. In addition, the dyestuff fixation rate and Right First Time (RFT) dyeing percentage would also affect the overall consumption of dyes. Some reactive

dyes have a fixation rate lower than 60%; some are claimed to have over 90%, which makes it further difficult to compare against each other [34].

Impact of wastewater on the environment

Technically, all water in the dyehouse should be in the wastewater, as it assumes that this is process water used in the textile wet processes. Therefore, other than evaporation losses, the whole dyehouse water should be in the wastewater, which is not the case. As low as 50% of dyehouse water went to the wastewater treatment plant, the highest was 105% of the dyehouse water, perhaps due to the rain and other stormwater coming into the wastewater treatment plant.

In our study, total reactive dye consumption was approximately 2,292 tons for 18 factories. Due to incomplete exhaustion/fixation of reactive dyes, the loss of dyes could be up to 40%. Considering a median loss of 20% will amount to a loss of ~460 tons of dyes in a year. As mentioned above, with more than 700 textile wet processing plants in the country, the wasted dyes could be ~ 320,000 tons a year, approximately double what was predicted elsewhere [52]. Dyes and pigments are designed to resist biodegradation and have high stability to light, temperature, water, detergents, chemicals, and other parameters such as bleach and perspiration [43]. Thus, wastewater is typically coloured, and one of the difficult tasks of any conventional WWTP is to remove colour. Although biological WWTP for the textile industry is typically suggested by various brands, along with heavy metals, colour cannot be removed from wastewater [52], which results in aesthetically unpleasant effluent that blocks sunlight, reduces the level of oxygen, and causes overgrowth of algae [38,43,53]. In a study, the half-life of the hydrolyzed Reactive Blue 19 dye is about 46 years at pH 7 and 25°C [54].

The impact of this high pollution with chemicals and heavy metals is multifold. The water from the rivers and canals is used for irrigation along the coastline of Gazipur and Keraniganj for paddy and vegetable cultivation, such as tomato, spinach, and cauliflower. Vegetable and fruit samples collected from around Savar, Dhamrai, and Tongi show the presence of heavy metals such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, molybdenum and vanadium [24]. The effect on health is getting significant through the use of water in domestic and cultivation, or the intake of food and drinking water. Diarrhoea, food poisoning, skin diseases, and other short-term and long-term diseases are widespread [12], although the overall impact of textile industrial wastewater on public health is still largely unknown. As a result, considerable attention has been given to the recovery and reuse of wastewater and, to some extent, recovery of the dyes/pigments, caustic soda, and salt [12,52,55,56].

The economic impact of higher water and chemical consumption

In any textile wet processing industry, the cost of raw materials is the highest (49 to 65%), followed by workforce (4–20%), energy (5–10%), chemicals/dyes (4 to 11%), water (0.3%) and others between 9 to 35% [9,57,58]. Since the cost of water is almost negligible in Bangladesh, it is very difficult for the processing units to focus on water savings. However, water savings are associated with reduced energy, chemical, and wastewater treatment and higher productivity. Steam is used as thermal energy for processing in high temperatures, and the more water is used, the more steam is required to raise the temperature. Natural gas, an expensive and finite resource, is typically used in boilers to produce steam, which runs 24/7 in a wet processing factory in Bangladesh and could be saved as high as 20.2% [9].

Similarly, reducing chemical use due to less water use would result in direct economic and indirect benefits of less pollution load in wastewater. For example, a 10% saving of chemical consumption in this study, 40 g/Kg, could ensure a specific cost saving of USD 40 per ton of

fabric. At this rate, even for factory S in this study, with the lowest production of 1,812 tons per month, calculated to save annually USD 869,760. Similar savings can be observed in Mexico [9] In addition, the associated energy and wastewater treatment costs will be reduced.

Limitations

We collected primary data on water from four sources: groundwater, dyehouse water, wastewater, and chemical use through a comprehensive questionnaire with complementary interviews. Few factories did not provide data in all categories; nonetheless, this study especially highlights that the empirical study of the consumption of water and generation of wastewater could be somewhat misleading. Many studies reported figures based on the extrapolation of data; only a few studies tried to understand the production process scenario and how it operates. The insufficiency of such studies is due to the difficulties of getting information from factories.

Conclusion

Bangladeshi factories are mostly cotton-based, with cotton blends with few rayons; therefore, reactive dyes are extensively used. On average, approximately half of the dyed fabric represents deep shade requiring more water, dyes and chemical. The average specific groundwater consumption to process textile materials is 164 L/Kg; dyehouse water is 136 L/Kg, while the corresponding wastewater generated is 119 L/Kg. For chemical use, a factory uses on average 449 g of chemicals to process 1 Kg of textile materials; however, the chemical use varies from 152 g/Kg to 705 g/Kg of textile production. The total chemical consumption has been in the range of 954 tons to 4,525 tons a year.

In general, the textile industry faces enormous challenges due to environmental concerns related to water footprint, wastewater treatment and hazardous chemicals. This study could serve as a baseline to help the Government, funding agencies, industry management and technologists to analyze the environmental impact of water, wastewater and chemical in textile production and to develop environment-friendly dyeing practices and technologies. The drive toward sustainability depends on private and national initiatives—an integrated approach will be the key to moving forward.

Supporting information

S1 Data. Questionnaire used for the survey.
(XLSX)

Acknowledgments

The authors have acknowledged Rahat Alam, Md. Raijul Islam, Alamgir Hossain, Rifat Tabasum Shuchi, Sumon Khandaker, Rakibul Islam Asif, Sahabul, Lutfur, Mahadi, and Farhadul Islam Rumman for collecting data and Dr Enayetur Raheem, Biomedical Research Foundation, Bangladesh for providing RedCap software to analyze data.

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