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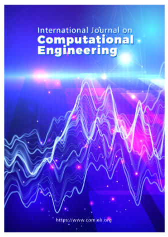

Water Footprint and Virtual Water Assessment for Textile Industries of Bangladesh

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***Abstract*— The textile and garment industry in Bangladesh, a significant contributor to the national economy and major exporter, heavily consumes water and causes environmental pollution. This thesis evaluates the water usage and pollution in the sector by assessing its blue, green, and grey water footprints, focusing on the dyeing, printing, and finishing stages in three industries: KDS, FOURH, and AMBER. The study aims to provide insights into the virtual water footprint and current water management practices, identifying areas for improvement to promote sustainable water resource management in the textile industry.**

***Keywords*— Water footprint; virtual water; textile industries; groundwater depletion.**

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I. Introduction

The textile and garment industry is a cornerstone of Bangladesh's economy, providing employment to over 4.5 million people and generating more than 84% of the country's export earnings. Despite its economic significance, the industry is a major consumer of water and a source of considerable pollution, particularly in the dyeing, printing, and finishing stages of textile production [1], [2]. This study aims to evaluate the water footprints—blue, green, and grey—of these stages in three specific industries: KDS, FOURH, and AMBER. By analyzing the water usage and pollution patterns, the research seeks to provide a comprehensive understanding of the industry's impact on water resources and propose strategies for sustainable water management. This is critical for mitigating environmental harm while sustaining the economic benefits of the textile sector in Bangladesh.

A. Literature Review

1) General Overview: the textile industry in Bangladesh is crucial for the country's economic growth, being the world's second-largest exporter of ready-made garments (RMG). However, this industry is also a major consumer of water, significantly impacting the environment through both consumption and pollution [3], [4].

2) Historical Background: global studies on the water footprint of the textile industry have largely overlooked Bangladesh. Research indicates that the annual water footprint of the textile sector is approximately 1.8 billion m³. The highwater usage and resultant pollution potentially lower groundwater levels, leading to severe health issues for local populations. A study anticipated that by 2021, the textile industry in Bangladesh would generate around 349 million m³ of wastewater [2].

3) Water Footprint Concept and Assessment: the blue water footprint refers to freshwater used in industrial processes, while the grey water footprint pertains to the volume of freshwater needed to dilute pollutants from manufacturing. Studies show that the textile sector's blue and grey water footprints in Bangladesh are significant, with the grey water footprint comprising 86.15% of the total water footprint.

4) Textile Industries and Economic Impact: the rapid growth of the textile industry in Bangladesh has substantial economic benefits but also brings environmental challenges. Conventional industrial methods, poor water management practices, and inadequate wastewater treatment facilities are key factors contributing to the highwater footprint of the textile sector.

5) Ground Water Depletion and Effluent Characteristics: the depletion of groundwater due to excessive water use in the textile industry poses a significant threat to sustainable water resources [5]. Effluent from the textile industry often contains high levels of pollutants, further exacerbating environmental issues.

6) Concept of Virtual Water: virtual water, the hidden water embedded in the production of goods, plays a significant role in the textile industry. The process of growing cotton, dyeing fabrics, and manufacturing clothing consumes vast amounts of water, often in regions already facing water scarcity. By understanding and managing virtual water consumption, the textile industry can make more sustainable choices, reduce its environmental footprint, and promote water conservation practices globally [6].

7) Summary and Implications: addressing the water footprint of the textile industry in Bangladesh is essential for sustainable development. Improved industrial practices, effective water management strategies, and advanced wastewater treatment technologies are critical to reducing the industry's environmental impact [2].

II. Material and Method

A. Materials and Data Collection

Product and Water Usage Data: Data on the quantity of product (tons per day) and water usage (liters per day) in the production process were collected from three textile industries: KDS, FOURH, and AMBER.

TABLE I
AMOUNT OF PRODUCT PER DAY AND REQUIRED WATER PER DAY OF KDS TEXTILE

Process	Product per day	Required water per day
Printing	10-ton/24hr	160,000l/24hr
Finishing	16-ton/24hr	20,000l/24hr
Dyeing	18-ton/24hr	1255328l/24hr
Sum	18-ton/24hr	1595328l/24hr

Water used in administration zone 125,000l/24hr

TABLE II
AMOUNT OF PRODUCT PER DAY AND REQUIRED WATER PER DAY OF FOURH TEXTILE

Process	Product per day	Required water per day
Printing	12-ton/24hr	300,000l/24hr
Finishing	47-ton/24hr	477,000l/24hr
Dyeing	47-ton/24hr	2457,000l/24hr
Sum	47-ton/24hr	5986000l/24hr

Water used in administration zone 166,000l/24hr

TABLE III
AMOUNT OF PRODUCT PER DAY AND REQUIRED WATER PER DAY OF AMBER TEXTILE

Process	Product per day	Required water per day
Finishing	39-ton/24hr	272,000l/24hr
Dyeing	31-ton/24hr	1230,000l/24hr
Sum	39-ton/24hr	46588,000l/24hr

Water used in administration zone 136,000l/24hr.

TABLE IV
AMOUNT OF YARN USED PER DAY IN THE FOLLOWING TEXTILES

Textile Name	Yarn used (ton per day)
KDS	38 ton/24hr
FOURH	94 ton/24hr
AMBER	98 ton/24hr

Effluent Characteristics Data: Both treated and untreated effluent samples were analyzed to determine the grey water footprint.

TABLE V
SAMPLE CHARACTERISTICS OF KDS TEXTILE

Parameters	RAW water	Treated water	Inlet	Outlet After ETP
BOD	0.6	0.1	316	9
COD	12	3	700	75
TDS	674	662	2430	2100
TSS	136	128	220	29

Effluent Discharge =1435,328l/24hr,
Abstract water =1760,328l/24hr

TABLE VI
SAMPLE CHARACTERISTICS OF FOURH TEXTILE

Parameters	RAW water	Treated water	Inlet	Outlet After ETP
BOD	1	0.2	280	9
COD	10	2	720	36
TDS	696	682	2300	2100
TSS	185	138	140	2

Effluent Discharge =3134,000l/24hr
Abstract water =3478,000l/24hr

TABLE VII
SAMPLE CHARACTERISTICS OF AMBER TEXTILE

Parameters	RAW water	Treated water	Inlet	Outlet After ETP
BOD	0.9	0.2	270	19
COD	13	4	628	56
TDS	696	654	2200	2100
TSS	138	126	677	48

Effluent Discharge =1502,000l/24hr
Abstract water =1852,000l/24hr

In this study, the ambient water quality standard (Cmax) was assumed to be 200 mg/l, the natural concentration (Cnat) in the receiving surface water body was 12 mg/l and the actual concentration (Cact) was 10 mg/l.

Imported Cotton Data: Data on cotton importation, including virtual water content, were gathered to assess the overall water footprint. Bangladesh, one of the world's top producers of textiles and clothing, imports a sizable amount of cotton from other countries to satisfy domestic demand. Bangladesh buys cotton from a number of international locations. India, the United States, Brazil, Vietnam, Uzbekistan, and Australia are the principal exporters of cotton to Bangladesh. These nations are significant producers of cotton and major exporters of cotton to other countries [7].

TABLE VIII
SHOWS THE TOTAL AMOUNT OF COTTON IMPORTS IN KILOGRAM UNIT IN RECENT YEARS.

Year	Cotton Imports (kg)
2018	1.5×10^{9}
2019	1.62×10^{6}
2020	1.79×10^{9}
2021	1.77×10^{9}

B. Water Footprint Calculations

Blue Water Footprint: The volume of groundwater used in the production processes was measured [8].

Grey Water Footprint: The volume of freshwater required to dilute pollutants in the effluent was calculated [9].

Green Water Footprint: Data from global studies were used to estimate the green water footprint for cotton cultivation [10].

C. Analysis Techniques

Chemical Oxygen Demand (COD): Samples were analyzed to measure the COD concentration using standard methods.

Total Dissolved Solids (TDS) and Total Suspended Solids (TSS): Water samples were filtered and analyzed for TDS and TSS concentrations using calibrated conductivity meters and weighing methods.

D. Methodology

Data Analysis: Factors influencing the water footprint, such as production processes, water management practices, and technology adoption, were analyzed.

Comparison: The wastewater output rates of the investigated textile industries were compared to identify patterns and areas for improvement.

III. Result and Discussion

A. Blue, green and grey water footprint

The blue water footprint of these 3 industries (KDS, FOURH, and AMBER) has been determined using the chain-summation approach. Table 5, Table 6 and Table 7 were utilized to compute the greywater footprint. Pollutant load is nevertheless determined by COD because it offers a more complete measurement of organic matter and because its value is higher in textile effluent than in other parameters [11].

TABLE IX
THE FOOTPRINT FOR BLUE, GREEN AND GREY WATER

Textile Name	Blue water footprint	Green water footprint	Grey water footprint
KDS	95.91 l/kg	3744l/kg	437.16l/kg
FOURH	96.389 l/kg	8335l/kg	488.23l/kg
AMBER	46.305 l/kg	4956l/kg	164.66l/kg

B. Import related water footprint

Table X lists the total amount of cotton Bangladesh has imported over time along with the footprints of blue, green, and grey water that are associated with it [4].

TABLE X
THE TOTAL AMOUNT OF COTTON BANGLADESH

Year	Cotton imports (kg)	Blue water (l)	Green water (l)	Grey water (l)
2018	1.5×10^{9}	4.43×10^{12}	7.74×10^{12}	1.50×10^{12}
2019	1.62×10^{6}	4.79×10^{12}	8.36×10^{12}	1.61×10^{12}
2020	1.79×10^{9}	5.29×10^{12}	9.24×10^{12}	1.78×10^{12}
2021	1.77×10^{9}	5.23×10^{12}	9.13×10^{12}	1.76×10^{12}

TABLE XI
THE TOTAL AMOUNT OF YARN BANGLADESH

Year	Yarn imports (kg)	Blue water (l)	Green water (l)	Grey water (l)
2018	2.22×10^{8}	8.85×10^{11}	1.54×10^{12}	2.89×10^{11}
2019	3.31×10^{8}	1.32×10^{12}	2.30×10^{12}	4.31×10^{11}
2020	6.48×10^{8}	2.58×10^{12}	4.51×10^{12}	8.45×10^{11}
2021	1.07×10^{9}	4.26×10^{12}	7.45×10^{12}	1.39×10^{12}

Table XI lists the total amount of yarn Bangladesh has imported over time along with the footprints of blue, green, and grey water that are associated with it.

C. Export related virtual water

The table XII lists the total amount of cotton Bangladesh has produced over time along with the virtual water of blue, green, and grey water that are associated with.

TABLE XII
THE TOTAL AMOUNT OF COTTON BANGLADESH HAS PRODUCED

Year	Cotton Produce (kg)	Blue water (l)	Green water (l)	Grey water (l)
2018	29×10^{6}	9.7×10^{10}	2.037×10^{11}	3.43×10^{10}
2019	30×10^{6}	1.00×10^{10}	2.11×10^{11}	3.54×10^{10}
2020	31.75×10^{6}	1.06×10^{10}	2.23×10^{11}	3.74×10^{10}
2021	32.61×10^{6}	1.09×10^{10}	2.29×10^{11}	3.85×10^{10}

D. Total virtual water footprint

Table XIII lists the total amount of cotton Bangladesh has imported over time along with the virtual water of blue, green, and grey water that are associated with BGD [3].

TABLE XIII
THE TOTAL AMOUNT OF COTTON BANGLADESH HAS IMPORTED

Year	Textile product exports (metric tons)	Virtual Blue water (l)	Virtual Grey water (l)
2018	4,219,415	5.69×10^{11}	3.55×10^{12}
2019	4,42,220	5.96×10^{11}	3.72×10^{12}
2020	4,229,716	5.69×10^{11}	3.55×10^{12}
2021	4,37,198	5.89×10^{11}	3.68×10^{12}

TABLE XIV
LISTS THE TOTAL AMOUNT OF VIRTUAL WATER THAT BANGLADESH IMPORTS VS EXPORT

Year	Virtual Blue water (l)		Virtual Green water (l)		Virtual Grey water (l)	
	Imports	Exports	Imports	Exports	Imports	Exports
2018	5.31×10^{12}	6.54×10^{11}	9.28×10^{12}	1.15×10^{11}	1.79×10^{12}	3.57×10^{12}
2019	6.11×10^{12}	6.84×10^{11}	10.66×10^{12}	1.55×10^{11}	2.04×10^{12}	3.74×10^{12}
2020	7.88×10^{12}	6.628×10^{11}	13.75×10^{12}	1.64×10^{11}	2.62×10^{12}	3.58×10^{12}
2021	9.49×10^{12}	6.854×10^{11}	16.58×10^{12}	1.68×10^{11}	3.15×10^{12}	3.71×10^{12}

The study analyzed the water footprint of three textile companies—KDS, FOURH, and AMBER—using data from their peak production month. The water footprint includes blue, green, and grey water footprints, with results varying based on production amount, fabric type, and dyeing process requirements.

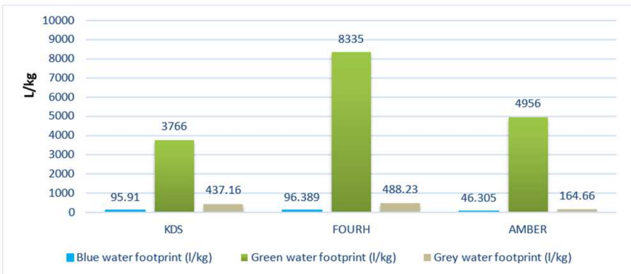

Fig. 1 Blue, green and grey water footprint of KDS, FOURH and AMBRR

These values indicate the volume of groundwater extracted and treated for use in textile production. AMBER Textile, being a denim industry, uses less blue water as it does not involve printing, which consumes significant water. FOURH has the highest green water footprint due to importing yarn from India, which has a large green water footprint for cotton lint. In contrast, KDS has the lowest due to China's lower green water footprint. AMBER Textile has the lowest grey water footprint as it avoids the printing process, leading to fewer pollutants in the effluent.

E. Comparision between studied industries

Figures 2 and 3 indicate that FOURH has a higher green water footprint, suggesting a greater reliance on freshwater resources, and operates on a larger scale with a higher daily output than KDS. Despite its larger scale, FOURH demonstrates more efficient water management with a lower grey water footprint, indicating better wastewater treatment practices. Conversely, KDS produces more wastewater, reflected in its higher grey water footprint, suggesting less effective water management compared to FOURH.

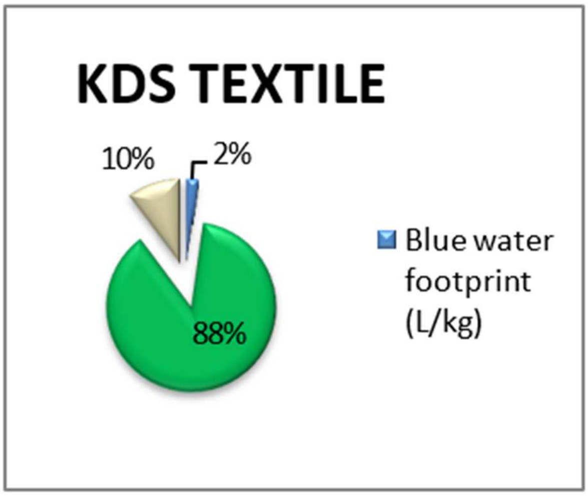

Fig. 2 Total water footprint percentage KDS

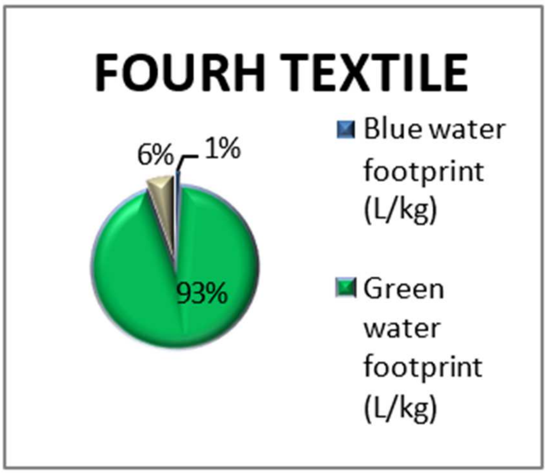

Fig. 3 Total water footprint percentage of percentage of FOURH

F. Virtual water footprint

Figure 4 shows that the blue water footprint for exports is higher than for imports over the years. In 2020, producing a kilogram of textile products for export in Bangladesh required an average of 0.675×10^{12} liters of freshwater. In contrast, importing a kilogram of products brought in goods produced abroad with a virtual water content of 7.88×10^{12} liters per kilogram, reflecting the freshwater used in the exporting countries.

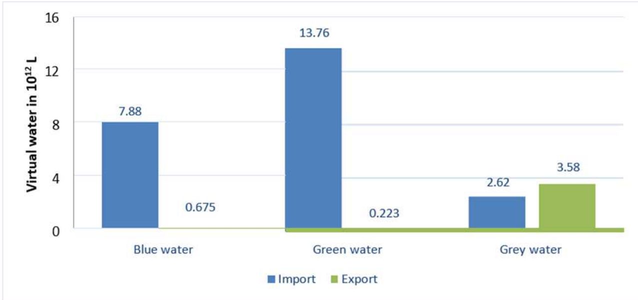

Fig. 4 Virtual blue, green and grey water of Bangladesh (import vs export) in the year 2020.

The green water footprint for exports is 0.223×10^{12} liters per kilogram, indicating that 0.09×10^{12} liters of rainwater or soil moisture were used for each kilogram of exported products. For imports, the green water footprint is 13.76×10^{12} liters per kilogram, showing that this amount of rainwater or soil moisture was used in the production of each kilogram of imported products, mostly cotton from countries like India, China, the USA, and Vietnam. This disparity indicates that Bangladesh uses less green water for its textile exports compared to the green water used by these countries for producing the imported cotton.

The grey water footprint for exports is 3.58×10^{12} liters per kilogram, meaning that this volume of water was polluted during the production of each kilogram of exported products due to wastewater containing chemicals and dyes. For imports, the grey water footprint is

2.62×10^{12} liters per kilogram, indicating that this volume of water was polluted during the production of imported goods. Thus, exporting products with a higher grey water footprint means Bangladesh indirectly exports the associated water pollution, while importing products with a lower grey water footprint means it brings in goods produced with less water pollution.

IV. Conclusion

The textile and garment industry in Bangladesh plays a pivotal role in the national economy but poses significant challenges in terms of water usage and environmental pollution [12]. This study assessed the blue, green, and grey water footprints of the dyeing, printing, and finishing stages in three textile industries: KDS, FOURH, and AMBER. The findings reveal that these processes are substantial consumers of water and contributors to pollution. Effective water management practices are essential to reduce the environmental impact of this sector. By adopting sustainable practices, the industry can maintain its economic benefits while mitigating adverse environmental effects. Future research should focus on innovative water- saving technologies and pollution control measures to further enhance the sustainability of the textile industry in Bangladesh.

Conflict of Interest

There is no conflict of interest regarding the publication of this thesis.

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Appendix A
Global average footprint of cotton lin

FAOSTAT crop code	Product description	Global average water footprint (m^3 ton^{-1})			
		Green	Blue	Grey	Total
249	Coconuts	2669	2	16	2687
	Copra	2079	1	12	2093
	Coconut (husked)	1247	1	7	1256
	Coconut (copra) oil , refined	4461	3	27	4490
	Coconut/copra oilcake	829	1	5	834
	Coconut (coir) fibre, processed	2433	2	15	2449
254	Oil palm	1057	0	40	1098
	Palm nuts and kernels	2762	1	105	2868
	Palm oil, refined	4787	1	182	4971
	Palm kernel/babassu oil, refined	5202	1	198	5401
	Palm nut/kernel oilcake	802	0	31	833
260	Olives	2470	499	45	3015
	Olive oil, virgin	11 826	2388	217	14 431
	Olive oil, refined	12 067	2437	221	14 726
265	Castor oil seeds	8423	1175	298	9896
	Castor oil	21 058	2938	744	24 740
267	Sunflower seeds	3017	148	201	3366
	Sunflower seed oil, refined	6088	299	405	6792
	Sunflower seed oilcake	1215	60	81	1356
270	Rapeseed	1703	231	336	2271
	Rape oil, refined	3226	438	636	4301
	Rape seed oilcake	837	114	165	1115
280	Safflower seeds	6000	938	283	7221
289	Sesame seed	8460	509	403	9371
	Sesame oil	19 674	1183	936	21 793
292	Mustard seeds	2463	1	345	2809
296	Poppy seeds	1723	0	464	2188
299	Melon seed	5087	56	41	5184
328	Seed cotton	2282	1306	440	4029
	Cotton seeds	755	432	146	1332
	Cotton lint	5163	2955	996	9113
	Cotton linters	1474	844	284	2602
	Cotton-seed oil, refined	2242	1283	432	3957
	Cotton seed oilcake	487	279	94	860
	Cotton, not carded or combed	5163	2955	996	9113
	Cotton yarn waste (including thread waste)	950	544	183	1677
	Garneted stock of cotton	1426	816	275	2517
	Cotton, carded or combed	5359	3067	1034	9460
	Cotton fabric, finished textile	5384	3253	1344	9982
333	Linseed	4730	268	170	5168
	Linseed oil, refined	8618	488	310	9415
	Linseed oilcake	2816	160	101	3077
336	Hempseed	3257	12	417	3685
358	Cabbages and other brassicas	181	26	73	280

APPENDIX B

VIRTUAL WATER CONTENT OF COTTON PRODUCING COUNTRIES

	Cotton lint		Grey fabric		Fabric		Final textile		
	Blue	Green	Blue	Green	Blue	Green	Blue	Green	Total
Argentina	5,385	12,589	5,611	13,118	5,971	13,118	6,107	13,118	19225
Australia	3,287	2,031	3,425	2,116	3,785	2,116	3,921	2,116	6037
Brazil	107	6,010	112	6,263	472	6,263	608	6,263	6870
China	1,775	2,935	1,849	3,059	2,209	3,059	2,345	3,059	5404
Egypt	9,876	0	10,291	0	10,651	0	10,787	0	10787
Greece	4,221	1,237	4,398	1,289	4,758	1,289	4,894	1,289	6183
India	5,019	15,198	5,230	15,837	5,590	15,837	5,726	15,837	21563
Mali	3,427	8,752	3,571	9,120	3,931	9,120	4,067	9,120	13188
Mexico	3,863	1,990	4,026	2,073	4,386	2,073	4,522	2,073	6595
Pakistan	9,009	2,460	9,388	2,563	9,748	2,563	9,884	2,563	12447
Syria	7,590	204	7,909	213	8,269	213	8,405	213	8618
Turkey	6,564	672	6,840	701	7,200	701	7,336	701	8037
Turkmenistan	13,077	951	13,626	991	13,986	991	14,122	991	15112
USA	1,345	3,906	1,401	4,070	1,761	4,070	1,897	4,070	5967
Uzbekistan	10,215	195	10,644	203	11,004	203	11,140	203	11343
Global average	4,242	4,264	4,421	4,443	4,781	4,443	4,917	4,443	9359