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Water footprint assessment of textile enterprise based on ISO14046

Xiaojing Ren[a], Xue Bai[b,*], Mengting Hu[b], Dan Liu[a], Yue Wu[a], Zhongguo Zhang[a]

[a]*Environmental Protection Research Institute of Light Industry, Key Laboratory of Energy-Water Conservation and Wastewater Resources Recovery, China National Light Industry, Beijing Academy of Science and Technology, Beijing 100089, China*
[b]*China National Institute of Standardization, Beijing 100191, China, email: baixue@cnis.ac.cn (X. Bai)*

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ABSTRACT

With increasing severe global water crisis, effective management and utilization of water resource have become an important problem to be solved for enterprises. Water footprint assessment has provided a new perspective in making flexible water resources development strategy. This study reports the results of a water footprint (WF) assessment for a typical textile printing and dyeing enterprise using the international method based on ISO14046. Since the calculation boundary "gate to gate" is select, the study pays particular attention to the industrial production stages from 2011 to 2013, and present an impact assessing caused by freshwater consumption and wastewater discharge at organization, product and process level. The results show that both the enterprise and product water scarcity footprint (WSF) in 2012 are the highest. Through the analysis of direct water scarcity footprint (DWSF) composition of each facility, it can be seen that dyeing factories account for 68% of the total enterprise DWSF. In light of the product level, the WSF of products are sorted from the highest to the lowest as follows: chemical knitted fabric > cotton knitted fabric > blended knitted fabric. Among the major water consumption working procedures of these three products, the water consumption of dyeing working procedure is the largest, which is successively followed by that of the printing and washing working procedure as well as that of sizing working procedure. The water degradation footprint, water eutrophication footprint and water acidification footprint of products show an overall downward trend. It is meaningful to reduce the freshwater consumption and wastewater discharge of the hot-spots through the improvement of freshwater management pattern and production techniques. Specific recommendations for further research in this field were also proposed in this study accordingly.

Keywords: Corporate water footprint; Product water footprint; Life cycle assessment; ISO14046; Textile; Knitted fabric

1. Introduction

As a basic element during the production and operation process of textile printing and dyeing enterprises, water resources run through each stage of full life cycle of textile products, ranging from the crop (for instance, cottons, hemps, etc.) plantation which produces the fibrous raw materials or livestock (e.g., sheep, silkworms, etc.) rearing, to the industrialized produced and processed spinning, yarn steaming in the weaving process, sizing water consumption and air conditioner water consumption which intends to maintain the relative air humidity in the production environment, further to the boiling, scouring, bleaching, washing and finishing water consumption during the dyeing and finishing link, then to the daily care of finished products.

Textile industry is one of the significant high-water-consumption industries. According to statistics, the fresh water total intake amount of textile enterprises above designated size is 2.95 billion tons in 2015, which accounts for 7.6% of the national industrial water intake amount and ranks

* Corresponding author.

third among the national industrial sectors [1]. However, the water efficiency of textile industry is far below that of the chemical fiber manufacturing industry, especially in the printing and dyeing link which features in large water consumption, tough wastewater treatment and water recycling level as low as 30% only. Meanwhile, textile industry is also the typical wastewater discharge industry. As per the statistics, the wastewater discharge amount of enterprises above designated size in textile sector ranks third among the 41 industrial sectors, while the discharge amount of both COD and ammonia-nitrogen ranks fourth [2]. With the further expanded industrial scale and continuously reduced water-saving space, the textile industry is still the key monitored sector of discharge reduction in industrial enterprises. As proposed in the "13th Five-Year Plan" for textile industry, as of 2020, the water intake amount per unit of industrial added value will be decreased by 23%, while the total amount of major pollutants discharged will be decreased by 10%. In light of the emerging problem of water resources shortage and water environment pollution, how to prepare the reasonable and effective water resources management plan, and cope with the water resources risk encountered by the textile printing and dyeing enterprises, become the key issues to be solved at present.

As a new analysis tool, water footprint facilitates the identification of impacts of human activities and products upon the water resources shortage and pollution and provides the science reference for promoting the sustainable utilization and management of water resources. Under the trend of strong initiation of sustainable development and vigorous promotion of greening and environmental protection in China, water footprint assessment provides a new perspective for textile enterprises to develop flexible water resource development strategies [3,4]. There are two major water footprint assessment methods. One is based on Water Footprint Network (hereinafter referred to as "WFN"), its representative work The Water Footprint Assessment Manual (hereinafter referred to as "Manual") was released in 2009 and modified in February 2011 [5]. In the manual, water footprint is divided into blue, green and grey water footprint, while the specific calculation method is also given.

At present, based on the WFN method, scholars both at home and abroad have already carried out a large amount of water footprint assessment studies regarding the textile industry and products from variable perspectives. Yu et al. [6] have already calculated the direct blue water footprint and direct grey water footprint of China's textile industry from 2001 to 2010. It is found that the direct blue water footprint reached a peak value of 1.09 × 109 m^3 in 2007, while the direct grey water footprint was 50–70 times of direct blue water footprint. Meanwhile, after wastewater treatment, the direct grey water footprint reduced to about 10 times of direct blue water footprint, while the water footprint of textile products is far above that of clothing and chemical fiber. Zhang et al. [7] have evaluated the water footprint of five sorts of common jeans materials with the variable fibers (inclusive of cotton fiber and cellulose fiber) and different production processes.

It is found that the average water footprint of 1 piece of pure cotton jeans (from the cotton plantation to the production of pure cotton jeans materials) is 3,233 m^3, including 2,767 m^3, 263 m^3 and 203 m^3 of blue, green and grey water footprint, respectively. Besides, the average water footprint of 1 piece of Lyocell fiber jeans (from tree plantation to the production of Lyocell fiber jeans materials) is 1,454 m^3, including 34.5 m^3, 1,384 m^3 and 35.3 m^3 of blue, green and grey water footprint, respectively. Hoekstra et al. [8] have already compared the water footprint contribution rate of water saving and emission reduction measures upon the textile print and dyeing enterprises. It is found that as per the clean production auditing, the blue and grey water footprint per unit of product yield are reduced to 171 and 146 t/t separately, with the decline rate of 26.3% and 31.1%, respectively. Meanwhile, the reduction effects of water recycling measures upon the blue and grey water footprint are about 27 and 36 times, respectively. On the basis of analyzing the difficulties of applying the water footprint calculation methods to the textile industry, Nan [9] attempts to put the calculation focus on the industrial production chain and build the product water footprint calculation methods based on the features of textile industry.

The study intends to put the focus of water resources management of textile industry on the water footprint of textile products, as well as clothing industrial production and processing process. Based on the industrial water footprint theory, Wang et al. [10] have calculated the industrial water footprint of four typical cotton textiles, namely, heather grey, white sheeting, dyed fabric and yarn-dyed fabric. It is found that the industrial water footprint of cotton fabric mainly comes from the direct industrial water footprint, among which, blue water footprint has made a much greater contribution. On such basis, this study comes to the conclusion that the number of dyeing, washing and heating duration are the major factors affecting the industrial water footprint of variable products. Chico et al. [11] and Kamal et al. [12] have discussed the water footprint factor of raw coal, oil, gas, thermal power, paper products, plastic products, metal products, and other common energy and materials in textile and garment industry during the textile and garment industrial water footprint calculation process, analyzed its uncertainty, and provided the theoretical and data basis for the indirect water footprint calculation.

Based on the water footprint theory and in combination of the enterprise production features and industrial development trend, Sun et al. [13] have considered the reuse of water resources and wastewater pretreatment of enterprises during the process of calculating the product water consumption, which causes the calculation results to reflect the product water consumption and enterprise's water resources management level in a more realistic manner and has a much stronger application value. However, due to the unclear calculation boundary of enterprise and product water footprint assessment provided in the Manual, greater differences exist among the relevant studies, while the unified criteria are not developed [14].

The other water footprint assessment method is based on the ISO14046 (Environmental Management-Water Footprint-Principles, Requirements and Guidelines) released in August 2014 by International Standard Organization (hereinafter referred to as "ISO") [15]. Based on the method framework of Life Cycle Assessment (hereinafter referred to as "LCA"), this criterion assesses the size and significance of water-related potential environmental impact at each life cycle phase of process, product and organization. The release of this standard provides the evidence for unifying and regulating the relevant principles, requirements and methodology framework of water footprint assessment. As per the literature research and analysis, it is found that there are very few studies regarding the water footprint assessment of textile enterprises and products with the aforesaid method [16]. In light of the above, this article selects a typical textile printing and dyeing enterprise, and carries out water footprint assessment method and case study of textile enterprise based on ISO14046, intending to explore a new water resources management method which can effectively combine the water footprint assessment and textile enterprise greening manufacturing by using the actual case, and really achieve the water resources sustainable development of textile enterprises.

2. Materials and methods

According to the methods given in ISO14046, water footprint assessment shall consist of four phases of life cycle assessment, namely, goal and scope definition, water footprint inventory analysis, water footprint impact assessment and interpretation of the results. The major methods and steps at each phase will be separately explained in the upcoming sections.

2.1. Goal and scope definition

It is critical to define the system boundary of water footprint assessment at this phase. As per the requirements of ISO14046, four types of system boundary are available, as shown in Table 1.

2.2. Water footprint inventory analysis

The inventory analysis refers to the qualitative and quantitative analysis of the water-related input and output within the system boundary. The inventory data mainly include the input and output of water, materials, energy and others of each process, for instance, input and output of water resources, parameters of water quality, product combined water amount and evaporated water amount, as well as the outsourcing raw materials, auxiliary materials, power, energy, etc. Different from WFN, it not only considers the pollutants contained in the water but also includes the water quality affecting substances discharged into the air and soil, such as SO_2, heavy metal, etc.

2.3. Water footprint impact assessment

Water footprint impact assessment divides the water footprint inventory results taken from the upper phase into two major impact categories, namely, water scarcity footprint (resulted from water quantity variation, hereinafter referred to as "WSF") and water degradation footprint (resulted from water quality variation, hereinafter referred to as "WDF"). Then, it adopts the characterization factor to characterize the inventory substances. Finally, it obtains a series of index results of different influence types, or adopts the comparison, normalization and weighted methods provided in Environmental management—Life cycle assessment—Requirements and guidelines (GB/T 24044-2008; ISO 14044:2006), to combine the results into a single parameter [17,18]. As per the difference of particular pollutants, WDF may also be fractionized into water eutrophication footprint (considering the nitrogen and phosphorus effects, hereinafter referred to as "WEF"), water acidification footprint (considering the acid effects, hereinafter referred to as "WAF"), etc. This study adopts the methods and equations provided in national standard Guideline of water footprint assessment and reporting for organization (GB/T 34341-2017), to calculate the WSF and WDF [19].

2.4. Interpretation of the results

The result interpretation of enterprise water footprint assessment mainly includes the identification of process that causes significant impacts upon the water footprint calculation, mainly affected environmental mechanism and input and output that have the maximum impact upon the water footprint assessment, assessment of the completeness, sensitivity and consistency of water footprint assessment, illustration of study limitation (for instance, boundary selection, data collection, etc.), and providing the relevant comments.

3. Case study

3.1. Enterprise overview

The selected textile enterprise is located in Guangzhou city, Guangdong province. This enterprise is one of the global

Table 1
System boundary of water footprint assessment

S. No.	Name	Assessment objects and processes
1	Facility Boundary	Water footprint produced by a given facility, department, plant and working procedure of an enterprise
2	"Gate-to-gate" Boundary	Water footprint produced by the whole enterprise production process "from the incoming raw materials to the outgoing products" and relevant activities
3	"Cradle-to-gate" Boundary	Water footprint produced by the whole enterprise production process "from the acquisition of raw materials to the ex-factory of products" and relevant activities
4	"Cradle-to-grave" Boundary	Evaluate the water footprint produced by the enterprise production process of product full life cycle and the relevant activities

largest knitted fabric producers and its major products are the fabrics used for all sorts of textile and garment, which has a much higher competitiveness on the international market. Since the wastewater discharge amount of textile industry in Guangdong province ranks third in China, the selected enterprise has good representativeness [1]. This study intends to compile and quantify the water-related input and output of the selected enterprises in the life cycle, identify the major water-saving links inside the enterprise, so as to strengthen the water-saving management, reduce the water footprint and fully play the significant role of water footprint in water resources management via the enhanced process, optimized procedures and other manners.

3.2. System boundary

The enterprise has the dyeing factory, yarn dyeing factory, printing factory, finishing factory and other production departments, as well as the water treatment plant, thermal power plant, dorm, canteen and other auxiliary production departments. This enterprise mainly undertakes the fibrous raw materials provided by the customers, makes them into the warp knitted fabric, weft knitted fabric, 100% cotton knitted fabric, chemical fiber knitted fabric, printing knitted fabric and other fabrics as per the requirements. Given this, from the perspective of strengthening the water-saving management and reducing the water footprint, this study emphasizes the evaluation of industrial production chain and selects the "gate to gate" boundary, namely, the system boundary is set as the whole industrial production process from the incoming yarn to the outgoing products, while the accounting contents include all the water-related inputs (fresh water, outsourcing energy, etc.) and outputs (wastewater, final products, etc.). The system boundary is as shown in Fig. 1.

3.3. Inventory analysis

After the site survey and sampling analysis, the data within the enterprise system boundary by the year is collected and sorted out. Enterprise water intake mainly includes two parts, namely, surface water and municipal tap water. After being filtered by the multi-media filter, and further going through the ion exchange treatment, surface water and partial municipal tap water will be supplied for the industrial water consumption of plant and main building, as well as the domestic water consumption of office building, canteen, etc. Both the water consumption of canteen and direct drinking water system comes from the municipal tap water. All the industrial water comes from the self-made water of the company's water treatment plant. The wastewater drained by the enterprise will be collectively drained into the company's own sewage treatment plant for sewage treatment. After being treated, the effluent sewage will be directly drained into the water body adjacent to the major watercourse. This study selects the water-related input and output data of the enterprise from 2011 to 2013, to conduct the enterprise water footprint assessment. All the collected data come from the raw data of enterprise's site survey, as shown in Table 2.

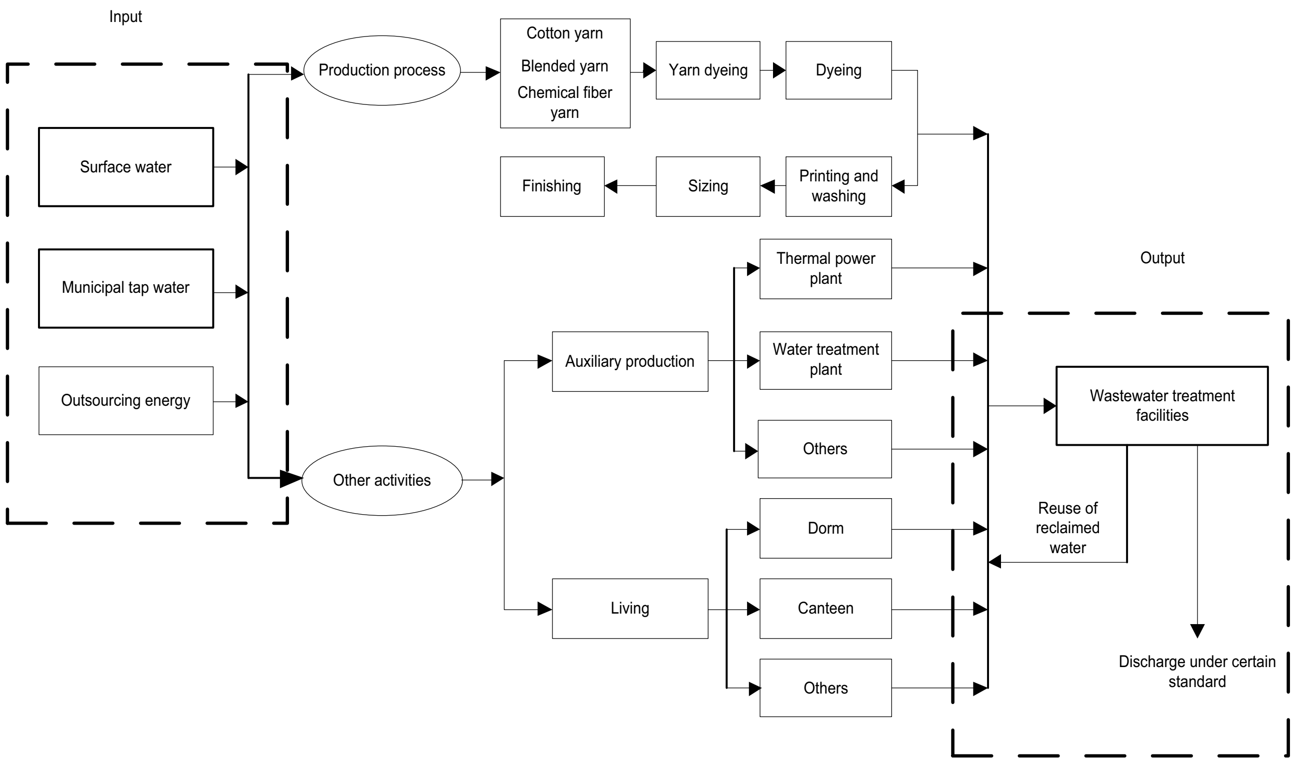

Fig. 1. System boundary of enterprise water footprint assessment.

Table 2
WF inventory data using the ISO14046 method

Year			2011	2012	2013
Input	Total consumption amount of fresh water, 104 m^3		49.4	100.1	53.9
	Energy	Coal, 104 t	28.9	27.2	27.9
		Diesel, 104 t	0.03	0.02	0.02
Output	Total volume of wastewater discharge, 104 m^3/year		954.39	831.7	893.6
	Water pollutants discharge Concentration, mg/L (three-year average)	CODCr	47.7		
		NH_3–N	3.2		
		TN	8.6		
		TP	0.3		
	Total volume of waste gas emissions, 104 m^3/year		2.1	21.2	27.0
	Air pollutants emission concentration, mg/m^3	NOX	151.5	145.2	146.2
		SO_2	166.8	185.4	105.3
	Product output, 104 t	Knitted fabric	7.8	7.6	8.8

3.4. Results and discussions

3.4.1. Water scarcity footprint

In this study, the direct water scarcity footprint (hereinafter referred to as "DWSF") refers to the water footprint produced by the fresh water directly consumed by the enterprise, while the indirect water scarcity footprint (hereinafter referred to as "IWSF") refers to the water footprint produced by the outsourcing energy products consumed by the enterprise. The enterprise adopts the self-built combined heat and power plant to supply the power and heat for the plant area. As a result, the outsourcing energy products only include the coal and diesel, while the 3.56 m^3/t of water footprint per unit standard coal of Akmal et al. [20] is adopted during the calculation. The local characterization factor of WSF adopts the WSI proposed by Chen et al. [21], while the WSI in this study is provided by Google Earth Layer. As per the search results, it is found that the local WSI of the enterprise is 0.091. Meanwhile, the DWSFs and IWSFs of the enterprise from 2011 to 2013 are, respectively, calculated as per the data provided in Table 2, while the calculation results are shown in Table 3.

As shown in Table 3, both the enterprise WSF and product WSF in 2012 are the highest. All the IWSFs from 2011 to 2013 are much higher than the DWSFs in the corresponding year. All the facilities of this enterprise are at the same location. Therefore, the characterization factor has played an insignificant role in the calculation of DWSF. However, the calculations of DWSF are different for any enterprise whose facilities are scattered at variable locations [22].

The enterprise's IWSF mainly comes from the coal combustion in the combined heat and power plant, while the 3-year data vary slightly. Therefore, as per the requirements of ISO14046, this study analyzes and explores the water consumption links which have much higher WSF contribution to the enterprise activities in 2012 mainly from the organization and product levels, providing the data support for the next phase of results interpretation.

Fig. 2 analyzes the DWSF composition of each facility which constitutes the total WSF of the enterprise in 2012 from the organization level [23–25]. It is found that the DWSF produced by the enterprise production activities (such as the dyeing factory, yarn dyeing factory, finishing factory and printing factory) accounts for about 80%, while the DWSF produced by other auxiliary activities (such as the power plant, water treatment plant, dorm, canteen, etc.) accounts for 20% only. Meanwhile, among the production activities, the DWSF produced by six dyeing factory occupies the maximum proportion, namely, 68% of the total enterprise DWSF.

Therefore, the dyeing factory contributes the most to DWSF. In light of the product level, the major production raw materials of the enterprise in 2012 are three types, namely, cotton yarn, cotton/polyester blended yarn and all sorts of chemical filament, which correspond to three products, namely, cotton fabric, blended fabric and chemical fabric [26–30]. The production processes of these three products are almost the same. Among which, dyeing, printing and washing, and sizing, these three working procedures are the major water consumption working procedure. As per the water consumption per unit product of each working procedure

Table 3
Water scarcity footprint of enterprise and products

Year	DWSF 104 m^3 H_2O-eq	IWSF 104 m^3 H_2O-eq	Enterprise Total WSF 104 m^3 H_2O-eq	Product WSF m^3 H_2O-eq/t
2011	4.5	6.7	11.2	1.4
2012	6.0	6.3	12.3	1.6
2013	4.9	6.5	11.4	1.3

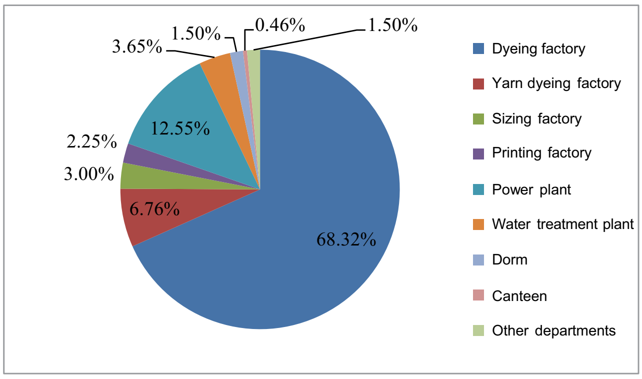

Fig. 2. DWSF composition of each facility in 2012.

and product yield, this paper calculates the DWSF of the enterprise's three major products in 2012, as shown in Table 4.

As shown in Table 4, the WSF of products are sorted from the highest to the lowest as follows: chemical knitted fabric > cotton knitted fabric > blended knitted fabric [31,32]. Among the major water consumption working procedures of these three products, the water consumption of dyeing working procedure is the largest, which is successively followed by that of the printing and washing working procedure and that of sizing working procedure.

3.4.2. Water degradation footprint

As shown by the survey data, after being properly treated by the self-built sewage treatment plant, the sewage (wastewater) of the enterprise will be discharged under certain standard to the third-grade water body. This study adopts the critical water volume method to calculate the 3-year WDF [19]. Due to the lack of data and other reasons, this study adopts the 3-year average as the water quality parameter of exterior drainage. The comparison of WDF results facilitates finding the potential problems of the potential water environmental deterioration. As shown in Table 5, the enterprise WDFs are ranked from the highest to the lowest by the year as follows: 2011 > 2012 > 2013, while the product WDF is reduced year by year.

WDF composition in 2012 is shown in Fig. 3. It is found that the nitrogen and phosphorus pollutants (NH_3–N, TN and TP) that causes the potential eutrophication of water body contributes the largest WDF, accounting for about 85%, which is far above the proportion of organic pollutants (mainly COD) that causes the potential organic pollution (accounting for about 15%). Therefore, as per the requirements of GB/T 34341-2017 [19], this study adopts the ReCiPe model to independently assess the WEF and WAF

Table 5
Water degradation footprint of enterprise and products

Year	Enterprise, WDF, 104 m^3-water equivalent	Product, WDF m^3-water equivalent
2011	14,969.6	1,919.2
2012	13,045.2	1,716.5
2013	14,016.1	1,592.7

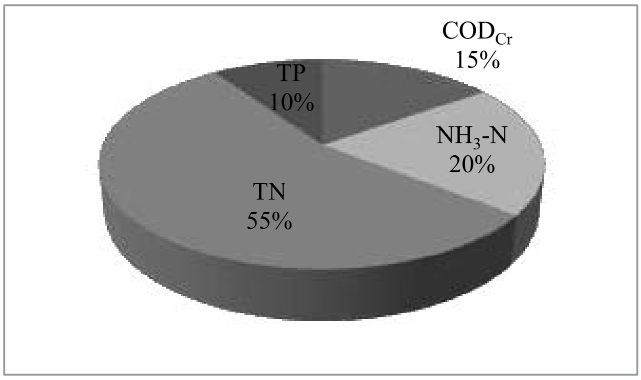

Fig. 3. WDF composition in 2012.

Table 6
WEF and WAF of enterprise and products during 2011–2013

Year	WEF		WAF	
	Enterprise, 104 kg PO_4^{3-} eq	Product, kg PO_4^{3-} eq	Enterprise, kg SO_2 eq	Product, 10–4 kg SO_2 eq
2011	6.3	0.81	950.7	121.9
2012	5.5	0.72	1,026.2	135.0
2013	5.9	0.67	775.7	88.1

Table 4
Water consumption per unit product

Working procedure		Product		
		Cotton knitted fabric	Blended knitted fabric	Chemical knitted fabric
Water consumption (t water/t fabric)	Dyeing	68	72	121
	Printing and washing	35	15	25
	Sizing	0.8	0.8	0.8
	In total	103.8	87.8	146.8
WSI		0.091		
DWSF, m^3 water equivalent/t knitted fabric		9.4	8.0	13.4

of enterprise and products, as shown in Table 6. It is found that the WEF and WAF of products in 2013 were dropped by 17% and 28% separately, compared with that in 2011, because the enterprise intensified the wastewater treatment and reuse of reclaimed water, and also conducted the boiler flue gas in-depth treatment technological upgrading project in 2012.

4. Conclusion

The following conclusions can be drawn from the analysis of water footprint inventory results and water footprint evaluation results:

- The direct water footprint of chemical knitted fabric is the largest, among which, the dyeing working procedure contributes the most. Therefore, it is urgent to adopt the advanced water-saving technology and equipment during the chemical fiber and textile production process, so as to enhance the utilization efficiency of water resources.
- Since all the facilities of the assessed enterprise are at the same location, the WSF is equivalent to blue water footprint of WFN. However, the results of WSF are obviously different for the enterprise whose facilities are scattered at variable locations.
- WDF, WEF and WAF of products show an overall downward trend. It demonstrates that the enterprise has begun to adopt the sub-quality water, source-separated wastewater discharge, and high-efficient wastewater in-depth treatment and reuse technology since 2012, which has achieved a better actual effects for further reducing the pollutant emission and enhancing the water consumption efficiency.

Limitation

The enterprise discussed in this study is only a case, which is only a substitution and application of water footprint assessment methods provided in ISO14046. It should be pointed out that, the conclusions of this study have a certain limitation either in product category or in the accounting boundary. While it is only a substitution and application of water footprint assessment methods provided in ISO14046. Besides, due to the regional variation of production technical level and difference of quantitative statistics and other management methods, the applicable scope of product LCA basic database has the regional limitation, which makes it urgent to establish the water footprint accounting basic database of each chain section, as per the production features of products. At present, most WSI selected in the calculation of WSF adopts the internationally used method which has the approximation and estimation in calculating the specific data in China. Therefore, it has the very significant realistic meaning to establish the local basin or regional WSI database in China.

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