Environmental Impact Assessment of Discharged Heavy Metals in Textile Production

DOI: 10.5604/01.3001.0014.5047

Abstract

Heavy metals discharged from textile production have serious impacts on human beings and the environment. Chemical footprint (ChF) methodology is an important method in quantifying the environmental loads of discharged chemical pollutants. With the help of ChF methodology, this study used the mean impact method to assess the environmental loads of heavy metals discharged from a textile enterprise. The results showed that the ChFs of discharged heavy metals calculated based on the aquatic environment of Lake Tai and Lake Poyang were 1.43E+8L and 4.64E+8L, respectively. Zinc was the largest contributor, followed by copper, lead, and cadmium for the two lakes.

Key words: aquatic environment, chemical footprint, environmental impact, heavy metals.

Introduction

Chemicals play a vital role in modern industrial production [1]. Taking China as an example, over 50,000 chemicals are used or produced nowadays [2]. Chemical pollution is increasingly serious with the increasing quantity and types of chemicals. Uncombined heavy metals are discharged into the environment with waste water and waste residue in industrial production [3]. The discharged heavy metals can bio-accumulate through the food chain. They are difficult to degrade and have had serious impacts on human beings and the environment [4, 5]. Assessing these impacts and reducing heavy metal pollution are the common concerns at present [6].

As a footprint tool, the chemical footprint (ChF) was first proposed by Panko and Hitchcock in 2011 [7]. ChF methodology focuses on the environmental impact assessment of chemical use and pollutant emissions. The USEtox model has been widely used in ChF studies, and environmental impacts are now expressed in comparative toxic units (CTU). The definition of ChF based on CTUs reflects the potential environmental impacts of chemical pollutant emissions on species. The results can be converted into volume under certain conditions [8]. Another method for ChF assessment is based on the safe operating space, which is defined as the ratio of the water volume requirement to availability in the study region [9]. This method is more flexible and ChF results are easy to communicate and aid cooperation. Zijp et al. [10] introduced volume-weighted mixture toxic pressure as the quantisation method and calculated the ChF of 630 organic chemicals in Europe and pesticides in the Rhine, Meuse, and Scheldt rivers (RMS). The results showed that the natural carrying capacity of RMS could not tolerate the environmental load of the pesticides.

Currently, researches relating ChF have mainly focused on the environmental impacts of organic chemicals. ChF methodology can also quantify the environmental impacts of heavy metal emissions with toxicity data measured in the experimental environment. However, dissolved organic carbon (DOC) in an aquatic environment is complex with heavy metal ions [11]. The concentrations of OH⁻ and CO₃²⁻ in a water environment will affect metal speciation, and cations such as H⁺, Na⁺ and Ca²⁺ in the water environment will compete with heavy metal ions for biotic ligand sites, eventually affecting the toxic effect caused by heavy metals [12]. Therefore, current ChF assessment methods cannot work effectively as to the environmental impacts of heavy metals discharged into different water bodies in different regions. This study aims to calculate the ChF of discharged heavy metals with the AMI method and biotic ligand model (BLM) in order to assess the environmental impacts accurately. This will fill the gap in ChF calculation of heavy metals.

Method and data

The essence of ChF based on dilution theory is to investigate the relationship between the environmental carrying capacity of the study region and the environmental load of production activities [10]. Based on the dilution theory, assessment of the mean impact (AMI) method can quantify the ecological toxicity of chemical pollutants. The ChF obtained by this method represents the available environment volume required to dilute the chemical pollutants to a safe concentration. The impacts of the water environment in the region selected on heavy metal toxicity can be quantified by the biotic ligand model (BLM). The BLM method, which is combined with the theory of gill surface interaction and free ion activity, incorporates the competition of free heavy metal ions with other naturally occurring cations, together with complexation by abiotic ligands for binding with the biotic ligands [13]. The ChFs of heavy metals discharged to the selected water body can be calculated with Equation (1):

$$\text{ChF} = \sum_i C_{wi} \cdot V \cdot \frac{Y_{HC\text{S}_{50i}}}{\text{Dis}_{\alpha\beta}}$$

where, $C_{wi}$ is the exposure concentration of heavy metal i in the aquatic environment of the study region, mg/L; $V$ is the volume of the aquatic environment in the study region, m³; $HC\text{S}_{50i}$ is the concentration value of heavy metal i corresponding to 50% of the potentially affected fraction (PAF) of species on the curve of species sensitivity distribution (SSD), mg/L; $Y$ is the conversion coefficient of $HC\text{S}_{50i}$ to $HC\text{S}$, with the value of

---

Xiang Ji¹,², Weiran Qian¹,², Xiaoxiao Qiu¹,², Yiduo Yang¹,², Pinghua Xu¹,², Laili Wang¹,²,³,

¹ Zhejiang Provincial Research Center of Clothing Engineering Technology, Hangzhou, Zhejiang 310018, China
² Zhejiang Sci-Tech University, Silk and Fashion Culture Research Center of Zhejiang Province, Hangzhou, Zhejiang 310018, China
³ Zhejiang Academy of Ecological Civilization, Hangzhou, Zhejiang 310018, China

Weiran Qian, Pinghua Xu, Yiduo Yang, Xiang Ji, Zhejiang Academy of Ecological Civilization, Hangzhou, Zhejiang 310018, China

DOI: 10.5604/01.3001.0014.5047

FIBRES & TEXTILES in Eastern Europe 2021, 29, 1(145); 66-69. DOI: 10.5604/01.3001.0014.5047
Results and Discussion

The ChFs of copper was 1.43E+8L according to the equations. Fig. 1 shows the ChFs total ChF based on biotic ligand complex i.e., the ChF of aquatic environment to heavy metal toxicity, where the greater the coefficient, the stronger the inhibition of aquatic environment in the aquatic environment of selected regions to heavy metals (i.e., cadmium, lead, copper and zinc) based on different regions. The total ChF based on the aquatic environment of Lake Tai (ChF_{Tai} for short) was 1.43E+8L. Zinc contributed the most to the environmental load with a result of 1.39E+8L. The ChFs of copper, lead and cadmium were 3.03E+6L, 6.75E+5L and 6.45E+5L, respectively. The total ChF based on the aquatic environment of Lake Poyang (ChF_{Poyang} for short) was 4.64E+8L. Zinc was also the largest contributor, followed by copper, lead and cadmium. ChFs calculated based on the aquatic environment of Lake Poyang for cadmium, lead, copper and zinc were larger than those calculated based on the aquatic environment of Lake Tai.

The aquatic environment of Lake Tai, with low pH as well as relatively high concentrations of DOC and ions (inorganic anions and metal cations), had a great influence on the ecotoxicity of heavy metals. DOC can ameliorate the ecotoxicity of heavy metals by its ability to bind heavy metals [22]. High concentration of DOC means that the metal-DOM complex has a higher proportion in the speciation of heavy metals, and that the concentrations of heavy metal ions that can bind to biotic ligand sites are lower, thereby reducing bioavailability to target surfaces such as gills [22]. Ions in water affect the toxicity of heavy metals by their effects on both the organism and metal speciation. Inorganic ions decrease the availability of heavy metals by complexing with them. Mg²⁺ and Ca²⁺ (particularly the latter) not only play a significant role in decreasing heavy metal action at transport sites by apparent competition but also in decreasing ionic losses associated with toxicant action by stabilising the paracellular junctions in the gill epithelium [23, 24]. H⁺ showing a low pH not only changed the speciation of heavy metals but also offered protection by competing with them for binding sites [25].

Changes in heavy metal toxicity based on the aquatic environment of Lake Poyang are shown in Figure 2. The abscissas

Figure 1. ChFs of four heavy metals in two lakes.
represent the water quality parameters and the ordinates the ratio of heavy metal toxicity in the aquatic environment with a corresponding concentration to that in the aquatic environment of Lake Poyang. The intersection of lines in each graph is the datum of each variable.

As can be seen from Figure 2, the concentrations of Ca$^{2+}$ and DOC had an obvious effect on the toxicity of cadmium. In the BLM model, Ca$^{2+}$ played a protective role, where it was the major cation that competed with the free Cd$^{2+}$ for the binding sites. The strength of DOC-Cd$^{2+}$ binding was about 10 times greater than that of gill-Cd$^{2+}$ binding; therefore, DOC can effectively reduce the toxicity of cadmium [13]. This is the main reason for the largest reduction ratio of ChF caused by copper was the smallest.

### Conclusions

Heavy metals discharged from industrial production have serious impacts on the environment as well as human beings. As a footprint indicator, ChF quantifies environmental loads by evaluating the performances of discharged pollutants. However, current ChF methodology has the main weakness of low distinguishing ability for quantifying the environmental loads of heavy metal based on different regional aquatic environments.

In this paper, we improved ChF methodology by using the BLM model and considering the impact of the aquatic environment on environmental loads. ChFs of four kinds of heavy metals were calculated based on the aquatic environment of two regions. The results showed that ChF$_{Tai}$ was smaller than ChF$_{Poyang}$. Zinc was the largest contributor for the total ChFs of the two lakes, followed by copper, lead and cadmium.

Currently, the lack of availability of pollutant data on auxiliary composition and emission is one of the limiting factors for ChF research, which makes it difficult for inventory accounting to reflect real environmental loads. On the one hand, producers are concerned about the effects of auxiliary, and due to the pressure of environmental protection policies, they often pay close attention to the emissions required by the policies. Obtaining relatively real data and building transparent and flexible databases are necessary for ChF research in the future.

### Acknowledgements

The authors are grateful to the Zhejiang Provincial Natural Science Foundation of China (LY20G030001), science and technology innovation activities of university students in Zhejiang Province (2020R406074), the National College Students’ Innovative Entrepreneurial Training Program of China (202010339017), and to the National Natural Science Foundation of China (61702460) for providing funding support for this research.

### References

1. Yu L, Jiang YY. Strengthening Chemical Management is the Need of Sustainable Development of Human Society. 2008 Annual Meeting of Shanghai Society