ASSESSMENT OF WATER FOOTPRINT OF THE STEEL INDUSTRY: CASE OF BANGLADESH

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ABSTRACT

Bangladesh is the world's 29th producer of iron and steel, with 9 million metric tons of capacity. This large industry is distinguished by substantial water use and various water-related dangers. It is estimated that about 250-300 cubic meters (66043-79250 gallons) of water are used to produce 1 ton of steel. The production facility uses water for cooling, cleaning, and other processes. This study suggests using water footprint instead of traditional indicators (freshwater consumption (FWC) per tonne of steel or carbon footprint). This study used a water footprint computation approach that covered blue and grey water footprints with data from some prominent steel companies in Bangladesh. A chain summation approach establishes a standard industrial water footprint assessment approach. This study has selected two major steel industries in Bangladesh to calculate the water footprint. The selected steel industries have the blue water footprint estimated as 1.095*107m^3/yr, 9.125*106m^3 /yr, and the grey water footprint was calculated as 9.297*10^7 m^3/yr, 73.73*10^6 m^3/yr, which indicates that these industries pose a severe risk to the water environment. An uncertainty assessment was conducted based on the results of the water footprint calculation. Based on the findings, a risk assessment was also performed in this study.

Keywords: *water footprint assessment, steel industry, uncertainty assessment, blue water footprint, grey water footprint*

1. INTRODUCTION

The steel industry in Bangladesh has been rapidly growing in recent years as the country undergoes significant urbanization and infrastructure expansion. The sector also plays a crucial role in Bangladesh's economy by providing work opportunities and making a noteworthy contribution to the country's GDP.

However, the increase in steel production has raised concerns regarding the environmental impact of this industry, particularly regarding water usage. The water footprint calculates the amount of water used throughout the production process and has become an essential metric in assessing the sustainability of industrial activities (Ding & Ghosh, 2017). This study dealt with two steel industries that make TMT bars from Scrab. The production process in those two industries involves melting and rolling facilities. The raw material is the scrabs coming from inside as well as from outside, mainly from China. After melting the scrab, they convert them into billet; TMT bars are produced from these billets. This study will explore the water footprint of the steel industry in Bangladesh, considering both the production process.

Bangladesh's steel industry has multiplied in the past few decades, producing around 1.5 million metric tons of steel in 2019. In 2022, it reached up to 16.638 million metric tons of steel. Figure 1 shows the upward movement in Bangladesh's steel production rate from 2015 to 2022. In September 2022, the production of iron and steel mills in Bangladesh stood at 12,339.000 Metric tons, the same as the previous month, August 2022. This data is updated monthly and has been observed over 90 months, averaging 9,075.000 Metric Tons from April 2015 to September 2022. The highest point in these statistics was reached in June 2022 at 16,638.000 Metric Tons, while the lowest recorded figure was 6,930.000 Metric Tons in November 2015. This data is still available in CEIC and is reported by the Bangladesh Bureau of Statistics. Bangladesh's iron and steel industry is mainly led by the private sector, consisting of large-scale integrated steel mills and smaller local producers. The primary focus of steel production in Bangladesh is on long steel products, including bars and rods, mainly used in the construction industry.

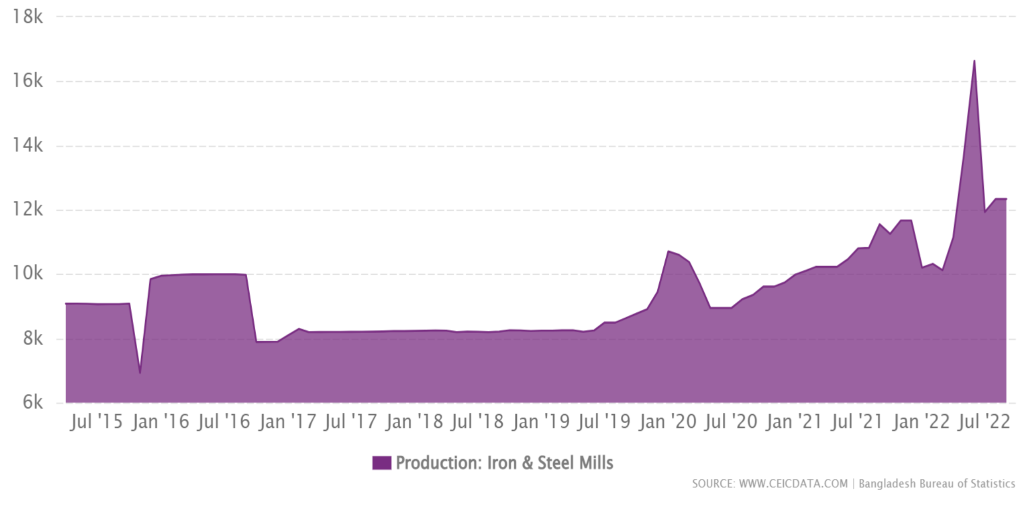

Figure 1: Steel Production in Bangladesh (2015-2022)

Water is essential to several vital operations and processes in the steel industry. Water is mainly used for worker comfort, cooling, and equipment protection. Apart from these uses, water is also used to process steel, quench slag and coke, purify coke-furnace gases, and concentrate steel ore. Water is set aside for boiler feed water and hygienic and servicing requirements. In mines and concentration plants, water is used for hydraulic stripping, drilling, and dust management. In particular, water cooling is used in electric furnaces to preserve metal quality and avoid warping, and water is used in hot-rolling mills to regulate temperature during rolling. Water is also used sparingly throughout the pickling and cleaning procedures to guarantee the creation of high-quality steel. The steel industry's water routing practices vary based on factors such as water availability, quality, and plant infrastructure (Colla et al., 2017; Lv et al., 2023).

Wastewater discharge from the iron and steel industries may substantially impact nearby aquatic habitats. A study found that dissolved metals such as Cadmium, petroleum-based chemicals, volatile phenol, and arsenic are present in water resources affected by the iron and steel industry (Agoro et al., 2020). In this industry, water has a considerable influence on resources locally, regionally, and globally and is at high risk for water scarcity. The production process of steel requires a massive amount of water, which is generally collected from rainwater, nearby dams, or groundwater. Sometimes, excessive water consumption may cause problems for nearby living habitats and the overall ecosystem of that area. If the industries discharge the used water into the environment, it may cause severe problems as the water is contaminated with several pollutants. So, precautionary and policy measures must be taken for a sustainable practice and production policy to support Bangladesh's water resources.
This study aims to calculate the water footprint of steel industries and analyze the water consumption pattern in steel industries. It also provides a water risk assessment based on the findings of the footprint from the steel industries.

2. METHODOLOGY

The water footprint of a steel industry can be calculated in several ways: direct water consumption, virtual water footprint, and cumulative grey, blue, and green water footprint. Direct water consumption involves the water used in manufacturing and the cooling system (Sachidananda et al., 2016).

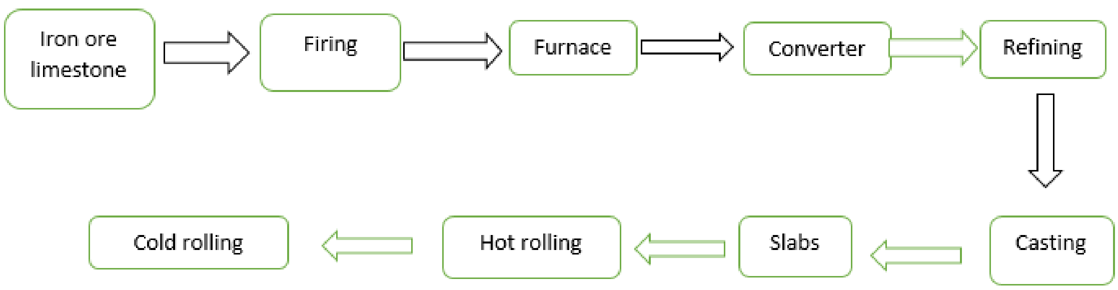

Figure 2: Iron and steel production process diagram

The steel manufacturing process is complex; it takes various stages like scrap melting, refining, making billet, and giving shape. Each stage of the production process needs significant water and energy consumption, and each step generates some wastewater that can be treated for reuse. Fig.2 shows the system boundary of an industry used for the study. Calculating the water footprint of the steel industry in Bangladesh is complex and challenging due to insufficient private data. A system analysis approach is used to estimate the water footprint, considering water consumption, energy use, and local environmental impacts in a specific plant to address this. This approach can be applied to industries without extensive data or research. Boulay et al. 2013 developed the water footprint concept, which relates to the sum of W.C. and gross virtual water inputs that may be analyzed at many scales, such as one procedure, a factory, a manufacturing sector, national, and regional. Hoekstra's research established the water footprint concept to quantify distinct places' worldwide water resource appropriation(*Herkson*) (The WaTer FooTprinT AssessmenT Manual). Ridoutt & Pfister (2010) advocated reducing personal water footprint to ease the stress on water supplies.

Blue, green, and grey water footprints are all water footprints (Gerbens-Leenes et al., 2009). "Blue water footprint" relates to surface and groundwater withdrawals from the environment for personal use(Mekonnen and Hoekstra, 2011). The grey water footprint is the quantity of water required to dilute contaminants in natural water systems while maintaining water quality. In many contexts, wastewater treatment can lower the water necessary to achieve these aims(De Girolamo et al., 2019). Essentially, the greywater footprint influences water quality (Muthu, 2014). The LCA-based water footprint technique developed by the life cycle assessment (LCA) community can help examine the impact of products or enterprises on aquatic habitats throughout their life cycle (Jeswani & Azapagic, 2011; Muthu, 2014). Calculating the virtual water footprint is challenging and complex because many factors are required, such as the type of materials, chemicals used, internal energy, transportation energy, etc. (Gao et al., 2011). Accurate statistics of power consumption, energy production process, and fuel usage data are necessary to calculate the footprint in the power sector (van Zalk & Behrens, 2018). According to the data collected from steel industry units in Bangladesh, water usage varies from industry to industry but is generally high(Dey & Islam, 2015). The average water used in steel industries is 25-65m3 per tonne(Sirajuddin et al.). The average water intake for integrated steelworks is 28.6 m3 per tonne of produced steel, with an average water discharge of 25.3 m3/tonne. For the electric route, the average intake is 28.1 m^3 per tonne of steel, with an average discharge of 26.5 m3 per tonne of steel (Colla et al., 2017).

Water footprint may be calculated using the chain summation technique and the step-by-step accumulative approach (Herath et al., 2011; WWF-UK, 2009). Chain summation is commonly employed in manufacturing processes with a single output product. The water footprint connected to every process in the manufacturing system may be related to the system's output. The stepwise accumulative method is an overall water footprint estimating technique based on the water footprint of the final stages of manufacture of final and necessary commodities and calculating the water footprint in the processing steps(Mekonnen & Hoekstra, 2011b, 2012; Muthu, 2020).

This study used another method described by Gu et al**.** to calculate the greywater footprint. It consisted of three WFgrey indices (α,β, ϒ)(Gu et al., 2014). α for water quality effect evaluation, β for water quantity effect assessment, and ϒ for time effect assessment (ϒ).

In this method, the Water stress index is also used, and the standard water parameters were taken from the value given by the Department of Public Health, Govt. of Bangladesh.

$$dW.F._{gray} = \frac{\alpha * V}{1 - WSI} = \beta \text{ ....(1)}$$

$$\alpha = \text{Max}\frac{Qi}{Bi} \text{ ....(2)}$$

$$WF_{total} = WF_{blue} + WF_{green} + \beta \text{...................(3)}$$

(α =water quality assessment index, β = water quantity assessment index, V = volume of wastewater, Qi = pollutant concentration, Bi = natural concentration, WSI = water stress index (based on region))

Samsudin et al., 2020 conducted a study on the water stress index; they made range-based data of WSI value there. The water stress value depends on the baseline water stress for a specific region.

Table 1: Standard WSI value

WSI	Level
<0.2-.09	Low
0.1-.19	Medium
0.2-0.49	Moderate
0.50-0.89	High
0.9->0.95	Extreme high

A report published in The Business Standard in March 2023 shows that Bangladesh is one of 64 select countries with 'low' baseline water stress (M.A.&M. 2019). So, the WSI value for the calculation is taken as 0.9.

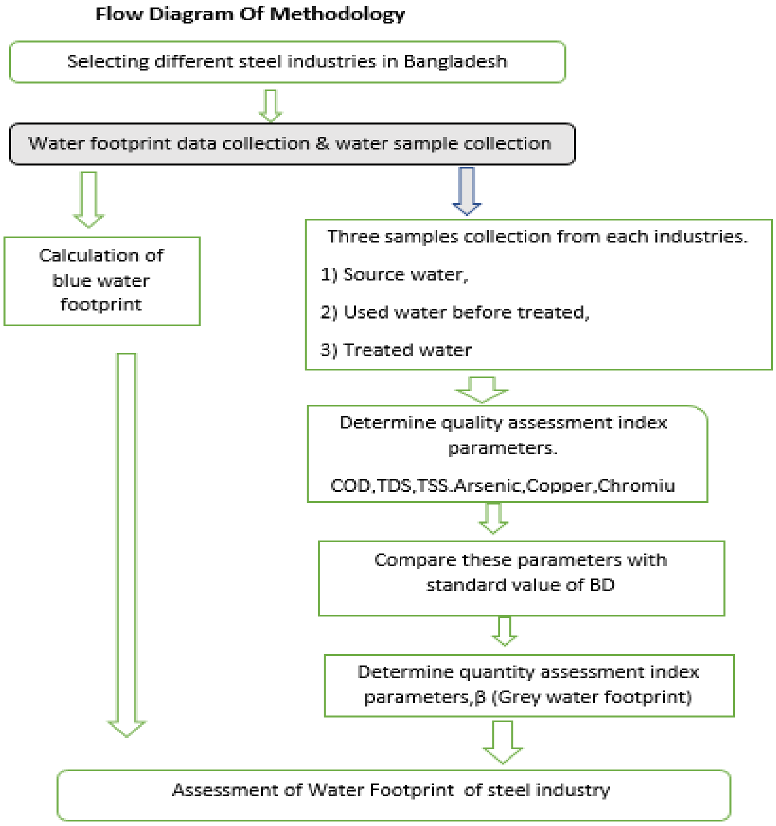

Figure 3: Methodology of estimating of water footprint of steel industry

3. RESULTS

This study has collected data from some prominent steel industries in Bangladesh, located in Shitakundu, Chattogram. The manufacturing process of the chosen industry is complicated. Various procedures need up to ten distinct compounds, such as corrosion and scale inhibitors. The company utilizes 216 tonnes of chemicals each year. 60% are solid with no direct water footprint; the water needed for the other chemical was factored into the DWF. Due to limited data availability, the virtual water of these chemicals could not be calculated, but it is likely to be much smaller than DWF. This industry uses 270KW of energy daily, produced at their gas-based power plant. So, the calculated water footprint from the energy sector is 112.347 m^3/yr. The applied water quality standard for the calculation was followed by the Water quality parameters published by the Department of Public Health Engineering, Govt. of Bangladesh.

The findings of a product or company's water footprint evaluation are typically presented as the total water footprint, calculated by adding the green, blue, and grey water footprints. On the other hand, it seems that the overall water footprint produced by a hypothetical "pollution volume" (greywater) and W.C. amounts (bluewater) has minimal environmental relevance. Instead of the sum, the overall W.C. footprint (blue water footprint) and water pollution footprint (grey water footprint) are computed individually in this study to offer specific water risk information. During this period, the total water footprint was $1.03*10^8$ m^3/yr, and the grey water footprint of this industry was $9.297*10^7$ m^3/yr. The enterprise's substantial greywater footprint suggests a significant risk to the water ecosystem. Generalizing the result of this study, a study conducted by Gu et al., 2015, in Eastern China found that the grey water footprint value is $6.5*10^8$ $m^{3,}$ and the blue water footprint is $2.24*1010^7$ m^3/yr.

Table 2: Water footprint of steel industries

Name	WF_{Blue}	WF_{gray}	$WF_{energy\ sector}$	WF_{total}
Industry-I	$1.095*10^7 m^3$/yr	$9.297*10^7$ m^3/yr.	112.347 m^3/yr	$1.03*10^8$ m^3/yr
Industry-II	$9.125*10^6 m^3$ /yr	$73.73*10^6$ m^3/yr	117.420 m^3/yr	$8.28*10^7$ m^3/yr

The steel industry consumes much water and poses many water-related dangers. The chosen steelworks company's total W.C. (blue water) footprint is around 8–10 times larger than its grey water footprint. According to a study, the worldwide animal production's grey water footprint is just 1.06 times more than its blue water footprint (87.2% green, 6.2% blue, and 6.6% grey water footprint) (Mekonnen & Hoekstra, 2011a). The difference in grey and blue water footprint ratios causes a specific industrial wastewater exit from the steelworks company to have a high concentration.

4. UNCERTAINTY ANALYSIS

Uncertainties arise due to the presumptions used to define the study range and system boundaries. A shortage of data and various sources challenges estimating the water footprint of raw material extraction and transportation operations. The usage of iron and steel goods varies greatly as well. This study calculates the water footprint of iron and steel manufacturing steps while ignoring the water footprints of raw materials and product consumption mechanisms. The primary statistics on the selected enterprise's water consumption, wastewater output, and energy consumption are precisely acquired based on the statistical information from the firm within 5% in this study. The estimate of the energy-water footprint is still being determined as it took help from secondary data. Following irrigation, the energy industry is the world's second-greatest water user regarding withdrawals (Wu et al., 2019; Zhang et al., 2018). Even for the same primary energy, the amount of water required varies significantly according to the precise technologies and processes used, the principal energy carrier's source, and even time (Dreizler et al., 2021). The data sets can be used to calculate water footprints, but they may need to pay more attention to the actual virtual water consumption contained in energy in this industry.

Moreover, the water footprint from the scarp collection was not possible due to a lack of data. These scarps were imported from China(90%), and the rest were collected locally. There is a huge possibility of having a more significant number of virtual water footprints. As a result, there are uncertainties in the outcomes.

5. RISK ASSESSMENT

Water risk assessment is a method that evaluates the potential water-related risks associated with a good, process, or organization. This approach helps companies identify hotspots of freshwater consumption and deterioration along the value chain and assess the environmental and process risks related to water use. Water risk assessment evaluates potential risks associated with goods, processes, or organizations, while WFA concentrates on water consumption, scarcity, and pollution(Chapagain, 2017). Physical, regulatory, and reputation risks are components of enterprise water risk(Orr & Cartwright, 2010a). Physical danger is the most similar to the water footprint of the three risks. The direct threat to water resources is physical risk. When water is scarce or severely contaminated, businesses may experience physical danger, including water quantity and quality risks(Orr & Cartwright, 2010b). The water footprint is a valuable instrument in water risk assessment, and three primary aspects are involved: calculating the water footprint, estimating water risk, and water risk management. The water footprint analysis of the entire organization and each manufacturing process may offer the information needed for more effective and sustainable water resource management. Furthermore, businesses can adopt managing steps depending on the water risk assessment results(Wang et al., 2021).

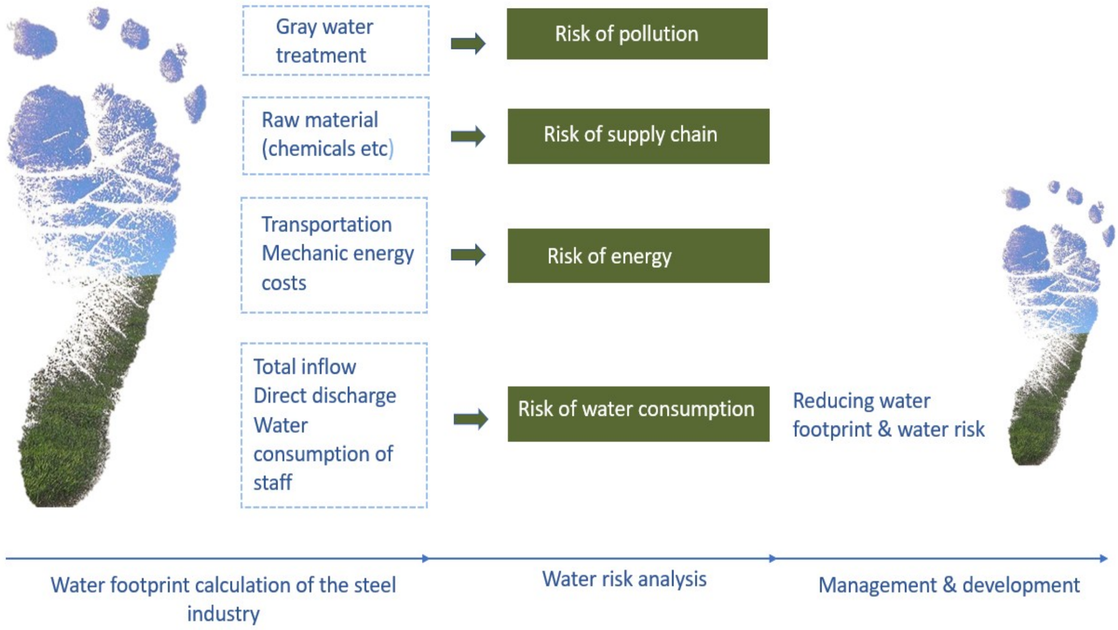

Figure 4: From water footprint to water risk analysis

Based on the findings of Banerjee et al. (2023), Rai et al. (2023), Ren et al. (2023), Elina et al. (2015) developed a risk assessment approach. The risk assessment considers local concerns that might jeopardize manufacturing operations or the environment. To conduct a thorough risk assessment, it is necessary to identify and connect any potential risk factors to the immediate surroundings. One method is to connect the process flow chart to the plant layout and identify the locations of the supply chain on a map. In this study, there could be several risks for the steel industry based on the Water footprint value and their water source. Baseline water stress, safety and security aspects, water quality, and water quality stability are significant findings for these industries. Baseline water stress covers water availability, inter-annual variability, seasonal variability, and access to water. Table 3 represents the used water quality of the selected industries, and some of the parameters of the used water are much above the given guideline. Last but not least, stability in water quality is concerned with effects on production and water shortages for the company process. In this study, water must be treated before use; its pH, alkalinity, and hardness should be checked and maintained.

In addition to water treatment technologies, adopting sustainable practices throughout the steel production lifecycle can significantly reduce the water footprint. Optimizing production processes to minimize water wastage, exploring alternative materials with lower water footprints, and improving energy efficiency to reduce indirect water consumption are critical steps. As demand for steel increases, manufacturers should look to incentivize manufacturing to ensure sustainable use of water (Nallaperuma et al., 2023; Pomponi & Stephan, 2021).

6. DISCUSSION

The water footprint from the steel industry in Bangladesh shows some valuable insights about its water use pattern, its water quality, and scopes for resource management for sustainable water management. Water consumption by the steel industry can be addressed, and raised a few questions about the environmental challenges. Another raising concern should be the high water footprint of the steel industries, for which some proactive strategies are essential for sustainable water management. Advanced water treatment technology and promoting water recycling and reuse should be the top priorities for decreasing the pressure of groundwater and other freshwater sources.

Water Footprint Assessment (WFA) examines water usage, shortage, and pollution in producing, consuming, and trading water-intensive commodities and services. It evaluates the possible water-specific environmental consequences of a product, process, or organization.

Table 3: Tested parameters of the raw and used water

	Industry-I			Industry-II				
Parameter	Raw water (mg/l)	Used Water	Treated Water	Raw water (mg/l)	Used Water	Treated Water	paramete r by DPHE	WHO guideline
COD	12	320	64	13	340	60	4	-
TDS	610	1220	100	620	1250	85	1000	-
TSS	40	30	20	40	50	30	10	-
Cr	-	.03	0.00	-	0.233	-	0.05	0.05
Cu	-	.03	0	-	0.0289	-	1	2
As	-	10ppb	0	-	15ppb	-	0.05	0.01

Table 3 shows the tested parameters for the selected industries and standards and guidelines given by national and international organizations.

7. CONCLUSION & RECOMMENDATION

For the chosen steel industries, the blue water footprint was calculated as 1.095*107m3/yr, 9.125*106m3 /yr, and the footprint of grey water was calculated as $9.297*10^7$ m^3/yr, $73.73*10^6$ m^3/yr. Water efficiency can be improved using a water footprint instead of direct water consumption. Analyzing the stepwise procedure of the steel industry, the water footprint can be reduced, improving cleaner production.

This paper presents the chain summation approach to build a standard and viable industry water footprint assessment methodology. Rather than a simple numerical sum of the two footprints, the blue water (total W.C.) footprint and the grey water (water pollution) footprint are computed individually to comprehend the various water hazards better. This results in precise suggestions for risk reduction. This effort is intended to help create industrial water footprint assessment techniques. This study is focused on calculating the water footprint of the steel industry, but to establish a sustainable environment in the steel production process, further study is necessary. Energy consumption, greenhouse emissions, waste generation, waste management, etc., should be equally important for sustainable water management in the steel production sector. Collaboration between stakeholders and policymakers is needed to address and mitigate water-related challenges. Both parties should enact policies and regulations for setting water consumption targets, billing mechanisms, etc. Steel manufacturing companies should also be responsible for sustainable water management in steel industries and be open to sharing their data with the related authorities. Such transparency is essential for healthy competition among steel producers and will help encourage the best practice to reduce water footprint collectively.

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