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A modified approach to Industrial Pollution Projection System for the assessment of sectoral pollution loads in Bangladesh

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Abstract Industrial pollution in Bangladesh has posed a serious threat to human health, economic activity, and the environment. By emphasizing industries that produce major pollutants, substantial improvements can be made to pollution mitigation measures. In countries where primary pollution data is not readily available, the Industrial Pollution Projection System (IPPS) could be used to calculate the pollution load utilizing total industrial output or employment data. IPPS data, which was designed for developed countries like the USA, had been used directly for other countries without any normalization in previously reported studies. The main purpose of this study is to modify the current IPPS approach for any other country by incorporating specific correction factor for a specific country. In this study, a specific correction factor for Bangladesh was determined, taking into account the country's major polluting industries, and used to estimate the pollution scenario for the year 2020. The accuracy of the specific pollution intensities was also evaluated by comparing the data obtained using both gross output and employee number. According to this study, the top three air-polluting industries are structural clay products, cement-lime-plaster industry, and iron and steel industry. Similarly, for water pollution, the food industry, paper and paper product industry, and textile industry are the largest pollutant contributors. The detailed pollution load matrix in terms of air and water pollution is also developed, and can be used to predict both short-term and long-term scenarios of industrial pollution in Bangladesh, which eventually will assist the policy makers to adopt appropriate pollution management approach. Moreover, the methods developed in this study will help to tailor the IPPS data for any country and increase the accuracy of the pollution load.

Keywords Pollution projection · Industrial Pollution Projection System (IPPS) · Pollution intensity · Air pollution · Water pollution · IPPS normalization

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Introduction

Industrial operations are directly responsible for the majority of polluting agents that damage the atmosphere, endangering ecosystems and human health.

Developing countries are becoming increasingly worried about rising levels of pollution, especially in the cities (Pandey, 2005). It has been long recognized that developing countries often lack the requisite knowledge to set effective environmental protection goals, policies, and action plans (Bell & Russell, 2002). In most industries of developing countries, plant-level monitoring of air, water, and toxic pollution are inadequate and disorganized. Moreover, a lack of trained personnel and monitoring equipment and questionable data collection and measurement methodology are creating severe limitations in determining the actual pollution load (Hettige et al., 1994). Since it is very difficult to determine the massive pollution load of various industrial sectors of a country directly from conventional sampling and direct chemical analysis, alternative methods must be explored. Even though most developing countries have little or no data on all types of industrial emissions, many of them have reasonably comprehensive data on employment, value-added, and production. The size of industrial production, its sectoral composition, and the process technology are all directly linked to industrial pollution (Hettige et al., 1998). Using these data, it is possible to deduce the industrial pollution load. One such method is the Industrial Pollution Projection System (IPPS), a modeling system that can estimate detailed profiles of industrial pollution for nations, territories, urban areas, and potential new projects using indirect industry data. IPPS integrates data on industrial activity, such as production, employment, and pollution emissions with available data on pollution emissions to calculate pollution intensities (defined as pollution per unit of output or pollution per unit of employment) for three main economic variables: total output, value-added, and employment (Aguayo et al., 2001; Benoit & Craig, 2001). Using this method reasonably accurate pollution load data on the various industrial sectors can be determined. While technology, production processes, and emissions vary by country, the IPPS database's sheer scale accounts for these differences and allows for pollution projections at the sectoral and national levels of developing countries (Dessus & O'connor, 2003; Dinda, 2004). This method has been used in various research studies for developing countries and several of them have been published (Aguayo et al., 2001; Odesanya et al., 2012; Oketola & Osibanjo, 2007; Pandey, 2005; San et al., 2018).

Rapid economic growth and industrial development in Bangladesh have reduced poverty to a large extent during the last decade (Inchauste & Olivieri, 2014; Shabab & Islam, 2018; World Bank, 2012). Subsequently, this has also led to increased pollution in the air, water, and soil (Azom et al., 2012; Hasan et al., 2019; Hussein, 2020; Kashem & Singh, 1999). Every year millions of dollars are being spent on pollution abatement measures (Haque, 2017; Ministry of Finance, 2020); however, due to a lack of data on the heavy polluters, the mitigation measures could not be applied effectively (Hasan et al., 2019; Rahman & Ancev, 2014; Sakamoto et al., 2019). There have been a number of experimental and computational studies regarding the impact and abatement of water and air pollution in Bangladesh (Ahmed & Hossain, 1 C.E.; Ali et al., 2010; Chakrovorty et al., 2021). These studies often focus on a specific industrial sector and therefore are unable to portray the overall pollution scenario in Bangladesh. All of those studies till date have been performed by applying the IPPS database directly (Rasul et al., 2006), without any normalization or modification of the IPPS pollution intensities for Bangladesh. Moreover, those studies are quite old and not updated with the latest employment and gross output data.

One major drawback of the previous studies with the IPPS method is that the pollution load was determined by using data from the USA; hence, the predicted pollution load and actual pollution load of major industrial sectors for a developing country may vary drastically since the employment rate, gross output, and technology of two countries are not entirely the same. There are several factors that can affect IPPS pollution load, such as industry size, energy efficiency, industry type, change in workforce, technology employed, raw material characteristics, efficacy of facility, and product grades. These parameters vary significantly in different countries. Energy-efficient technologies are generally clean technologies and reduce contribution to air pollution. Also, different changes in workforce such as power shedding and rapid increase or decrease in employment can affect pollution intensity. Besides, changing from old technology to new and modern technology reduces pollution intensity. Moreover, the type of raw material and product grades can reduce the amount of waste generated. For example, if riverbed silt is used for brick production substituting clay, fine particle emissions are reduced (Fatema & Hossain, 2022). Because of the low wages, it is pretty common in developing countries to adopt a semi-manual production approach than a

fully automatic one. Therefore, the same amount of production can be achieved with a varying number of employees in different countries. In this research, the variability of these factors has been addressed by incorporating a country-specific correction factor and that was validated for Bangladesh. A correction factor is determined based on some known and reliable data to improve the accuracy of the pollution load intensities. This proposed correction factor has been applied to determine the pollution load intensities of several industries for both air and water pollution. This allowed better prediction of pollution load of industries along with more defined pollution load intensities which could be used directly for future studies. This is a novel concept and rarely found in IPPS-based research studies. Moreover, the gross output of the IPPS database was also adjusted for inflation value. Both three-digit and four-digit International Standard Industrial Classification (ISIC) codes (United Nations. Statistical Division, 2008) have been used in this study depending on the type of industry and its level of aggregation and mapped to Bangladesh Standard Industrial Classification (BSIC) codes (Bangladesh Bureau Of Statistics. Statistics & Informatics Division. Ministry Of Planning, 2019). This research study should serve as a guidance for using a specific correction factor for obtaining reliable and more accurate pollution load and help determine proper pollution abatement measures for different developing countries.

The article provides a background to emphasize the importance of the study followed by the "Materials and methods" section containing the calculation approach, steps, and equations for the modified IPPS method. The "Results and discussion" section analyzed the calculated data and interpreted based on the proposed modified approach. Finally, in "Conclusions," the article summarizes the key findings and the changes in the modified approach, which are the specific contributions of this study.

Materials and methods

Data collection

From the World Bank IPPS database (Hettige et al., n.d.), the US pollution intensity data were taken directly. From various published sources like the Survey of Manufacturing Industries (SMI, 2012) (Bangladesh Bureau of Statistics, 2012), the total employment and gross output of major polluting industries (e.g., textiles, leather, steel rerolling, construction materials, pharmaceuticals, food processing, pulp and paper, fertilizer, basic chemicals industries) were obtained.

Selection of industries for pollution intensity correction in Bangladesh perspective

In order to correlate and correct the air pollution intensity, the brick industry (structured clay product) was selected. This is because the brick industry in Bangladesh is quite large, consisting of about 8000 brick kilns. Their emission contains particulate matter, carbon dioxide, and nitrogen oxides. Brick kilns are therefore considered one of the major air pollution sources in Bangladesh (*Technical Assistance for Brick Kiln Financing in Bangladesh*, n.d.). Using average pollutant concentration in coal (Safiullah et al., 2011) and coal consumption amount (Department of Environment Bangladesh, 2017), the pollution load was calculated. For correlating the water pollution intensity, the textile industry was chosen. This is because the textile industry is the largest industry in Bangladesh accounting for about 80% of the country's exports. There is a wide range of chemicals like azo dyes and bleaching agents being used for dyeing and printing in textile industries. The wastewater released from these textile industries contains these hazardous chemicals. Previous studies showed that the toxic effects of these dyes include hypersensitivity and other malignancies like stomach, nasopharyngeal, and lung cancers (*Textile Industry in Bangladesh*, n.d.). The estimated pollution load of the textile industry based on conventional treatment approaches was obtained from recent studies (Hossain et al., 2018; Sarker, 2017).

Calculation of correction factor and pollution load

IPPS intensities were corrected based on available pollution and production data of at least one well-established industrial sector (textile industry for water pollution and structural clay product or brick industry for air pollution). The following equation was used to determine the correction factor.

$$\text{Correction Factor} = \frac{RPL \times 1000}{\text{ID} \times RPI} \quad (1)$$

where RPL = reference pollution load (Bangladesh) of an industry in (MT/year).

ID = industrial data (number of employees in thousands or gross output in million USD).

RPI = reference pollution intensity (IPPS database) of an industry (in kg/1000 employee or kg/million USD).

In Eq. 1, firstly, the pollution load intensity of Bangladesh for a particular industry is determined from the ratio of the pollution load (RPL) and industrial data (ID) for that industry. Next, this pollution intensity is divided by the IPPS pollution intensity for the same industry (RPI) and the correction factor is obtained. The IPPS pollution intensities for all other industries were multiplied by this correction factor to determine the corrected specific pollution intensity for Bangladesh. This corrected specific pollution intensity was multiplied by the total number of employees or gross output in million USD (adjusted for inflation values) to predict the pollution load for major polluting industries in Bangladesh for the year 2020.

Air pollution intensities are determined from the sum of SO_2, NO_2, CO, VOC, fine particulates (PM_{10}), and total suspended particulates' (TSP) specific intensities for each industry. Water pollution intensities are based on the sum of biological oxygen demand (BOD) and total suspended solids (TSS) intensities.

Accuracy of pollution load

In order to verify the accuracy of the model, the estimated pollution load for a specific pollutant category (air or water) based on gross output as well as employment were compared. The following equation was used to determine the acceptability criteria.

$$\text{Acceptability Criteria} = \frac{\text{ABS}(\text{PG} - \text{PE}) \times 100\%}{\text{MIN}(\text{PG}, \text{PE})} \quad (2)$$

where PG = pollution load based on gross output data.

PE = pollution load based on employee data.

ABS = absolute value.

MIN = the minimum of the two values.

A value of 80% was set as the maximum acceptability criteria and any value above it was considered unacceptable. This decision is based on the fact that the possible inaccuracy of gross output and employee data might cause some deviation; however, as long as these are of the same order of magnitude, they can be considered as a good predicted value.

Results and discussion

In the case of air pollution, the corrected specific intensities for various industries based on both employment and gross output are shown in Table 1. The difference between the IPPS database intensity and the modified intensity for each sector is pretty substantial, and therefore can lead to significant error in pollution load calculation if the IPPS database values were used directly. The highest air pollution intensity is for the cement, lime, and plaster industry in Bangladesh, and the lowest one is for wearing apparel (except footwear) industry. It is to be noted that the highest one will not always correlate to the highest pollution load since the pollution load is determined by multiplying the specific intensities with employee number or gross output. A higher intensity value indicates the higher level of pollution per unit number of employees or production.

The estimated pollution intensities were validated further by comparing the pollution load based on both employee number and production value. Figure 1 summarizes the air pollution loads calculated for different industries. Out of the ten industries chosen for air pollution, 70% of them satisfy the acceptability criteria. Only three did not satisfy the acceptability criteria; however, those were still in the same order of magnitude. These are rubber and plastic products, tobacco manufactures, and wood products (except furniture). One of the reasons for not satisfying the acceptability criteria could be due to the fact that significantly high number of people employed in those industries in Bangladesh compared to the lower number of employees in mostly automated industries in the developed countries. Therefore, the correction factor was unable to compensate for the increased employment level thus resulting in more air pollution load based on employment than gross output.

Table 1 The air pollution intensities suggested by IPPS database and the modified ones specific to Bangladesh

Name of industries	IPPS air pollution intensities (kg/1000 emp/year)	Bangladesh air pollution intensities (kg/1000 emp/year)	IPPS air pollution intensities (kg/million USD/year)	Bangladesh air pollution intensities (kg/million USD/year)
Iron and steel	4,692,073	6,468,947	67,456	128,374
Chemicals and chemical products	6,927,256	9,550,588	58,557	111,439
Cement, lime, and plaster	33,839,863	46,654,921	175,129	333,284
Coke and refined petroleum products	32,299,702	44,531,505	93,546	178,025
Rubber and plastic products	746,470	1,029,156	11,176	21,268
Drugs and medicines	416,659	574,446	3131	5958
Tobacco manufactures	510,386	703,667	2509	4776
Tanneries and leather finishing	412,646	568,914	6009	11,436
Fabricated metal products	140,889	194,243	3110	5919
Wood products, except furniture	693,551	956,197	15,615	29,716
Glass and products	779,556	1,074,772	14,814	28,192
Wearing apparel, except footwear	1417	1953	59	111
Motor vehicles	229,506	316,419	1188	2261
Shipbuilding and repairing	78,198	107,811	2274	4327

The corrected water pollution intensities for Bangladesh were calculated as well. Table 2 compares the water pollution intensities of various industries for both the IPPS database and Bangladesh. Here, the highest pollution intensity is for the paper and paper products industry and the lowest one is for the ship building and repairing industry. This means the paper industry has the maximum pollution load per unit production value or even unit number of employees. Like air pollution intensities, modified water pollution intensities were also compared between the two approaches to assess their accuracy using the same acceptability criteria.

Figure 2 summarizes the water pollution load of ten major water-polluting industries. Out of the ten industries chosen for water pollution, 70% of those satisfy the acceptability criteria. Only tanneries and leather finishing, coke and refined petroleum products, and the iron and steel industry did not satisfy our criteria. One of the main reasons for not satisfying the acceptability criteria could be due to the large variation in gross ouput of those industries in developed

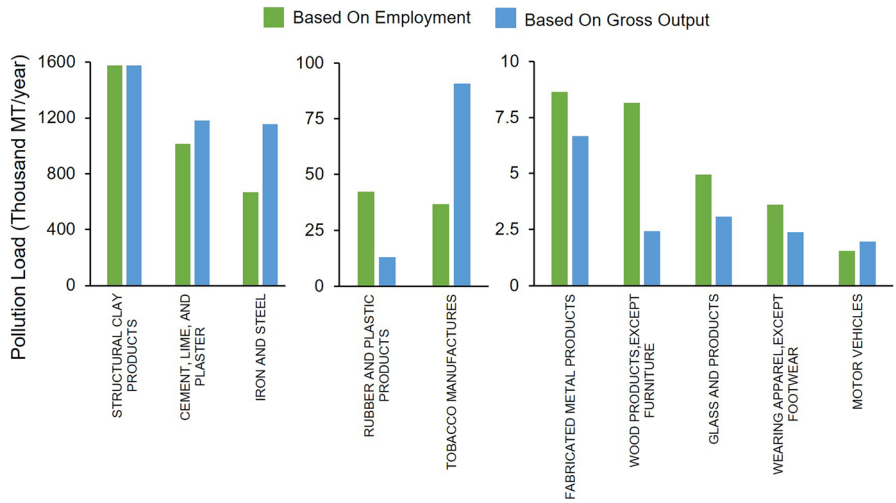

Fig. 1 Establishing the accuracy of pollution load of major air-polluting industries

Table 2 The water pollution intensities suggested by IPPS database and the modified ones specific to Bangladesh

Name of Industries	IPPS water pollution intensities (kg/1000 emp/year)	Bangladesh water pollution intensities (kg/1000 emp/year)	IPPS water pollution intensities (kg/million USD/year)	Bangladesh water pollution intensities (kg/million USD/year)
Food products	162,772	2,030,865	1684	112,849
Paper and products	530,625	6,620,473	6597	442,126
Textiles	5205	64,943	116	7770
Chemicals and chemical products	343,822	4,289,783	2659	178,231
Rubber and plastic products	24,869	310,287	539	36,130
Tanneries and leather finishing	50,454	629,498	853	57,141
Leather and related products	9642	120,302	267	17,919
Drugs and medicines	6433	80,268	63.5	4252
Coke and refined petroleum products	116,696	1,455,987	187	12,547
Iron and steel	955	11,915	13.7	920
Wood products, except furniture	4085	50,974	92.0	6164
Fabricated metal products	648	8080	14.3	958
Tobacco manufactures	324	4042	1.6	107
Machinery electric	1222	15,249	25.8	1729
Structural clay products	21.4	267	0.6	39.0
Cement, lime, and plaster	109	1364	1.2	82.1
Glass and products	80.2	1000	1.5	102
Motor vehicles	26.0	324	0.2	16.0
Shipbuilding and repairing	5.4	67.9	0.2	10.4

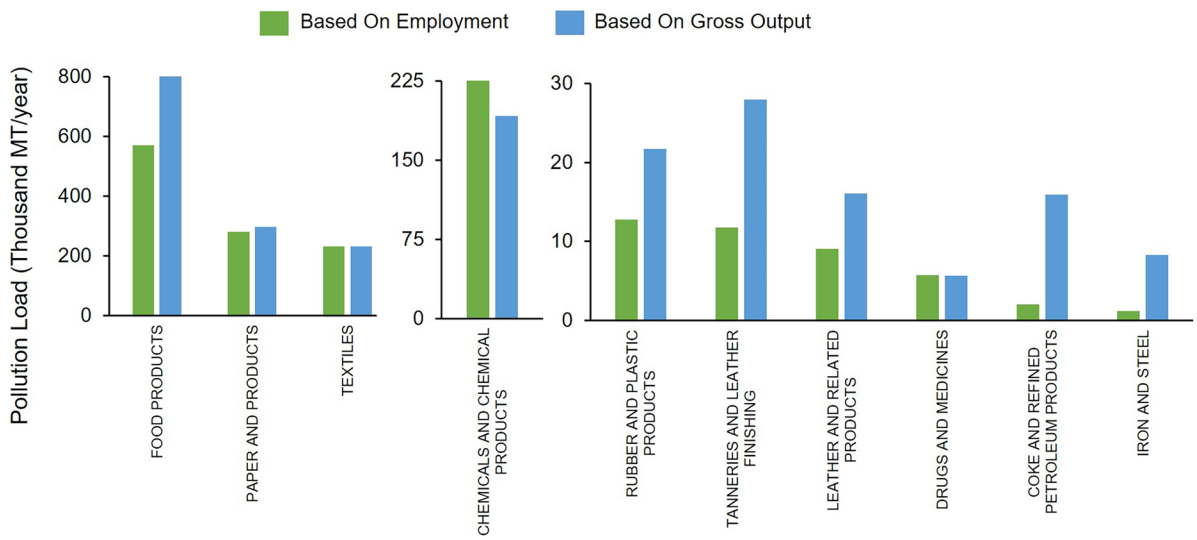

Fig. 2 Establishing the accuracy of pollution load of major water-polluting industries

countries and Bangladesh. Also, these industries in Bangladesh are more physical labor–dependent unlike the automated ones in the developed countries. Therefore, the single correction factor was unable to compensate for such significant changes.

Tables 3 and 4 highlight the important parameters used for calculating the total air and water pollution loads along with the respective International Standard Industrial Classification (ISIC) codes used. For some industries, combined values were used as seen by the presence of multiple ISIC codes.

The total air and water pollution load from the major industries based on employment and gross output have been ranked to understand the pollution scenario in Bangladesh. The ranking for air pollution and water pollution are shown in Figures S1 and S2, respectively. The structural clay product industry (specifically brick kilns) was found to be the most polluting sector in Bangladesh in both approaches when air pollution was concerned. Similar indications have been reported in previous studies as well (Alam, 2019; Rana, 2019). The cement industry is the second highest air-polluting sector followed by the iron and steel industry. Most of the industries have similar ranking based on either of the two approaches (i.e., employment or production) followed to calculate the pollution load. However, the ranking of some of the other industries such as chemical and chemical products, tobacco, drugs and medicines, rubber and plastic products, tannery and leather, and glass products ranking (Figures S1 and S2) is slightly different based on the two approaches followed to calculate the pollution load (i.e., employment or production). The fact that the ranks of most industries are almost similar for both of the approaches indicates the accuracy of the estimations made using this method.

The water pollution ranking is unchanged for the top four water-polluting industries as seen in Figure S2. The food processing industry is found to be the most water-polluting sector in Bangladesh followed by the paper industry. In contrast to popular belief, the textile industry was not found to be the most water-polluting sector (*Bangladesh's Polluted Waters: Rivers Dying Due to Dyeing*, 2019; Sakamoto et al., 2019). Water pollution load from the textile industry is approximately one-third of that of the food processing industry.

Table 3 Employee data and gross output data of air-polluting industries in Bangladesh

Name of industries	ISIC4	ISIC3	Number of employees	Gross output (million USD)
Iron and steel	3691		429,772	52,728
Chemicals and chemical products	3692		21,757	35,504
Cement, lime, and plaster		321	3,567,843	298,203
Coke and refined petroleum products		371	102,903	90,122
Rubber and plastic products		351 352	52,598	10,777
Drugs and medicines		311	280,257	71,621
Tobacco manufactures		341	42,376	6728
Tanneries and leather finishing		353 354	1417	12,719
Fabricated metal products	3551 3559 3560		41,139	6017
Wood products, except furniture	3522		71,380	13,302
Glass and products		314	52,204	189,971
Wearing apparel, except footwear	3231		18,706	4898
Motor vehicles		381	44,462	11,279
Shipbuilding and repairing		331	8528	813
Iron and steel		362	4618	1091
Chemicals and chemical products		322	1,852,834	214,057
Cement, lime, and plaster	3843		4906	8723
Coke and refined petroleum products	3841		11,752	1198

Table 4 Employee data and gross output data of water-polluting industries in Bangladesh

Name of industries	ISIC4	ISIC3	Number of employees	Gross output (million USD)
Food products		311	280,257	7162
Paper and products		341	42,376	6728
Textiles		321	3,567,843	298,203
Chemicals and chemical products		351 352	52,598	10,777
Rubber and plastic products	3551 3559 3560		41,139	6017
Tanneries and leather finishing	3231		18,706	4898
Leather and related products		323	75,524	8962
Drugs and medicines	3522		71,380	13,302
Coke and refined petroleum products		353 354	1417	12,719
Iron and steel		371	102,903	90,122
Wood products, except furniture		331	8528	813
Fabricated metal products		381	44,462	11,279
Tobacco manufactures		314	52,204	189,971
Machinery electric		383	13,528	1546
Structural clay products	3691		429,772	527,277
Cement, lime, and plaster	3692		21,757	35,504
Glass and products		362	4618	1091
Motor vehicles	3843		4906	8723
Shipbuilding and repairing	3841		11,752	1198

Since the ranking varied slightly for some of the sectors depending on the approach, an average pollution load (average of both approaches) has been ranked as well. From Fig. 3, it is evident that the five most water-polluting industries are food products, paper and paper products, textiles, chemicals and chemical products, and rubber and plastic industries. Similarly, for air pollution, structural clay products, cement, lime and plaster, iron and steel, chemicals and chemical products, and coke and refined petroleum products industry are the major polluting sectors.

In a previous study (Rasul et al., 2006), the top five air-polluting industries were food, cement/clay, pulp and paper, textile, and tobacco industries. Moreover, the top five water-polluting industries are industrial chemicals, fertilizers/pesticides, food, metal, and pharmaceuticals industries. These rankings are quite different compared to the ones obtained in this study and highlight how the employment and gross output data has changed over the years, and directly applying the IPPS data is not a good approach to determine the accurate pollution-based ranking.

Figure 4 shows the contribution of each sector towards the pollution load. It can be seen that the top three air-polluting industries (brick industry, cement, lime, and plaster industry, iron and steel industry) are responsible for almost 82–89% of the total air pollution in Bangladesh. Structural clay products contribute between 36 and 40%, whereas cement, lime, and plaster industries contribute about 25–27% of the total air pollution load. This is because these materials are commonly used for constructions in Bangladesh. The construction process includes erection, maintenance, and repair of buildings and other immobile structures. Previous studies also show that construction materials of urban surfaces and air-pollutant emissions from those materials can stimulate high temperatures in the cities which is one of the main reasons for human discomfort (Sampson et al., 2021). As a developing nation, Bangladesh is witnessing substantial growth in the infrastructure sector, and according to some studies, construction is going to increase by about 6.5% till 2027 (*Bangladesh Construction Market—Growth, Trends, COVID-19 Impact, and Forecasts*

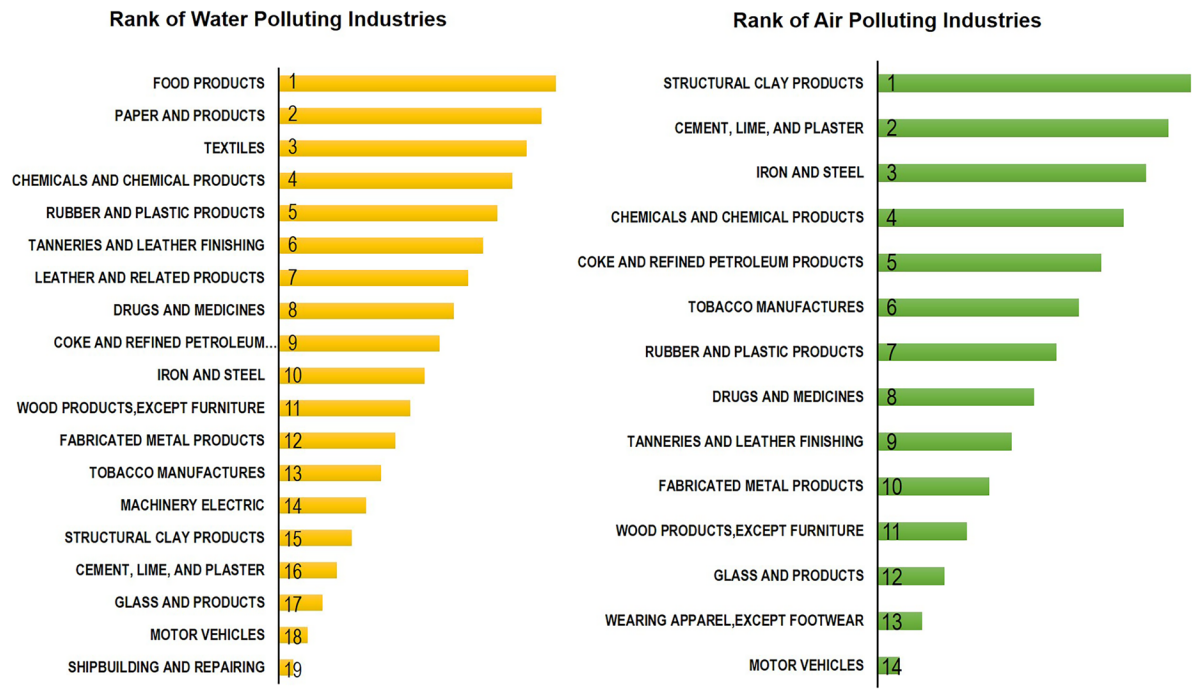

Fig. 3 Ranking of air- and water-polluting industries based on the combined approach

(2022—2027), n.d.). It is to be noted that the top five air-polluting industries are responsible for almost 96–97% of total air pollution in Bangladesh.

As discussed earlier, food industries are the most water-polluting industries in Bangladesh contributing 42–50% of the total water pollution load (Fig. 5).

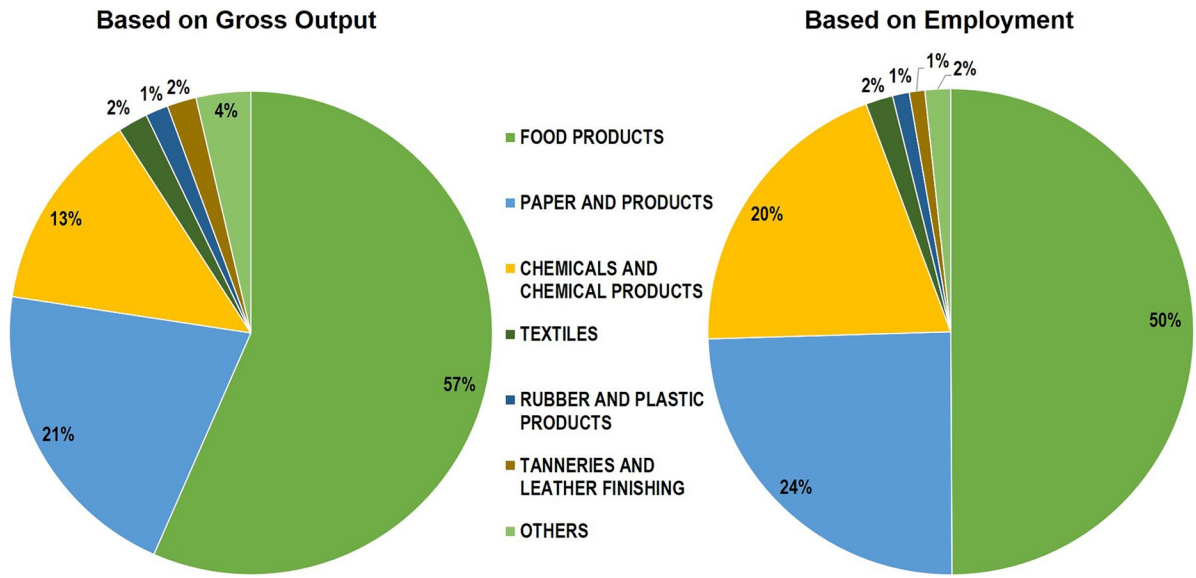

Fig. 4 Contribution of air-polluting industries based on total air pollution load

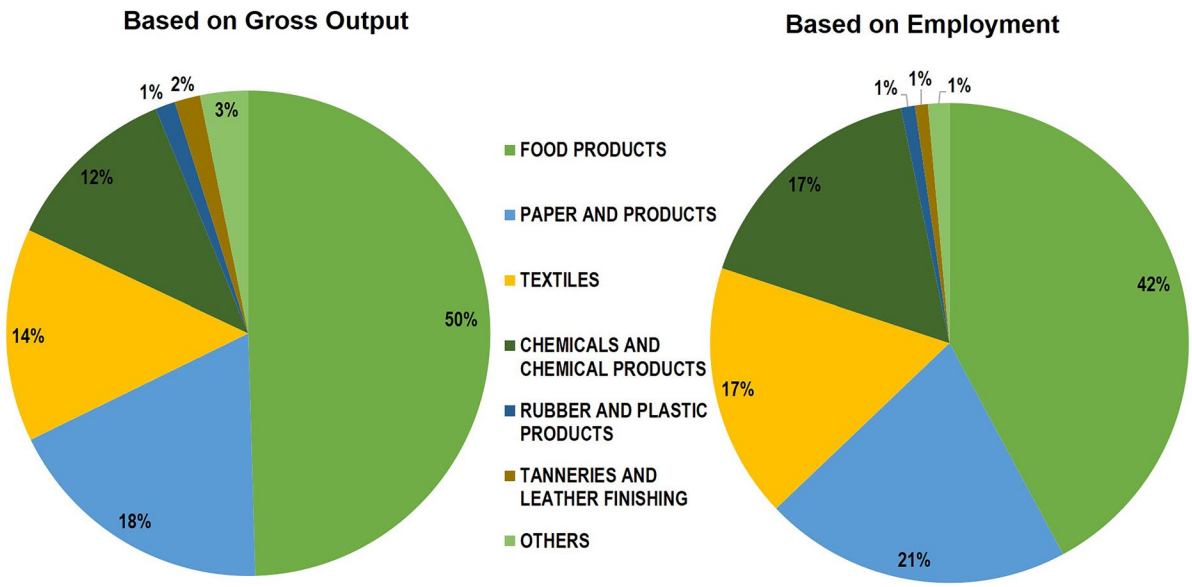

Fig. 5 Contribution of water-polluting industries to total water pollution load

The paper and textile industries are the next two largest water-polluting industries contributing 18–21% and 14–17%, respectively. These data clearly indicate that the common perception of the textile and paper industries being the highest water-polluting industries in Bangladesh may not be accurate (*Bangladesh's Polluted Waters: Rivers Dying Due to Dyeing*, 2019; Sakamoto et al., 2019) (Rasul et al., 2006). Moreover, due to international rules and export regulations, most textile industries have adopted effective water treatment plants which have reduced pollutant discharge significantly. Chemical and chemical products are almost equally polluting the water contributing 12–17%. The rubber and leather industries are contributing almost equally and they are the fifth-highest water-polluting industries depending on the approach used for calculation. The leather industry was considered to be one of the top three water-polluting sources; however, due to the shrinkage of the leather industry in the last decade, the pollution contribution was also reduced (Ovi, 2020; Paul et al., 2013; Shibli & Islam, 2020). The five most water-polluting industries are responsible for almost 97–97% of the total water pollution in Bangladesh, of which 82–89% are coming from the top three water-polluting industries. Membrane separation technologies like ultrafiltration and reverse osmosis could be effective to purify wastewater generated from these industries (Ciardelli et al., 2000). Also, organic adsorbents like PAN fibers can be used to remove toxic metal contaminants like Arsenic in wastewater (Bhatti et al., 2020).

Conclusions

This study is based on the principle of the Industrial Pollution Projection System (IPPS). It uses already available local metrics to estimate the specific pollution intensity of different industries of Bangladesh. Unlike previous studies, instead of using the specific pollution intensity of another country directly, a correction factor was deduced by using the pollution load data of a specific industry in Bangladesh. Moreover, to determine the accuracy of the obtained data, this study used both employment data and gross output data, which was adjusted for inflation and used the latest available employee and gross output data. The results indicated that this method could be used to determine reasonably accurate pollution load which is very crucial for a developing country. The results show that the contribution to air pollution is mainly from industries with a high overall output of TSP, PM_{10}, SO_2, NO_2, CO, and VOC such as industries related to the construction of infrastructures

such as the brick industry, lime and plaster industry, cement industry, and iron and steel industries. Therefore, more engineering controls need to be enforced in these industries. Also, in some cases, raw material grades should be substituted and more clean technology should be adopted for production. Another important conclusion that can be drawn from this study is that the food industry and paper and textile industry are responsible to a large extent for water pollution since the relative output of TSS and BOD of these industries is quite high. In previous studies, the IPPS data was directly used to determine the air and water pollution load which resulted in higher air and water pollution load of non-conventional air and water-polluting industries. This indicates the relevance and importance of this study. Also, this study compares industrial data of over 15 major industries. Every year, millions of dollars are spent on pollution mitigation measures. However, if the specific industrial sectors responsible for severely polluting the environment are not identified, then the mitigation measures will not be very effective. This method has some inherent drawbacks. For example, it uses only one industrial sector to adjust for a specific type of pollution load of all other industrial sectors. Hence, the whole accuracy depends on the data of that industrial sector which is used for correction. Considering the fact that the pollution data in developing countries like Bangladesh are often limited, this approach can provide a very sound pollution projection. This is the first IPPS-based pollution estimation study for Bangladesh that uses the modified pollution intensities and recent industrial data. Furthermore, the correction factors developed in this study can be used to predict the future pollution load of Bangladesh based on new employment and gross output data and this approach could be employed for other developing countries as well to determine a reliable and more applicable pollution matrix of various industries.

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Author contribution The contributions of the authors are as follows: (i) all the authors designed the experiments. (ii) The first and second authors conducted the data collection and analysis. (iii) The first author composed the article and all three authors corrected and revised the manuscript. (iv) The corresponding author provided research guidance and technical advice on the design of the study and corrected article text and figures.

Data availability All of the data necessary for calculation have been provided in the main manuscript. Specific calculation data could be obtained from the authors upon request.

Code availability N/A.

Declarations

Competing interests The authors declare no competing interests.

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