Environmental pollution generated from process industries in Bangladesh

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Abstract: The sources of environmental pollution in process industries in Bangladesh are discussed. Total pollution load into environment (i.e., into air, water and land) generated from process industries is determined and presented using industrial pollution projection system (IPPS) developed by the World Bank. Most polluting industries in Bangladesh are identified and ranked. The projection of this pollution load for year 2011–2012 is estimated and discussed. It was found that the food industry was the worst air polluter, whereas pulp and paper was the worst water polluter, and tanneries and leather industries were worst polluter of toxic chemicals. Industrial pollution control measures are recommended.

Keywords: environmental pollution; process industries; energy recovery systems.

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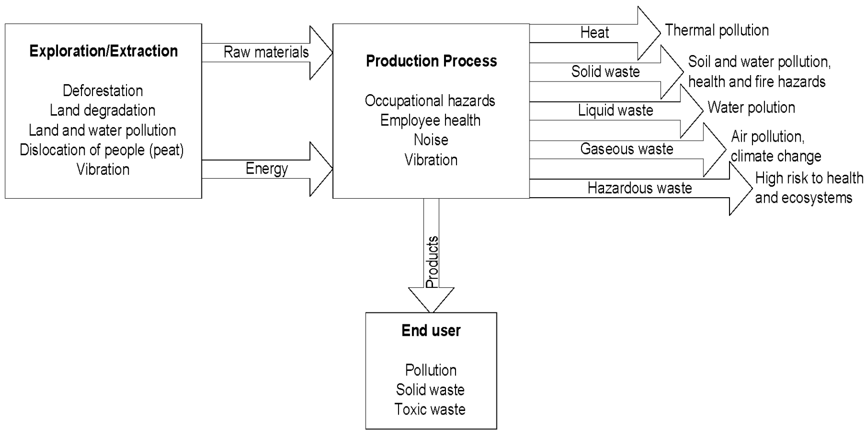
1 Introduction

Industrial emissions pose a major threat to human health, ecosystems and economic activity. Large accumulation of industrial wastes and effluents has the potential to cause serious contamination of the environment, especially when they are left unattended. Treatment of industrial waste and effluent has so far been considered a low priority in some countries, particularly in the developing countries, for example, Bangladesh. Owing to lack of awareness as well as the absence of strong punitive actions, the practice of circulating waste and effluent into water bodies including ponds, canals, creeks and rivers in the developing countries still remains widespread. The serious public health hazards they create are to some extent minimised as the wastes and effluents are mostly flushed out into the sea during the rainy season. But excessive localised pollution is already threatening the sustainability of the resource base and having effects on the health of people, most of who are affected but unaware of or hardly have any other choices. On the other hand, in the vicinity of the process industries in the developed countries, for example, in Australia, ALCOA (Australia) Ltd, Queensland Cement Ltd (QCL), Australian Magnesium Corporation (AMC), etc., environmental pollution is of major concern and special attention is given by the Australian Government to maintain safe local environment.

Environmental degradation is always present throughout the life cycle of a process industry, starting from exploration of raw materials and energy resources to disposal of wastes and end product. A conceptual model of generation of pollution in process industries can be presented through the schematic diagram shown in Figure 1. However, only the pollution generated at the end of the production process is addressed in this study. The major industrial pollutants generated in process industries are listed below (Faisal and Haque, 2000; Hettige et al., 1994; Masters, 1995; De, 1993; Rao and Rao, 1993; World Development Indicators, 1998; Haq, 1989; Rahman, 1997).

Figure 1 Conceptual model of generation of pollution in process industries



Air pollutants

- total suspended particles (TSP)
- carbon monoxide (CO)
- oxides of nitrogen (NO_x)
- oxides of sulphur (SO_x)
- ammonia (NH_3)
- volatile organic compounds (VOC).

Water pollutants

- biological oxygen demand (BOD)
- total suspended solids (TSS)
- total dissolved solids (TDS)
- chemical oxygen demand (COD).

Toxic pollutants

- toxic acids
- toxic chemicals
- toxic metals.

The definition of these pollutants is widely known in environment related literature, and for brevity it is not defined again. Owing to the page constraint, the sources of industrial and environmental pollution are addressed only in integrated iron and steel industry, sugar industry and fertiliser industry. However, pollution load into environment from 12 process industries is determined using industrial pollution projection systems (IPPS) developed by the World Bank (Hettige et al., 1994). The projection of the pollution load for year 2011–2012 is discussed. Industrial pollution control measures are reviewed and recommended.

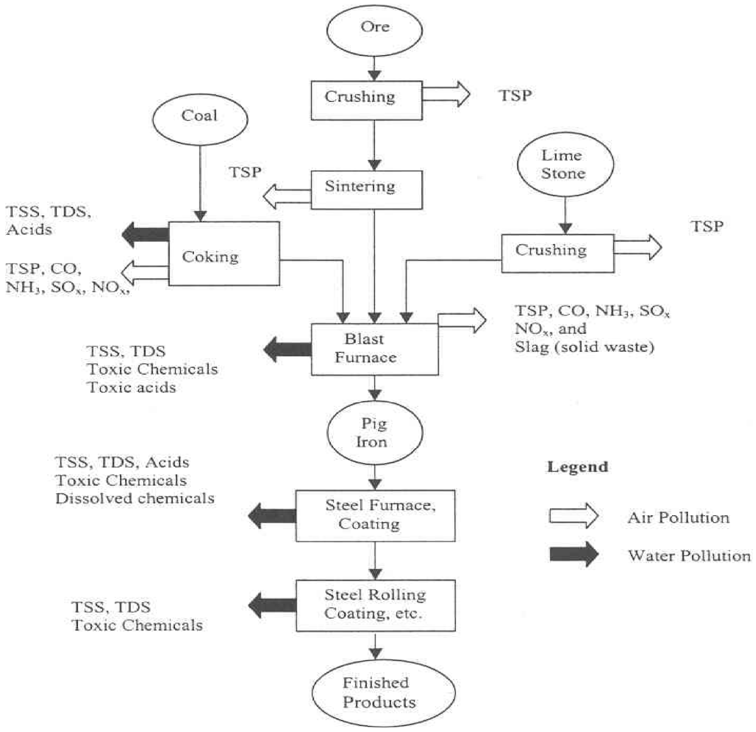
2 Sources of industrial pollutants

An extensive investigation was carried out to identify the sources of pollution generated in iron and steel industry (metal industry), sugar industry (food industry) and fertiliser industry. These are described below.

2.1 Iron and steel industry

Integrated iron and steel industry is one of the largest sources of noxious exhaust gases (air pollution), contaminated process water (water pollution) and toxic acids or chemicals (toxic pollution). Figure 2 shows the main sources of the pollution in iron and steel industry. Although Figure 2 is self-explanatory and shows sources of pollution in a broader sense, the pollution involved with each process is briefly described below:

Figure 2 Sources of pollution in an iron and steel industry



- *Coking process*. Noxious waste substances such as dust, hydrogen sulphide, sulphuric acid, ammonia and phenol are the major sources of pollution.
- *Material handling*. Iron ore preparation, material handling and sintering units are the root sources of air pollution. They account for the largest percentage of the total emissions at the plant. Gases, such as sulphur dioxide, dusts and fumes are emitted.
- *Iron making*. The main sources are dust from charging of material into the furnaces and chutes, screening and preparation of ore, sorting and transportation of coke, blast furnace cleaning, etc. Waste gases and blast furnace (BF) slag add to air pollution through steam and sulphuric acid fumed from slag.
- *Steel making*. All three types of furnaces (open hearth furnaces (OHF), electric arc furnace (EAF) and basic oxygen furnace (BOF)) emit particulates and carbon monoxides. BOF generates more particulates than OHF because of the high level of turbulence caused by introduction of oxygen at high pressure.
- *Coke making*. In coke making, major water pollutants emitted are suspended solids, phenols and oils. Water pollution is created during cooling and quenching, and by drainage waters. Coal supplies are stored in open field and the resulting drainage is contaminated as acid mine wastewater. Quenching water cool the coke by direct contact, thereby accumulating suspended solids, hydrocarbon, ammonia, cyanides, chlorides and sulphates along with heat. Cleaning the coke furnace add ammonia, phenol, acids, etc., into the atmosphere.
- *Sintering*. Crushed iron ore produces suspended solids and heat as water pollutants.
- *Blast furnace*: The coolant (water) of furnace gas gets contaminated both physically and chemically in the blast furnace units. This water contains scales, sediments, sludge, dissolved inorganic salts, poisonous cyanides, etc.
- *Rolling and finishing*. Water-borne wastes are produced in these units. The pollutants are suspended matter, dry sediments and oils from lubrication points. Removing scales and dust from the metal surface is a dangerous water pollution source in the finishing process. This wastewater contains insoluble ferric oxide and ferric chloride.

2.2 Sugar industry

The types of wastes generated and their associated pollution in sugar industry is listed in Table 1. Sugar cane crushing produces 35–40% bagasse, 3–3.5% filter mud (which contains about 60% water, 10% fibre, 5–6% albumin, 5–7% wax and traces of calcium, magnesium, zinc and aluminium) and 3.5% molasses (which contains 50–55% carbohydrate and 8–10% ash, and the rest is water) as by-products. Molasses is highly concentrated and a dangerous polluter with a BOD in excess of 40,000 mg/l and COD in excess of 90,000 mg/l. Sugar mills require about 1.25 ton of water per ton of cane processed. Surplus condenser water and wastewater from washing of floor, vessels and equipment contain traces of juice, sugar, mud and molasses, and cause organic pollution and may cause odour nuisance during decomposition. Air pollution mainly results from burning of bagasse in the boiler and furnaces, which contains sulphur dioxides, nitrogen oxides and suspended particulate matter.

Table 1 Wastes and the sources of pollution in sugar industry

Wastes	*Sources of pollution*
Solid	Bagasse, filter mud, molasses, and boiler ash
Liquid	Cooling water, surplus condenser water, wastewater from washing of floor, vessels and equipment
Gaseous	Boiler flue gas and stack emission

2.3 Fertiliser industry

The types of wastes generated in fertiliser industry and their pollution is summarised in Table 2. The acidic and alkaline wastes generated from fertiliser factory affects aquatic life, if those are dumped into pond, river or sea. Ammonia present in the waste is toxic to fish. The amines have high oxygen and chlorine values. Rainwater run-off from storage areas carries dissolved and suspended solids, urea dust and other materials such as chromium and nickel. Ammonia and urea dust may affect land areas around the fertiliser plants. Other substances found in the effluent of fertiliser factories that are toxic to aquatic life are urea, hydrogen sulphide, hydrogen cyanide, arsenic, methanol and fluorides.

Table 2 Wastes and sources of pollution in fertiliser industry

Wastes	*Sources of pollution*
Solid	Contaminated sludge, process condensate
	Urea dust
	Waste catalyst and catalyst dust containing cobalt, zinc, nickel, chromium, copper and iron
	Other solid scraps and waste dumped in scrap yards
Liquid	Wastewater with high ammonia content
	Wastewater containing sulphates, phosphates, fluorides, urea, amines, methanol and hydrogen sulphide
	Effluent from cooling towers, boiler blow downs, washing, spills and leakage, surface runoff and gypsum sludge in case of TSP complex
Gaseous	Ammonia in purge gas
	Flue gas containing CO_2, CO, CH_4, As, etc
	Formaldehyde vapour
	Urea dust

3 Pollution load generated from process industries in Bangladesh

Although the sources of pollution were identified only for three industries discussed above, the relative contribution of air, water and toxic chemicals pollution into environment were determined for a range of other process industries. Industrial Pollution Projection System (IPPS) developed by the World Bank (Hettige et al., 1994) was used to estimate pollution intensities, also called the emission factors, expressed in pollution per unit of output or employment. IPPS is capable of making reasonable projections for all the major pollutants discussed in the previous section. Although the technology, production process and emission vary across different countries, the sheer size of the IPPS database reasonably accounts for such variations and provides a basis of pollution projection at the industry and national levels.

IPPS provides emission factors with respect to three key-economic variables – total output, value added and employment. Of these, using employment data is the most convenient as it does not require any complicated and often unreliable unit conversion. Correlation analysis indicates that all three sets perform nearly the same (Hettige et al., 1994). In this study, employment-based emission factors are used. These factors are available for various industrial sectors identified by four-digit codes known as International Standard Industrial Classification (ISIC) code. The basic idea behind the IPPS is simple – for each industrial sector, determine the appropriate ISIC code and look up the corresponding emission factor. The pollution load is then estimated as

$$PL = \frac{EF \times TEM}{10^6}$$

where,

PL: Pollution load for a sector in tons/year.
EF: Emission factor in kg per thousand employees per year.
TEM: Total number of employees in that sector.

IPPS has already been applied in several World Bank projects documented in World Bank publications. The Bank, in its sector reports for Mexico, Malaysia and several Middle Eastern countries has used IPPS-based estimates (Brandon and Ramankutty, 1993; Calkins et al., 1994). Work on the trade and environment by the OECD has been based on IPPS, particularly the paper by David Roland-Holst and Hiro Lee (1993).

Emission factors developed for IPPS have been estimated from US industry data (Hettige et al., 1994). Owing to the differences in regulatory, economic and technological conditions, these factors may not be transferable to other countries without any modifications. High waste disposal costs in the USA provide strong incentive for waste minimisation, thus the IPPS factors are likely to give lower bound estimates for less-regulated developing countries like Bangladesh. Moreover, pollution control measures move waste from one medium to another. Thus, the estimates of total toxic pollution intensity will be more reliable than medium-specific intensities. Even though considerable international variation in the pollution load of various sectors is expected, the relative ranking of intensities across sectors may be expected to remain about the same. Thus, it is reasonable to expect that tanneries, fertilisers/pesticides and industrial chemicals will be found as the major contributors of toxic chemicals. Conversely, the soft-drink industry will rank near the bottom in terms of emission of toxic chemicals. In this study, the pollution load has been determined for twelve different industrial sectors, namely food, cement and clay, pulp and paper, fertiliser and pesticides, textile, tobacco, petroleum, wood and furniture, tanneries and leather, pharmaceuticals, metal and industrial chemicals.

3.1 Emission into air

Emission into air was determined based on the emission of TSP, SO_2, NO_2, CO and VOC. The contribution of those emissions into atmosphere by industry type is shown in Figure 3. It can be seen from Figure 3 that most of the TSP contribution comes from food and cement industries, whereas, SO_2 contribution comes mainly from food, pulp and paper and textile. VOC and CO contributions by different industries are almost the same. The relative contribution in percentage of air pollution into environment is presented in Figure 4. In terms of the total emission into air, the most polluting is the food industry (39%), followed by cement and clay (17%), pulp and paper (14%) and textile (11%). The major part of the food sector comes from sugar industry. The contribution of 5% corresponding to all others in Figure 4 represents the cumulative contribution of industrial chemicals, fertilisers and pesticides, metals, and wood and furniture industries.

Figure 3 Annual contribution of TSP, SO_2, NO_2, CO and VOC to air pollution

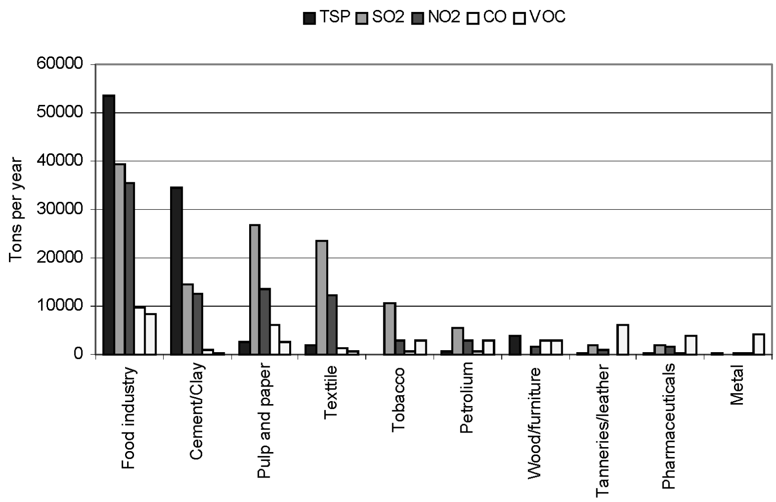
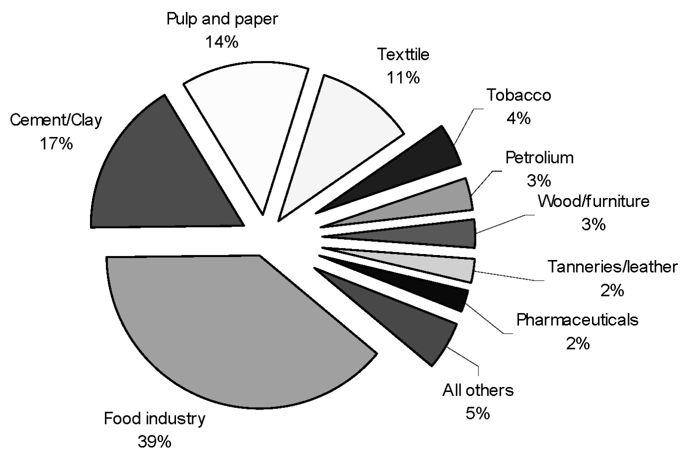


Figure 4 Relative contribution of different industries to air pollution



3.2 Emission into water

Emission into water was determined in terms of biological oxygen demand (BOD) and total suspended solid (TSS). The contribution of BOD and TSS to water pollution from major industries is shown in Figure 5. The highest BOD contributor is the pulp and paper industry, followed by food industry. Collectively, pulp and paper and food industry emit 93% of the total BOD load. In terms of TSS emission, pulp and paper tops the list, followed by pharmaceuticals and metal industries. The relative contribution in percentage of water pollution into environment is presented in Figure 6. In terms of overall emission into water, pulp and paper industry is the major contributor (47%), followed by pharmaceuticals (16%), metal (14%) and food industries (12%). It is to be noted that the contribution of 3% corresponding to all others in Figure 6 represents the cumulative contribution of cement and clay, textile, wood and furniture, tanneries and leather and petroleum industries.

Figure 5 Annual contribution of BOD and TSS to water pollution

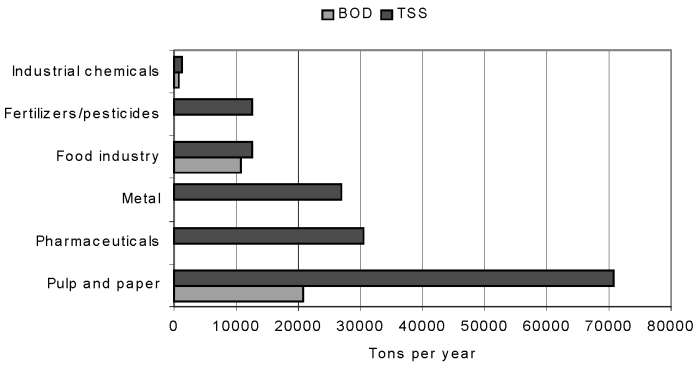
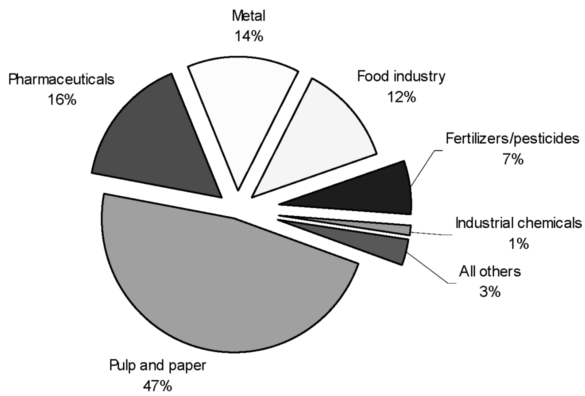


Figure 6 Relative contribution of different industries to water pollution



3.3 Toxic chemical pollution

In most cases, the chemicals are disposed on land as part of the solid waste, parts of which are then collected and recycled. Exceptions are the pulp and paper and cement factories – these emit most of the chemical into air. Direct emission into water appears to be minimal – the two significant ones are 18% by the pulp and paper and 10% by the industrial chemicals. However, it is quite likely that a significant part of the land pollution eventually ends up in water through direct run-off and seepage. The contribution of toxic chemical emissions to air, water and land by various industrial sectors are shown in Figure 7. The number one toxic chemical polluter is the tanneries and leather industry, followed by pulp and paper, pharmaceuticals and fertiliser industries. The relative contribution in percentage of toxic chemical pollution into environment is presented in Figure 8. In terms of overall toxic chemical emission into environment, tanneries and leather industry tops the list (21%), followed by pulp and paper (15%), pharmaceuticals (13%) and fertiliser and pesticide (12%) industries. The contribution of 6% corresponding to all others in Figure 8 represents the cumulative contribution of cement and clay and wood and furniture industries.

Figure 7 Annual contribution of toxic chemicals emission into environment

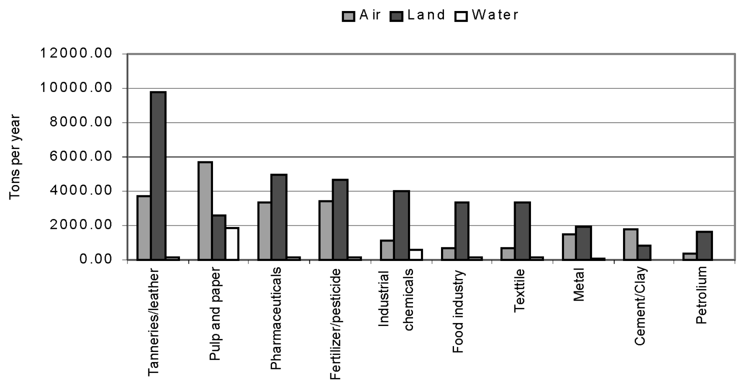
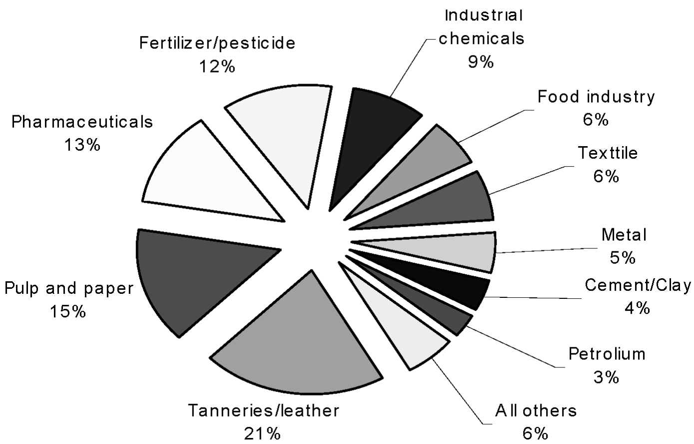


Figure 8 Relative contribution of toxic chemicals of different industries to environment



3.4 *Most polluting sectors*

Table 3 shows the ranking of top-five most polluting industries. The total pollution load per year and the relative and cumulative contributions of these industries to different types of pollution are also shown in Table 3. It can be seen that some industrial sectors, namely food and pulp and paper industries are common in the top-five list. These are clearly the most polluting industries in Bangladesh. A final list of the most polluting industries is presented in Table 4, where the ten most polluting sectors have been identified based on their cumulative ranks (ranks for different pollution types are added to arrive at the final rank). It is to be noted that the tenth item – petroleum and refineries – does not appear in Table 3 but its cumulative contribution is much higher than the tobacco sector, which has been dropped from the final list (Table 4).

Table 3 Ranking of the industrial sectors (top five polluters)

Rank	*Industrial sector*	*Emission* (tons/year)	*Contribution* (%)	*Cumulative* (%)
	Air pollution			
1	Food industry	146356	38.7	38.7
2	Cement/clay	62726	16.6	55.3
3	Pulp and paper	51964	13.7	69.0
4	Textile	39831	10.5	79.5
5	Tobacco	16992	4.5	84.0
	Water pollution			
1	Pulp and paper	91768	47.4	47.4
2	Pharmaceuticals	30867	15.9	63.3
3	Metal	27175	14.0	77.3
4	Food industry	23403	12.1	89.4
5	Fertilisers/pesticides	12715	6.6	96.0
	Toxic chemicals emission			
1	Tanneries/leather	13631	20.6	20.6
2	Pulp and paper	10133	15.3	35.9
3	Pharmaceuticals	8362	12.6	48.6
4	Fertilisers/pesticides	8226	12.4	61.0
5	Industrial chemicals	5714	8.6	69.6

Table 4 The ranking of top-ten polluting industries

Industries	*Air pollution rank*	*Water pollution rank*	*Toxic chemicals rank*	*Rank sum*
Pulp and paper	3	1	2	18
Food industry*	1	4	6	20
Tanneries/leather	8	8	1	20
Pharmaceuticals	9	2	3	22
Metal**	10	3	8	22
Cement/clay	2	11	9	24
Textile	4	9	7	25
Fertilisers/pesticides	14	5	4	27
Industrial chemicals	13	6	5	30
Petroleum/refineries	6	10	10	39

*Main contribution comes from the sugar mills and oil/fat factories.

**Includes all ferrous and non-ferrous metal based industries.

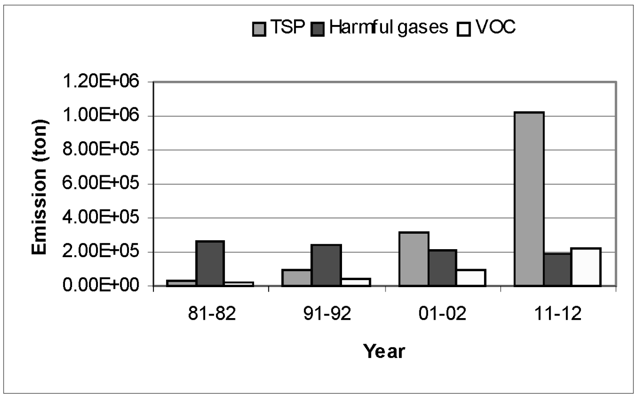
4 Projection of emission loads for year 2011–2012

In the previous sections, emission into air, water and land have been presented for which the data were available through the Census of Manufacturing Industries (CMI) and Ministry of Industry. It would be helpful to know how these emission loads are expected to change in the coming decade. This will provide guidance to the policy makers on the necessary course of action, if they want to limit emission of a particular chemical or compound. Emission projection for year 2011–2012 was estimated using IPPS developed by the World Bank from the available data on industrial projection for future industries obtained from the Ministry of Industry. For all types of pollutants, growth factors were calculated based on the emission data available for previous decades. The growth factors were then used to make projections for 2011–2012. The projection of air, water and toxic chemical pollution into environment is discussed below.

4.1 Emission into air

The projected emission loads of TSP, harmful gases (SO_x, NO_x and CO) and VOC for year 2011–2012 are shown in Figure 9. It is to be noticed from the data in Figure 9 that the TSP and VOC emissions have increased exponentially, whereas emission of harmful gases has decreased linearly. The increase in emission of TSP is at a higher rate than that of VOC. This is primarily owing to the high growth rates of the agro-industry, cement and clay, and wood and furniture industries. The metal-based industries grew very little and did not make a significant contribution to the increase of VOC emission. The emission of harmful gases shows a slightly declining trend owing to a big drop in the number of people employed by the metal-based industries between 1981–1982 and 2001–2002.

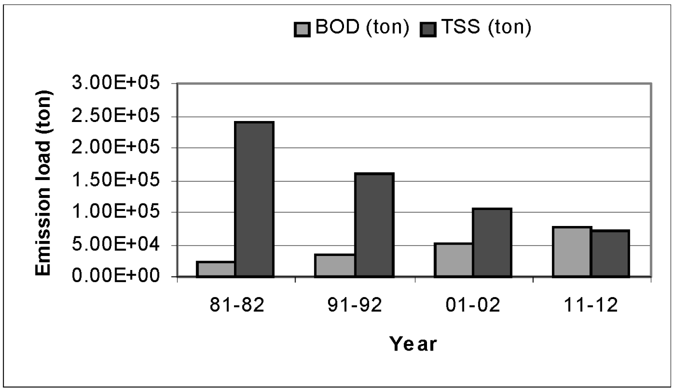
Figure 9 Projection of air pollution for year 2011–2012



4.2 Emission into water

The projected emission loads of BOD and TSS into water for year 2011–2012 is shown in Figure 10. It can be seen from Figure 10 that the contribution of BOD to environment increases linearly where as the contribution of TSS decreases exponentially. The total BOD load is likely to increase owing to the growth of agro-industries, pulp and paper, and industrial chemicals industries. However, the metal-based industries i.e., iron and steel, foundries and rerolling factories, had undergone a major drop in the number of workers employed between 1980s and 2000s, which is responsible for the declining trend of TSS emission.

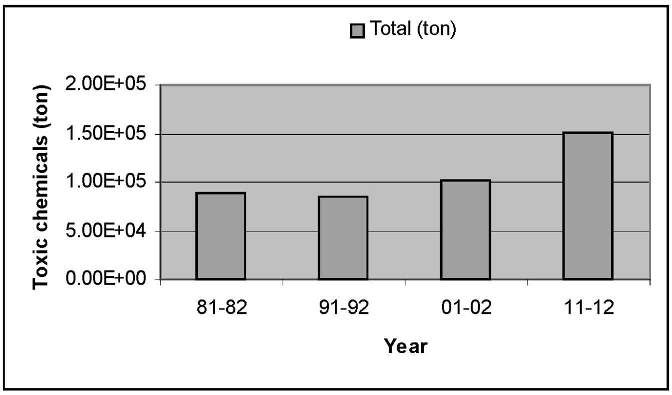
Figure 10 Projection of water pollution for year 2011–2012



4.3 Emission of toxic chemicals

The projected emission of toxic chemicals into environment, for year 2011–2012, is shown in Figure 11. It can be seen from Figure 11 that there is an exponential increase of toxic chemicals between 1991–1992 and 2011–2012, whereas, there is a slight decreasing trend between 1981–1982 and 1991–1992. With the growing industrialisation in the country, it is expected to increase exponentially between 1991–1992 and 2011–2012. However, the slight drop between 1981–1982 and 1991–1992 was owing to the shrinking in the number of tanneries and leather industries after liberation in 1971 (separation from Pakistan). It is to be noted that about 81% of the toxic chemicals will be discharged to air and rest will be mostly dumped on land (18%) with a small fraction (1%) into water in the year 2011–2012.

Figure 11 Projection of toxic chemicals pollution for year 2011–2012



5 Emission control measures

In protecting the environment and controlling industrial pollution, the following measures may be suggested: introduction of greener technologies and waste energy recovery systems, provision of incentives for retrofitting, reduction of industrial processes responsible for 'greenhouse' gas emission, relocation of obnoxious industries like tanneries which are located in densely populated areas, identification and design of environmental norms, setting up quality standards and enforcement of those to regulate industrial emissions.

On one hand, the Bangladesh Government wants to promote the industrialisation growth and on the other hand, the government needs to maintain the environmental control within the accepted set standards. So far, the government has not been very successful in implementing and enforcing the pollution control measures. The main reasons for that are: a lack of adequate trained manpower, equipment and resources, a lack of awareness among the law-enforcing agencies, low priority given to the environmental issues and the difficulty to establish environmental violations in the court of law.

'Win-win' strategies must be identified in order to strike a balance between the apparently conflicting objectives of rapid industrial growth and environmental protection. One possibility is to gradually switch to less polluting but higher value-added sectors like software and information technology, small/cottage industries producing export-oriented items and ecotourism. These industries will not require massive capital investments in controlling pollution, but will employ the growing labour force of the country with minimal training and promote self-employments in environment friendly sectors. Other possibilities are optimum use of energy and introduction of energy recovery systems in process industries, which is seen to reduce adverse environmental impacts. The energy recovery devices may be used for the optimal use of energy in the processes, thus minimising the industrial pollution. Energy recovery systems and techniques already exist in some of the developed countries to reduce liquid and solid wastes as well as environmental pollution from the industry, whereas, in the developing countries, the potential for energy recovery from industrial wastes and effluents has been largely overlooked. Energy recovery systems must be incorporated in the design of new industries with an integrated view to minimise energy consumption and environmental pollution. One such example is the pulp and paper industry (Mohanty and Mora, 1988; Mora, 1989), where an efficient cogeneration of heat and power (electricity) will permit better non-commercial fuel utilisation and significant reduction of industrial pollution through anaerobic treatment of organic effluents.

The efficiency of industrial power generation plant and cement and lime industry can be substantially increased through waste heat recovery (Gericke and Hansen, 2000). Environmental pollution caused by cement and stone-crushing industries has been studied elsewhere (Chandrasekaran et al., 1998; Peters, 1998; Tiwari and Kumar, 1998), and the issues related to dust controlling and managing air quality in the vicinity of cement plant were discussed. The cost-benefit analysis of pollution control measures in cement industry is also reported in the literature (Haq et al., 1997). About 14% of annual turnover, both energy and monetary, can be saved in rotary furnace of lead smelters by implementing energy conservation opportunities, suggesting significant reduction in environmental pollution (Rabah and Barakat, 2001). Environmental pollution can also be reduced and controlled by employing appropriate heat exchangers in the processes by reducing energy consumption or recovering energy from the processes in which they are used (Shah et al., 2000). Generally, less pollution is caused in highly efficient systems and vice versa. Thus, the development of recycling and energy recovery systems in industry is important and hence required to replace the conventional industrial processes with a continuous and sustainable structure in order to reduce industrial pollution. This development has progressively been implemented in many of the developed countries to control industrial (environmental) pollution. However, no such approach is seen considered or implemented in the developing countries despite its great need to control their industrial pollution. This study recommends an extensive energy audit to be carried out for existing process industries in Bangladesh to identify where and how energy conservation and recovery measures should be incorporated in order to reduce industrial pollution. Opportunities for energy recovery systems for an integrated iron and steel industry have been investigated in detail in this study and discussed below. It is expected that this would inspire and provide direction to the Ministry of Industry for carrying out an energy audit (Rasul et al., 2004).

Waste heat recovery from sinter cooler

This measure recovers and utilises the sensible heat of sinter. Sinter is usually cooled by air cooler and the resulting hot exhaust air is discharged into atmosphere. The exhaust air may reach as high as 300–350°C and energy content of its sensible heat is equivalent to approximately 30% of the energy input into the sintering machine. Two methods have recently come into use for the recovery and utilisation of the sensible heat of the hot air (Beer et al., 1994; Farla et al., 1998). These are recirculating fans and waste heat boiler.

Recirculating fans

Recirculation fans introduce the hot air to the ignition furnaces for use as a combustion air (energy saved = 1195–2390 kJ/ton of sinter) and the raw material layer for preheating (energy saved = 2390–4780 kJ/ton of sinter).

Waste heat boiler

The recovered hot air is sent to the waste heat boiler, where it is converted into steam that is either used as process steam or further sent to turbine for power generation (steam saved = 7.17–11.95 MJ/ton of sinter).

Coke dry quenching

Coke dry quenching (CDQ) permits recovery of the sensible heat of hot coke produced in coke ovens (temperature of about 1000°C). The conventional technique was to quench hot coke with a water spray and to allow the sensible heat to be discharged into the atmosphere. The principle of CDQ is to cool by circulating non-oxidising gas in a closed loop. The heat thus recovered is used to generate steam or electric power by means of a heat exchanger. Net energy saving in the form of recovered steam, allowing for power usage by CDQ equipment, amounts to about 19.12 MJ/ton of coke, which is equivalent to about 40% of the total energy input of the coke plant and 80% of the sensible heat of discharged hot coke. Other benefits of CDQ include improved coke quality and environmental protection.

Waste heat recovery in BF hot stove

Although the temperature of waste gas at the hot stove is rather low, at about 50°C, the recovery of hot stove waste heat is important, because of the large volume of waste heat available. The steam recovers waste gas at high efficiency for reuse as energy to preheat combustion air and fuel gas. The waste recovery systems include a heat exchanger installed in the pipe system that carries low temperature waste gas from hot stove to preheat combustion air and fuel gas. Net energy savings amount to about 4.78–7.17 MJ/ton of pig iron.

BOF gas (LD gas) recovery and utilisation

Gas generated by the oxygen converter (LD gas) in the BOF steel shop has a total energy of about 57.36 MJ/ton of crude steel. Two methods of recovering this heat are (i) waste heat boiler system (combustion-type steam recovery system), by which CO contained in the gas is completely burned using air and the resulting sensible heat is recovered in the form of steam in the upper part of the converter stack, about 16.73 MJ/ton of steel can be recovered in this way and (ii) OG system (suppressed combustion-type gas recovery system), by which the CO contained in the gas is not burnt, but is recovered as latent heat, about 47.8 MJ/ton of steel can be saved by this means, almost three times more than waste heat boiler. Because of the better recovery of energy, the latter system is preferred over the former. The OG system also includes gas cooling and dust collection. The recovered gas volume is determined primarily by

- steel-making conditions
- OG gas operating, particularly time setting of gas recovery
- conditions of recovered gas utilisation equipment.

The recovered LD gas, which accounts for about 8% of the total product gases in an integrated steel plant is used alone or may be mixed with blast furnace gas or coke oven gas as a fuel for low pressure boilers, power station boilers, hot stoves, soaking pits, reheating furnaces and calcining furnaces.

Currently, energy savings of about 20% is being achieved by incorporating waste energy recovery systems in some of the developed countries, for example, in Japan (Japan Iron and Steel Federation, 2003). Energy efficiency improvement researchers in the USA reported that they could reduce their energy use by 18% while producing same amount of iron and steel by introducing energy conservation measures (EETD, 1999). The reduction of 18% in energy use would result in a 19% reduction in emissions of greenhouse gases (EETD, 1999). This study strongly recommends a complete energy audit and implementation of energy conservation measures through capital investment and proper energy management practices for existing process industries in Bangladesh for

- optimum use of energy in industry
- significant reduction of energy cost per unit of product output
- reduction of environmental pollution generated from process industries.

6 Conclusions

This study has estimated the total pollution loads into air, water and land discharged by all the industrial sectors of Bangladesh using the IPPS method developed by the World Bank. Emission factors based on the number of employees were used for determination of pollution load. In terms of air pollution, the most polluting sector is the food industry, where most of the pollution is caused by the sugar mills and oil and fat factories. Pulp and paper is the worst water polluter. The largest amount of toxic chemicals is released by the tanneries and leather industries (raw and processed). In terms of the total emission into air, water and land, the top-three most polluting industries are the pulp and paper industry, food industry, and tanneries and leather industry. The other significant polluters include the metal and textile industries.

The study made projections for emission loads into air, water and land for year 2011–2012. The TSP emission into air is expected to increase at a higher rate compared to other gases. This is primarily owing to the high growth rates of the agro-industry, cement and clay, and wood and furniture industries. The projection of BOD was downwards owing to drop in number of people employed in metal industries. Owing to growing industrialisation in Bangladesh, the overall emission of toxic chemicals to environment is expected to go up, most of which (81%) will end up in air.

Energy audit and implementation of energy recovery systems in existing industries in Bangladesh is strongly recommended in order to reduce industrial, and hence environmental pollution. Energy recovery systems must also be incorporated in the design of new industries to minimise energy consumption, manufacturing cost and environmental pollution, and hence to improve the product quality.

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