



Preliminary mercury emission estimates from non-ferrous metal smelting in India

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ABSTRACT

Mercury (Hg), a potential contaminant to the environment is of global concern because of its toxic nature, trans-boundary movement and its ability to bio-accumulate and bio-magnify. Previous research showed that Hg based chlor-alkali production, coal fired thermal power plants, traditional gold mining, healthcare equipments, waste incineration, and some industrial processes are the major sources of mercury release into environment. Primary non-ferrous metal smelting is considered to be an important anthropogenic Hg emission source in India, but data availability in this regard is a limiting factor. The study thus attempts a preliminary estimation of Hg emission range and creates an emission inventory from non-ferrous metal smelting operations in India. The emission estimates are for the time period 2003 to 2007. Emission in the year 2003 has declined from 5.5 – 7.6 ton where it has increased to 15.5 – 22 ton in year 2007. Zn and Cu smelting contributed maximum (80%) to the total emissions and the rest (20%) was from lead (Pb) smelting. The range of Hg-emission per unit area (g/km^2) in the year 2007 was between 2.3 to 6.6 whereas the per capita emission was found between 7 and 19 mg from non-ferrous metal smelting industry in India. About 6 to 17 ton of elemental Hg (Hg^0), went into the global circulation in the year 2007 whereas mercuric (Hg^{2+}) emissions were in the range of 1.1 to 3.2 ton and the rest (3.8 to 10 tons) was in particulate-form (Hg^p). Share of Hg^{2+} and Hg^p in the total Hg-emissions is very small and has impacts on regional to local level.

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1. Introduction

1.1. Background

Mercury (Hg), a potential contaminant to the environment is of global concern because of its toxic nature, trans-boundary movement and its ability to bio-accumulate and bio-magnify (Lindqvist, 1991). Hg is extracted from the ore cinnabar (HgS) and used for various purposes and processes while eventually an appreciable amount of it gets released into the environment. Hg also gets released into the environment as an unintentional by-product through activities like fossil fuel burning, ore-smelting, cement kilns and waste incineration. These emissions have resulted in about three-fold increase in Hg-deposition in the environment since the pre-industrial times (Meili, 1995).

With the intention of resolving this global menace, United Nations Environmental Programme (UNEP) brought out The Global Mercury Assessment Report in December 2002 identifying the trans-boundary nature of the problem; state of science, significant sources of mercury releases, and suggesting reduction initiatives taken. The findings were presented to UNEP's Governing Council (GC) in 2003. About five years down the line, the GC recognized the need for long-term international action plans to address this global challenge. In 2009, the UNEP's GC agreed to deliberate on a global, legally binding treaty for Hg. The Intergovernmental Negotiating Committee 1 (INC-I) meeting was held in 2010 and INC-II in 2011, in an attempt to prepare a legally binding global framework on Hg. The GC further agreed to intergovernmental negotiations and the

adoption of the treaty at a Diplomatic Conference to be held in 2013.

The estimated global anthropogenic atmospheric Hg-emission was 2 190 tons in the year 2000 (Pirrone et al., 2001) and Asian countries were the largest contributors (67%) towards these emissions (UNEP, 2008). China ranks first followed by India, and the primary sources identified are fossil fuel burning and smelting industries.

Metallurgical processes (smelting) are one of the important anthropogenic sources of Hg (Nriagu 1989; Pirrone et al., 1996). Non-ferrous metal production rolls through the smelting process, which emitted 87 tons of Hg in Asia alone in the year 2000 (Pirrone et al., 2001). Copper (Cu), zinc (Zn), lead (Pb) and Hg have affinity to Sulfur, the reason behind Hg being associated with sulfide ores of these metals and in turn, its release during extraction of any of the aforesaid metals.

Hg-present both in the coal (fuel source) and in the ore is released during the smelting process. The Hg-content in these ores varies from metal to metal and their place of origin (Nriagu and Pacyna, 1988; Streets et al., 2005). During the smelting process that normally reaches about 1 000°C and above, almost all Hg in the ore gets evaporated from the matrix, and goes into the flue gases primarily in the form of elemental Hg (Hg^0) while a small portion as divalent Hg (Hg^{2+}) and particulate Hg (Hg^p) (Pacyna and Pacyna, 2002), and eventually gets emitted into the atmosphere, in the absence of appropriate pollution control mechanisms.

Physico-chemical properties of Hg depend on its state. For example, Hg⁰ is insoluble, whereas Hg²⁺ is soluble in water. Thus, Hg²⁺ has a tendency to get associated or adhered to the particles in the flue-gases making the particle heavy and increases the chances of its settling down locally. In other words the residence time of Hg²⁺ is short (a few days to weeks), whereas the residence time of Hg⁰ is longer varying between 0.5 to 2-years that makes this form of mercury circulate trans-boundary and thus has the potential to impact environment at a global scale. In contrast, other forms of Hg – exhibit similar impact potential at regional scales.

1.2. Indian scenario

Hg-content in Indian coal varies from place to place and the average value is 0.3 mg/kg of coal (BHEL, 2004). Data on the Hg-content in non-ferrous ores is not available in the public domain, and certainly needs to be quantified in India, growing at about 8% annually for over a decade, now is one of the fastest growing economies. The trend is bound to continue for another decade or so. Clearly, most of the growth would come from industrial expansion and need not to say that the non-ferrous metals would also play a vital role. The production of these metals has significantly increased in the past while in order to bridge the demand-supply gap, Government of India changed its stance by allowing privatization of state-owned companies. To compensate for the shortage of raw materials for Cu-industry in India the customs duty on the import of Cu-ore and concentrate has reduced from 5% to 2% (USGS, 2006). Cu-concentrates have been imported from mining countries like Chile, Canada, and Peru. Zn and Cu production have almost doubled (from 278 – 440 Gg and 394 – 734 Gg respectively). There are four Zn-smelters and two out of these are based on indigenous Pb-Zn ores. Vishakhapatnam and Benanipuram plants are partly based on imported concentrates. Similarly Cu smelters partly depend on imported concentrates (USGS, 2006).

Clearly the smelting plants are here on an expansion pathway and thus inherently a growing source of mercury emissions-though metal-ores and the coal-fuel that primarily meet the energy demand for metal extraction.

Let us look at the magnitude of coal consumption in these industries during the recent years. Between 2004 and 2008, the coal consumption in smelters has increased from 31 million tons to 60 million Tons (100% increase in just four years). The energy consumption-share of these smelting industries was about 12% to total coal used in the country (TEDDY, 2009). The increased demand of these metals in future would further add to the energy demand of this sector. Most importantly, Hg-content in Indian coal varies from place to place and the average concentration is 0.3 mg/kg of coal (BHEL, 2004). However, data on the Hg-content in non-ferrous ores is not available, and certainly needs to be quantified.

As negotiations on Hg gear up for the next level, a Global treaty is likely by 2013. It's very important to quantify Hg-emissions from this sector and assess the existing technologies to reduce them. Mukherjee et al. (2008) have made efforts towards estimating the average annual Hg emissions from various sectors including non-ferrous metal smelting industries for the period 2000 to 2004.

The current study aims to estimate the range of Hg emissions during the period 2003-2007 from non-ferrous metal smelting. The upper and lower possible emissions were calculated on the basis of emission factors (EFs) available from the literature. While recognizing the contribution of fossil-fuel burning etc, current assessment focused only on the non-ferrous smelting industries in India. The per capita and per unit area Hg emission from this sector was also calculated. As the residence time and Hg-capture technology varies for the different species (Hg⁰, Hg²⁺, Hg^p), further

quantification of total Hg was done to gauge species-specific sectoral emissions.

2. Non-ferrous Metal Production in India

2.1. Corporation in mining and smelting

Hindustan Zinc Limited incorporated in 1966 after the Government of India took over former Metal Corporation of India to own, manage and develop the mineral and smelting capacities for the strategic metals production such as Zn and Pb in the country. Hindustan Copper Limited incorporated in 1967 is presently the sole indigenous producer of primary Cu in the country. Sikkim Mining Corporation (in which Central Govt. has 49% equity participation) produces poly-metallic ore that is treated in the concentrator plant to produce Cu, Pb and Zn concentrates.

Hindustan zinc Limited. Hindustan zinc Limited is the India's largest and world's second largest integrated producer of Zn and Pb with a global market share of approximately 6.0% in Zn. It has four mines and three smelting operations. Mines are situated at Rampura Agucha, Sindesar Khurd, Rajpura Dariba and Zawar in the State of Rajasthan. The smelters are located at Chanderiya and Debari in the State of Rajasthan and Vizag in the State of Andhra Pradesh. Chanderiya Smelting Complex (CSC), Rajasthan, India is the single largest Zn-smelting complex in the world. It was commissioned in the year 1991 with an initial production capacity of 70 000 tons per annum of Zn and 35 000 tons per annum of Pb. In the past 6 years, the capacity of the plant has been expanded five folds to its current capacity of 525 000 tons per annum of Zn and 85 000 tons per annum of Pb.

Zinc Smelter Debari is a hydrometallurgical zinc smelter situated at Debari, about 13 km from Udaipur, in Rajasthan, India. The primary product of Debari is High Grade (HG) Zn and it also recovers Cd as a by-product. It has Roast Leach Electro-winning Technology and produces 88 000 Tons per annum of Zn.

Zinc Smelter Vizag is a hydrometallurgical Zn smelter situated at Vizag, in the State of Andhra Pradesh, India. The primary product at Vizag is high-grade Zn and it also recovers Cd as a by-product. It uses a similar technology to that of Zinc Smelter Debari. Zinc Smelter Vizag was commissioned in the year 1978 with an initial production capacity of 30 000 tons per annum and had been expanded to 56 000 tons since the year 2003.

Hindustan Copper Limited (HCL). Hindustan Copper Limited (HCL) a public sector undertaking under the administrative control of the Ministry of Mines, was incorporated in 1967. It has the distinction of being the nation's only vertically integrated Cu-producing company as it manufactures Cu-right from the stage of mining to beneficiation, smelting, refining and casting of refined Cu-metal into downstream saleable products (Hindustan Copper, 2011).

HCL's mines and plants are spread across four operating Units, one each in the States of Rajasthan, Madhya Pradesh, Jharkhand and Maharashtra as named below:

(i) Khetri Copper Complex (KCC) at Khetrinagar, Rajasthan: Khetri is situated at the foothills of the Aravalli Range, which hosts Cu mineralization, giving rise to 80 km long metallogenetic province from Singhana in the north to Raghunathgarh in the south, popularly known as Khetri Copper Belt. Regular mining ceased in this area by 1872. With the advent of 20th century, the Geological Survey of India, Indian Bureau of Mines undertook explorations. National Mineral Development Corporation (NMDC) started development of Khetri Mine and the project was handed over to HCL in 1967 when HCL was formed. Subsequently, smelting and refining facilities were added in KCC.

ii) Indian Copper Complex (ICC) at Ghatsila, Jharkhand: Singhbhum Copper Belt (SCB) comprises of a Proterozoic volcano–sedimentary rock that creates a shear zone known as Singhbhum shear zone. Prominent deposits of the belt are Chapri, Rakha, Surda, Kendadih, Pathargora, and Dhobani. A British company established Indian Copper Corporation Ltd. in 1930 at Ghatsila consisting of a cluster of underground Cu–mines, concentrator plants and smelter. In 1972, the Govt. of India nationalized the company under provisions of the Indian Copper Corporation (Acquisition of Undertaking Act) and merged the same with HCL.

(iii) Taloja Copper project (TCP) at Taloja, Maharashtra: The Taloja Copper Project (TCP) was set up in 1989, based on technology sourced from USA. The plant produces Continuous Cast Copper Rods (CCR) and has a capacity of producing 60 000 Tons per year. The inputs are sourced from the Company's own unit at Khetri and Ghatsila (i.e. KCC and ICC) as well as through direct purchase of cathodes.

iv) Malanjkhand Copper Project (MCP) at Malanjkhand, Madhya Pradesh: Malanjkhand Copper Belt comprises of a large body of Cu–ore in granite rocks. Prominent deposits are: Malanjkhand, Shitalpani (Balaghat, Madhya Pradesh), Gidhri Dhorli, Jatta and Garhi Dongri. MCP was established in 1982. Initial project was set up by Hindustan Copper Ltd. to exploit the copper ore through an open pit mine. Geological Survey of India took systematic geological exploration at this deposit during 1969. Mining lease of the ore was granted to HCL during 1973. With advancement of time this project was enhanced with viable operational developments. Malanjkhand Cu–deposit is the single largest Cu–deposit of India with nearly 70% of the country's reserve and contributing around 80% to HCL's total Cu–production.

The Sikkim Mining Corporation. It was established by a proclamation of Darbar of Sikkim in 1960 as a joint venture having 51% equity from the state Government (Sikkim) and 49% equity from Government of India. After about 6 years, production of the complex ore from Bhotang Mine started since 1966–67 onwards. This was the only mine till recently in the country, which produced three metals (Cu, Pb and Zn) from a poly–metallic complex ore. As on year 1998 the mine was estimated to have (proved and probable) reserves of about 3.28×10^5 tons and has already produced about 4.11×10^5 Tons of ore since its inception. Currently Bhotang mine is producing about 54 TPD (Tons per day) of ore and the other exploratory mine called 'Pacheykhani', is also producing about 18 TPD. The cumulative production would be enhanced to 90–100 TPD after the major repair of the existing Cone Crusher of the Mill plant by the end of the financial year 1998–99. The Cu–concentrate produced by the corporation is sold off to M/s Hindustan Copper Ltd.; Zn concentrate to M/s Hindustan Zinc Limited and Pb–concentrate is not saleable at present due to high Bi (0.6 to 0.7%).

The Indian Copper Industry. This was opened for private sector investment in 1992. Earlier the industry was dominated by Hindustan Copper Limited (HCL), a public sector undertaking. This industry currently has three major players like, Sterlite, Hindalco and Hindustan Copper Ltd., Hindalco and Sterlite accounts for about 90% of the Cu–metal in the market whereas HCL has 6% and 1% is by Jhagaria Copper (SWIL Ltd.) that, commissioned its 50 000 tons plant in Gujarat. Currently, SWIL Ltd., reportedly facing acute shortage of raw materials.

2.2. Processing

There are four Cu–smelters in India using mainly the Flash Smelting process, the Ausmelt process and the Imperial Smelting process. In the Flash–smelting Furnace, the pre–heated air and oxygen is used to produce Cu. In Ausmelt process, the feed materials are fed through a port located in the roof of the furnace that fall into the molten bath. Air and oxygen mix is used for

combustion; the molten metal and slag are removed and off–gases from the furnace are cooled and cleaned in gas clean–up systems before discharge.

Zn production in Udaipur, Rajasthan follows hydro–metallurgical process having the following steps: roasting, leaching, solution purification, Zn electro–winning, melting, casting, and alloying. Blast Furnace Process produces Pb in Tundoo, Jharkhand whereas in Chhattisgarh plant through the Imperial Smelting Process. The smelting procedures depend on ore types. Zinc ores can be divided into two major categories as sulfide and oxide. Oxide ores need only one step in processing i.e., ores and coal are filled in small ceramic jars, and heated to about 800 °C for a few hours in a furnace using coal as fuel (Feng et al., 2006). For sulfide ores desulfurization is the first step and followed by the steps as mentioned for oxide ore.

3. Methodology

The non–ferrous metal production (primary and secondary) in India has reached to 1 298 thousand tons in year 2007. Details about the trend of metal production trend between years 2003 to 2007 is given in the Supporting Material (SM) (Table S1). Though a small amount of Zn, Pb, and Cu are produced through the secondary smelting process where mainly scraps of these metals are used. However, recently the Cu production through secondary smelting has increased considerably, where Cu–scraps are mainly roasted and smelted in the converter charged with Cu–scrap. Under the current study estimation was made on the basis of primary smelting process only.

Estimation of Hg emissions from the non–ferrous smelting industries was done through following factors: annual primary–production of these metals (Cu, Zn, Pb) and Emission Factor of Hg. The following formula has been used for calculating Hg emissions from individual non–ferrous metal production process:

$$E_{Hg(\text{year})} = M(\text{year})EF(\text{year}) \quad (1)$$

where, $E_{Hg(\text{year})}$ is the annual emission of Hg (Kg) from non–ferrous metal smelting, $M(\text{year})$ is the annual production (Gg) of respective non–ferrous metal, and $EF(\text{year})$ is the emission factor of Hg (g/Mg) production of non–ferrous metals.

3.1. Emission factors (EFs)

Researchers from across the world (Nriagu and Pacyna, 1988; Pirrone et al., 1996; Streets et al., 2005) have worked out the EF of Hg in terms of unit production of these metals. There is a large difference between the EFs reported for developed and developing countries. Differences could be as a result of actual Hg–content in the ore, coal quality, Hg–recovery as a by–product and use of air pollution control devices. In developed countries, smelting companies not only recover Hg as a by–product, but also utilize air pollution control devices to prevent Hg emissions to the atmosphere and as a result EFs are generally quite low.

Globally, reported data on the Zn smelting EFs varied from as 8 mg/kg to as high as 156 mg/kg. Streets et al. (2005) reported an average value of 86.6 (13.8 to 156) mg/kg of Zn for China. Recently, Li et al. (2008) have used EFs, between 20 and 25 mg/Kg of Zn produced for developing countries and 7.5 to 8 mg/Kg for the developed ones. Hylander and Herbert (2008) have arrived at the global mean EF as 12 mg/Kg whereas for the developing countries many researchers including Li et al. (2008) got higher values than this (Table 1).

Indian EFs were unavailable so emission range of Hg was calculated using recent values from the literature. Mean, the

highest and lowest EFs were selected to calculate the range of emissions (Table 2).

Table 1. Review of Hg content (mg/kg) in non-ferrous metal production (Kg) across the world

Metal	Hg (mg/Kg)	Reference countries	Reference
	12.09	Global mean	Hylander and Herbert (2008)
	8 to 25	Developing	Pai et al. (2000); Feng et al. (2004)
	8 to 45	Global	Nriagu and Pacyna (1988)
Zn	13.8 to 156	China	Streets et al. (2005)
	86.6	China ^b	Jiang (2004)
	20 to 25 ^a	Developing	Li et al. (2008)
	7.5 to 8 ^a	Developed	
	5.81	Global	Hylander and Herbert (2008)
Cu	15	Developing	Pirrone et al. (1996); Nriagu and Pacyna (1988)
	15.71	Global	Hylander and Herbert (2008)
Pb	43.6	Developing	Feng et al. (2004)

^a Based on Nriagu and Pacyna, 1988; Pirrone et al., 1996; Prasad et al., 2000; Pacyna and Pacyna, 2002; Pacyna et al., 2003; Pacyna et al., 2006; Streets et al., 2005.

^b national average

Table 2. Emission factors (mg/Kg) used to estimate Hg-emissions from non-ferrous metal smelting in the current study

Metal	Hg (mg/Kg)	Scenarios (range)	Reference
	12.09	Average	Hylander and Herbert (2008)
	8	Min.	Prasad et al. (2000); Feng et al. (2004)
	25	Max.	
	5.81	Min.	Hylander and Herbert (2008)
	15	Max.	Pirrone et al. (1996);
	15.71	Min.	Hylander and Herbert (2008)
	43.6	Max.	Feng et al. (2004)

min: minimum, max: maximum

3.2. Per capita and per unit area emission

Per capita Hg-emissions for the year 2007 was calculated by dividing the estimated Hg-emissions with population of India (CIA World Fact Book, 2009) (see the SM, Table S2). Similarly, per unit area emissions were estimated by dividing annual estimated Hg-emissions by total geographical area of India i.e., 328 7590 km² [Equations (2) and (3), respectively].

$$PE_{Hg(year)} = \frac{E_{Hg(year)}}{P_{year}} \tag{2}$$

where PE_{Hg(year)} is the per capita Hg-emission, E_{Hg(year)} is the estimated Hg-emission from non-ferrous smelting industries, and P_{year} is the population of India in the year 2007.

$$PA_{Hg(year)} = \frac{E_{Hg(year)}}{A} \tag{3}$$

where PA_{Hg(year)} is the unit area Hg-emission (g/km²), and A is the area of India (km²).

3.3. Species-specific emission profiles of Hg

To see the quantum of Hg emitted in the form of Hg⁰, Hg²⁺ and Hg^p, fractionation ratios of 0.8, 0.15 and 0.05, respectively were adopted from Pacyna and Pacyna (2002) and used in Equation (4).

$$FRE_{Hg(year)} = E_{Hg(year)} FR_{(year)} \tag{4}$$

where FRE_{Hg(year)} is the fractionated species specific emission of Hg, E_{Hg(year)} is the estimated emission of Hg- in particular year, and FR_(year) is the relative fraction of Hg-species.

4. Results and Discussion

4.1. Estimated Hg-emissions from respective metals smelting

The estimated Hg-emissions from the Zn-smelting industries ranged between 2–6.3 Tons in year 2003 and increased to 3.310 Ton in year 2007 (Figure 1a).

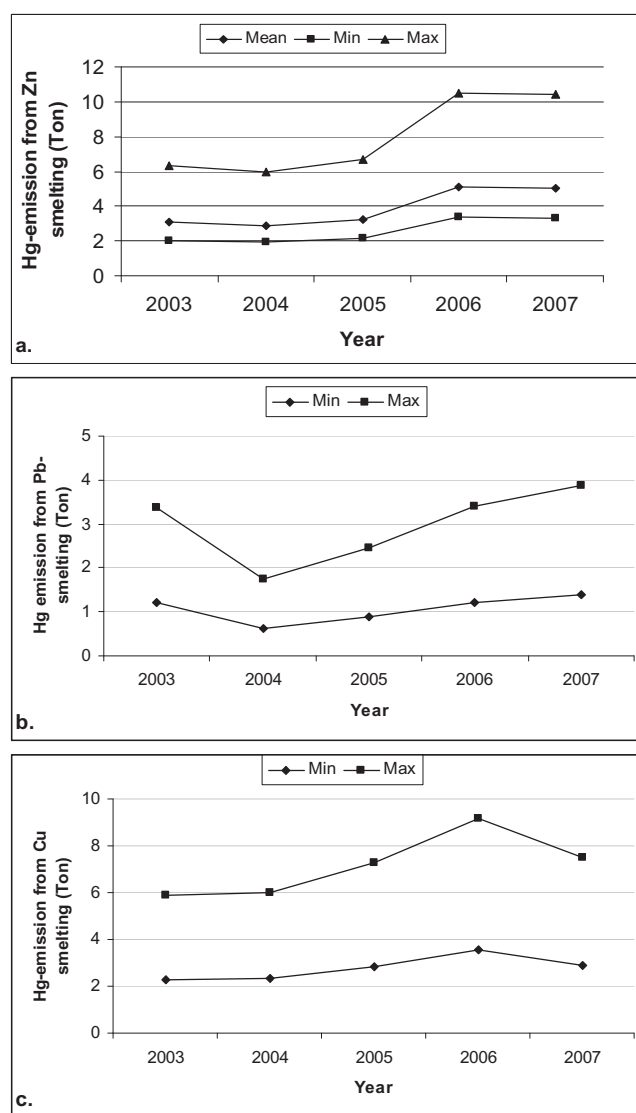


Figure 1. Estimated emission of Hg from primary non-ferrous metal production between 2003-2007 in India. (a) Zn, (b) Pb, and (c) Cu.

The estimated upper-end of emissions from Pb-smelting industries has declined by approximately 50% (from 3.3 Tons to 1.7 Tons) between the years 2003 and 2004 and further increased to 3.8 Ton in year 2007 (Figure 1b). The reason behind this trend was decline in the production figure in year 2004 and steady

growth in later years (see SM, Table S1). The EF range (upper and lower) was approximately 3-fold, so similar trends could be seen in the estimated emission range as well.

The estimated Hg-emissions from primary Cu-smelting industries showed a steady growth from year 2003 till 2006 and declined in the succeeding year. The estimated decline in Hg-emission trend in the year 2007 could be because of decline in the primary production (Figure 1c). There was constant deficiency of Cu-ore and concentrates in the country in spite of the reduction on import tax upon it. The Cu-production has increased through the secondary processing because of smelting from scraps in recent past.

We compared our estimates with a recent study from India (Mukherjee et al., 2008) and few other countries like China and Canada. The mean emission estimates from the current study was close to those reported by Mukherjee et al. (2008) (Table 3).

The upper and lower range of the estimated Hg-emissions from the non-ferrous (Zn, Pb and Cu) smelters was calculated by adding the respective contribution from these. The minimum estimated Hg-emissions had increased from 5.5 to 7.6 Tons whereas upper one was 15.5 Tons to 21.7 Tons respectively from 2003 to 2007. Estimation of the lower and upper possible emissions certainly provides a better understanding on emissions over the mean annual figure. For example for the year 2007, emission range is between 7.6 to 21.7 Tons which is a better indicator for the policy-makers to think about the policy options to reduce the Hg emissions (Figure 2).

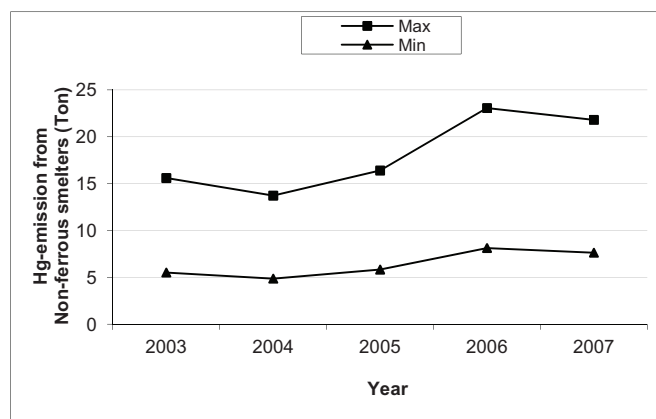


Figure 2. Estimated max. and min. emission of Hg (Ton) from non-ferrous smelters between 2003-2007 in India.

The estimated relative emission contribution from Zn smelting was about 65% followed by Cu (22%) and Pb (13%) industries (Figure 3).

4.2. Per unit area and per capita emission

The range of Hg-emissions per unit area in year 2007 fell between 2.3 to 6.6 g/km² whereas the range for per capita emission was 7 to 19 mg/person from this sector in India (Table 4).

4.3. Species-specific emission profiles of Hg from non-ferrous smelters in India

About 6–17 Tons of Hg⁰ forms were generated in the year 2007 whereas Hg²⁺ were 1.1–3.2 Tons and rest (3.8–10 Tons) in Hg^p (Figure 4a and 4b). It means the amount of Hg⁰, which enters to the global circulation, is about 6 to 17 Tons, whereas the rest (4.9–13.2 Tons) mainly in the soluble forms that settles on the regional level and pollutes soil, water etc.

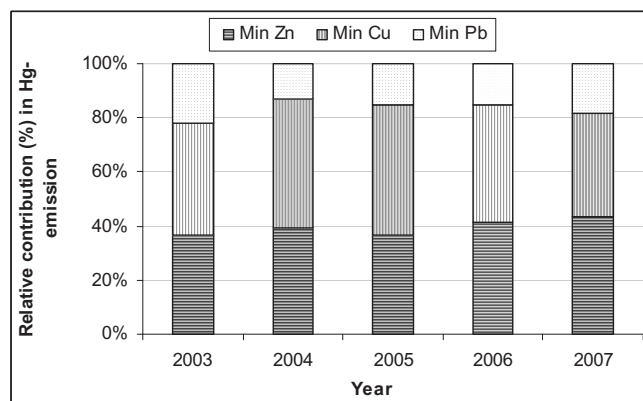


Figure 3. Relative contribution (%) of non-ferrous (Zn, Pb and Cu) smelters in the Hg-emissions estimated from 2003 to 2007.

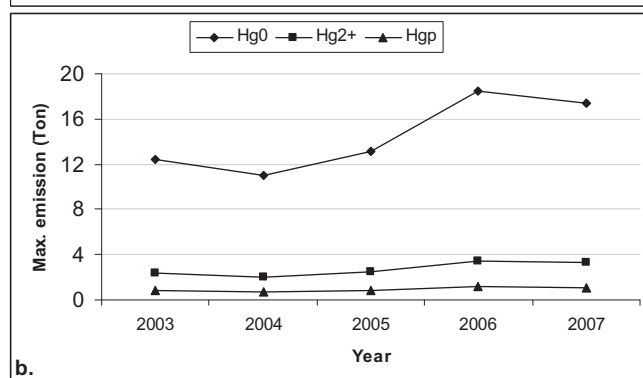
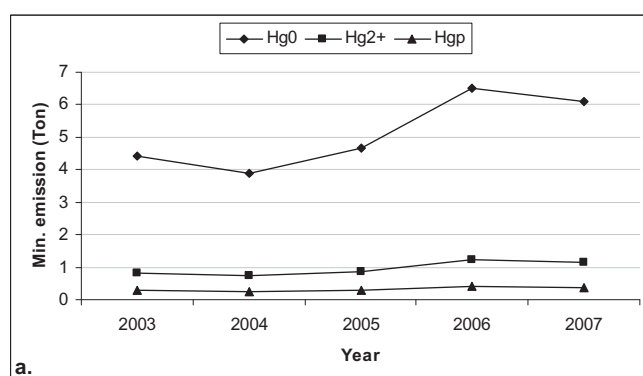


Figure 4. Estimated species of Hg from non-ferrous smelters in India. (a) max., (b) min.

4.4. Uncertainty, limitations and further scope of the study

The input parameters in the current emission estimation were, (1) production data of non-ferrous metals (Zn, Cu, Pb) and (2) EFs from other fast growing economy like India.

Through the literature review we noted that there are similarities in ore processing like hydrometallurgical smelting predominates in case of Zn, both in India as well as in China (Li et al., 2010). In recent past Cu-metal production through secondary smelting has accelerated and excluding this aspect from the current Hg-emission estimates might cause underestimation. EF's depend upon the Hg-content in the ore, coal used, smelting process and use of the air pollution control devices like sulfuric acid plants, Hg-reclaiming tower, wet electrostatic precipitators. Availability of Indian EFs in future can help to make a better estimate and reduce the uncertainty in estimates.

Table 3. Global trends in Hg-emissions from Non-ferrous metal smelting (tons/year)

Country	China		Canada		India			
	Year	Year	Year	Year	Year	Year	Year	
Year	2000	2003	2000	2006	2000	2004	2004	2007
Reference	Wu et al. (2006)	Wu et al. (2006)	EC. (2008)	EC. (2008)	Mukherjee et al. (2008)	Mukherjee et al. (2008)	Current study	Current study
Non-ferrous metal smelting	262	320	2	1.2	7.7	15	4.8-14	7.6- 22

Table 4. Estimated annual per capita (mg/person) and per unit area (g/km²) Hg-emissions

Estimated emission		Year				
		2003	2004	2005	2006	2007
Per unit area (g/km ²)	Max.	4.7	4.2	5.0	7.0	6.6
	Min.	1.7	1.5	1.8	2.5	2.3
Per capita (mg/person)	Max.	14.9	12.9	15.2	21.1	19.3
	Min.	5.3	4.6	5.4	7.4	6.8

5. Some of Hg-hotspots in India

i) The Singrauli area, Uttar Pradesh is surrounded by the Super Thermal Power Plants (STPP) namely Singrauli STPP, Vindhyachal SSTP, Rihand STPP, Anpara A & B STPP, Renusagar STPP. According to CPCB, 2001, Singrauli area, having an installed capacity of producing 9.5% of total thermal power in our country, stands responsible for 16.85% of total Hg-pollution through power generation. Industrial Toxicology Research Centre (ITRC), Lucknow have reported that Hg-content in blood was higher than 5 µg/mL for 66.3% of the sampled population. The Hg concentration in water in this region was 0.182 mg/L (Down to Earth, 2003).

ii) Tuticorin, India is a coal fired TPP, located along the Coastal region of Tuticorin, India, near Bay of Bengal. East and Southeast of this area is bound by Gulf of Mannar and Southeast Asia. Additionally, there are five TPPs each having the installed capacity of 210 MW and using 17 – 18 Gg of coal per day in the vicinity. The Hg concentration in respirable suspended particulate matter (PM₁₀) was found to be 0.02 ± 0.01 µg/m³ (Jayasekher, 2009).

iii) Kodai Lake, Kodaikanal, Tamilnadu, the tourist hill-resort, has been Hg-contaminated from waste dumped by a thermometer making company (Mody, 2001). Balarama Krishna et al. (2003) measured the ambient Hg level as 1.32 µg/m³, whereas reported concentration in lichen and moss were 7.9 µg/kg and 8.3 µg/kg respectively from the vicinity of the factory. Karunasagar et al. (2006) measured the Hg concentrations in water, sediment and fish samples. The reported total Hg and methyl-Hg was 356 – 465 ng/L, and 50 ng/L in water whereas sediments had 276 – 350 mg/kg of total Hg. Reported range of total-Hg in fish varied from 120 to 290 µg/kg.

iv) Thane Creek, Mumbai- Krishnamoorthy and Nambi (1999) determined the total Hg in sediments varied between 300 and 400 ng/g.

6. Conclusions

This study provides the estimated range of Hg-emission from Indian non-ferrous metal smelting industries during the years 2003 to 2007. Input data was obtained mainly from published sources. Zn and Cu production have almost doubled whereas Pb-production was almost steady during the period of the study. These metal productions are mainly depending on coal as the fuel. The coal consumption in these industries has increased from 31 million Tons to 60 million Tons between the years 2004–2008. The energy consumption-share of these smelting industries was about 12% to total coal used in the country. Emission factor data

from India was unavailable. Therefore, range (upper and lower) of emission estimates was calculated from available literature from other countries around the world, and developing countries in particular.

In the current situation these industries need much more raw materials to fully utilize their installed capacity, so Government of India has reduced the import duty on ore, concentrate, and scraps in the country.

The estimated Hg-emission spectra increased from 5.5 – 15.5 Tons in 2003 to 7.6 – 21.7 Tons in 2007. Primary production of Zn and Cu metals contribute 80% of the Hg-emissions from non-ferrous metal smelting industry and the rest was from Pb industries. This sector could be the second largest anthropogenic-source of Hg-emissions in the country.

Species-specific emissions like Hg⁰, Hg²⁺ and Hg^p were also estimated and it was found that 80% of total Hg is in the form of Hg⁰. This helps to understand the India's contribution towards elemental Hg and others, and look for technological options to control emissions as well. There is an urgent need for these industries to understand their role in controlling Hg-emissions, which will happen only if Government will take initiatives. The Hg-emission estimates can be significantly improved in the future after the availability of emission factors from Indian smelting industries.

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Supporting Material Available

Primary and secondary non-ferrous metal production (1 000xTonnes) in India (Table S1), Population of India between years 2003 to 2007 (Table S2). This information is available free of charge via the Internet at <http://www.atmospolres.com>.

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