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Implementation of the Minamata Convention to manage mercury pollution in India: challenges and opportunities

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Abstract

The Minamata Convention (MC), a multilateral environmental agreement (MEA), aims to protect human health and the environment from anthropogenic emissions and releases of mercury and its compounds. The success of the MC essentially depends on its effective implementation in developing regions especially those where the contribution to global mercury emissions is large. We assess the challenges and opportunities that lie ahead of the MC's implementation in India, which is among the top mercury emitters in the world. We examine the influence of existing Indian regulations on several aspects of the MC and highlight those areas that should be prioritized in future actions combating mercury pollution in India. India has elaborate regulations on several important aspects of the MC, yet their implementation and enforcement remain weak. To change the current situation, it is necessary to develop programs that systematically track mercury consumption, within-country trade, and emissions, monitor environment and human exposure to mercury, and reconcile the mercury management agenda and actions with national development plans in India. India needs to prepare, and timely provide to the secretariat of the convention, the National Action Plan (NAP) with a special focus on managing mercury emissions and releases as described in the Articles 8 and 9 of the MC. Overall, effectively implementing the MC in India will result not only in curbing mercury pollution, but also help in progress towards related Sustainable Development Goals.

Keywords: Mercury pollution, Minamata Convention, Indian policy, Human health, Implementation program

Background

The Minamata Convention (MC) on mercury, which entered into force on August 16, 2017, is a global treaty that aims to protect human health and the environment from anthropogenic emissions of mercury and its compounds [1]. The MC recognizes mercury as a pollutant of global concern considering mercury to be capable of long-range transport, to be persistent, and to bioaccumulate, which ultimately results in elevated human exposure levels associated with a range of negative health effects [1, 2]. The success of the MC in controlling mercury pollution largely depends on several factors (usually complementing each other) such as support from the scientific research and information, efficiency of the adopted and existing legislations at national level (in particular to reduce mercury import, export and uses), development and implementation of strategies and programs identifying and protecting the populations at serious risk of mercury exposure, scientific and political coherence between developing and developed countries, etc. [3–5]. Many of these factors are often overlooked in developing countries and countries with economy in transition and consequently the implementation of multilateral pollution management treaties like the MC might become a challenge [4, 6]. Recent review studies suggest that the mercury exposure levels in the human population in developing regions have not significantly declined during the last several decades [7, 8]. Importantly, some

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developing countries, such as India and China, contribute significantly to global mercury supply, trade, and anthropogenic emissions [9, 10]. Owing to the rapid economic development in recent decades, India is among the world's top emitters of anthropogenic mercury to the atmosphere, with projections of its continuous significant contributions to the global mercury emissions even in the future [11]. To minimize India's contribution to global mercury pollution, it signed the MC on 30 September 2014 and ratified it on 18 June 2018. To better support the socio-economic ambitions of the country and in parallel to fulfill the commitments towards the MC, it is essential to timely identify important challenges and opportunities that may emerge in the process of the implementation of the MC in India.

Overview of mercury consumption, emission, and exposure in India

India does not geologically extract mercury and its commercial mercury demands are completely met through import [12]; Fig. 1a depicts India's import of mercury and its compounds during the last two decades. Among different mercury consuming sectors, over the last several years, mercury demand for chlor-alkali production has declined globally including in India due to regulatory restrictions and/or technological improvements, whereas the mercury consumption in sectors such as vinyl chloride monomer production and artisanal and small-scale gold mining (ASGM) has increased [9]. Compared to several sub-Saharan African, East and Southeast Asian, and South American countries that are known for extensive ASGM activities, the mercury consumption in the ASGM sector in India is low. A global report estimated that an average of 1.5 tonnes Hg/year is consumed in the ASGM sector in India [10]. These estimates were, however, four times lower than the estimates of another study which claimed that about 6–8 tonnes Hg/year can be roughly accounted for the ASGM activities in India and an equal or higher amount must be accounted for use in jewelry shops in the vicinity of the artisanal gold mining clusters [13]. In addition to ASGM, the important sectors of major consumption of mercury in India are the manufacturing of healthcare instruments and products (including thermometers, dental amalgam fillings, pharmaceuticals, traditional medicines, etc.), electronics and lighting equipment, fungicides, paints, cosmetics, etc.; nevertheless, exact figures of sector-wise comprehensive mercury consumption data in India are not available for any of these sectors. The available estimates of mercury consumption in some of these sectors are presented in Fig. 1b [14]. A close proxy to the sector-wise mercury (and its products) consumption could be the corresponding sector-wise estimated mercury emissions in India (Fig. 1c). Globally, India is the second-largest mercury emitter to the environment with estimated emissions of 144.7 tonnes Hg/year [10]. Coal burning contributes the highest to the mercury emissions in India, 89.4 tonnes Hg/year. It is followed by industrial sectors such as non-ferrous metal production (contributing 22.5 tonnes Hg/year) and cement production (contributing 13.4 tonnes Hg/year). Compared to these sectors, estimated mercury emissions from other industries including ferrous metal production (1.9 tonnes Hg/year), chlor-alkali production (0.94 tonnes Hg/year), etc., were found lower. Apart from the manufacturing industries, another major contributor of mercury emissions in India is the waste of electronic and healthcare products, accounting for 13.6 tonnes Hg/year [10]. This is not surprising considering the current

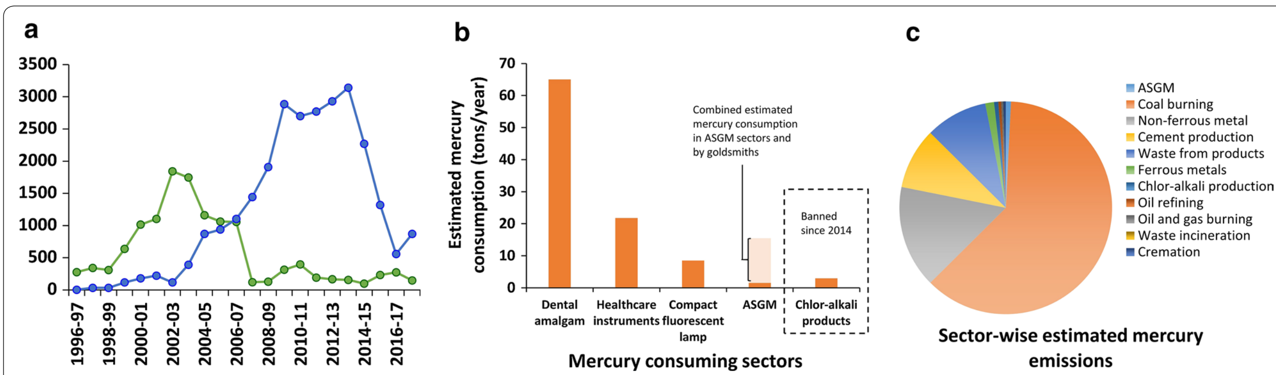

Fig. 1 Mercury trade, consumption, and emissions in India. **a** Import of mercury and its compounds, and items containing mercury in India during the last two decades (according to the data available from the Ministry of Commerce and Industry, Department of Commerce, Government of India). Green: total import of mercury and its compounds (in tonnes); blue line: total import of vapor lamps containing mercury (in thousands). **b** Estimated mercury consumption in different sectors in India. There are two different values of estimated consumption of mercury in the ASGM sector, the one displayed in dark orange is from the study conducted by AMAP/UNEP and the other displayed in light orange color is from the study by Deb, 2016 [10, 13]. **c** Proportion of sector-wise estimated mercury emissions in India

system and in-place capacity to manage wastes in India [15]. Recent research has demostrated the release of mercury (and other chemical pollutants) to the environment in the vicinity of waste treatment and disposal sites at several locations in India [16–22]. Along with this, mercury exposure levels in the Indian population are a reliable reflection of point-source mercury emissions to the Indian environment. Recent studies from India show that blood-, urine-, and breast milk-mercury levels in people working in or living close to an integrated steel plant were up to 30 times higher than those from control areas [23–25]. Similarly, people (including children and women in child-bearing age) living in an Indian city with active coal-fired power plants had higher hair-mercury levels than those in cities with no major mercury point-source [26]. Considering the fact that 34% the of Indian population resides in urban areas [27], it is expected that the number of people living around and working close to such mercury point-sources could be in the millions including a substantial number of vulnerable populations. These vulnerable populations are often children and women working as rag-pickers or waste segregators, families of industrial workers residing close to industrial units, or indigenous/tribal people living in regions exploited for mineral mining and processing industries [28–32].

Regulations relevant to mercury pollution management in India

Prior to the entry-into-force of the MC, India had implemented several environmental regulations (the term "regulation" is used here in a generic sense to include different regulatory instruments such as statutes, rules, and regulations) which focus on various kinds of pollutants including those specified in several MEAs such as the Rotterdam, Basel, and Stockholm Conventions. Unlike the pollutant-specific MEAs and their management strategies, Indian environmental regulations have broad scopes and coverages and usually their implementations and action plans focus on the overall problem of the environmental pollution management instead of managing a single specific pollutant such as mercury in the MC. In such a regulatory set-up, implementation of action plans to manage a specific chemical pollutant or a group of pollutants [such as Persistent Organic Pollutants (POPs)] becomes challenging due to absence of dedicated management strategies and their adequate surveillance. Nevertheless, the wide coverage of existing Indian environmental regulations is relevant to the successful implementation of various mercury management actions specified in the MC. At this initial stage of the MC's implementation, it is crucial that coherence between Indian regulations and the substantive obligations of the MC is established. For this purpose, in this section we summarize existing Indian environmental regulations as well as their context and relevance to the implementation of the MC in India.

The existing Indian environmental regulations that are relevant to the MC can be categorized based on their role in managing: (i) consumption and emission of mercury and its compounds; (ii) supply and trade of products containing mercury and its compounds; (iii) waste containing mercury and its compounds; (iv) manufacturing processes in which mercury and its compounds are used; (v) ASGM activities; (vi) rights of vulnerable populations including tribal communities affected by the activities involving mercury and its compounds; (vii) safety of workers handling mercury and its compounds, etc. In regard to these important aspects of mercury management, a summary of relevant Indian regulations is presented in Table 1.

The MC follows the structure of the Basel, Rotterdam, and Stockholm Conventions and sets out similar basic substantive obligations for parties to manage mercury pollution, while providing some differentiation and flexibility in specific substantive provisions, as well as provisions to mobilize financial resources, within their capabilities, for implementation in developing countries. The similarities among these multilateral agreements (Basel, Rotterdam, and Stockholm Conventions vs. Minamata Convention) exist in terms of activities pertaining to mercury wastes, environmentally sound interim storage of mercury, financial resources, awareness-raising and technical assistance including regional centers, etc. [4]. India is a party to all these conventions and their enforcement in India has led to formulating and amending several important environmental regulations to manage pollution threats from a variety of hazardous substances, for example POPs [33]. However, the implementation of these MEAs in India has not been really effective, which is clearly evident from the fact that the Indian environment and human population is highly exposed to pollutants listed in these MEAs [34]. The lack of comprehensive information and effective management strategies, under-enforcement of existing regulations, and flaws in governing structure impede the actions supporting effective implementation of these MEAs in India [33, 35].

One of the most relevant articles of the MC to the Indian situation is Article 8, which recommends controlling and, where feasible, reducing emissions of mercury and its compounds to the atmosphere. The article also obliges the parties to the convention to prepare and implement a national action plan (NAP) for managing mercury emissions, as soon as practicable but no later than 10 years after the entry-into-force of the MC. The

Table 1 Important Indian regulations corresponding to some of the Articles of the Minamata Convention on Mercury

Article of Minamata Convention	Overall scope of the Article	Related Indian regulations
Article 3: mercury supply sources and trade	Obligations to prohibit new primary mercury mining activity, to identify stocks (and supply sources) of mercury or mercury compounds, related to decommissioning of chlor-alkali facilities and management of related mercury, to prohibit export and import of mercury	The Mines Act, 1952; the Mines and Minerals (Development and Regulation) Act, 1957; the Factories Act, 1948; the Manufacture, Storage and Import of Hazardous Chemical Rules, 1989, 1994, 2000; the Hazardous and Other Wastes (Management, Handling and Transboundary Movement) Rules, 2016; the Foreign Trade (Development and Regulation) Act, 1992; the Customs Act, 1962
Article 4: mercury-added products	Obligations to prohibit manufacture, import or export of mercury-added products, to implement different measures or strategies to address products listed in Part I of the Annex A	The Factories Act and Rules, 1948; the Foreign Trade (Development and Regulation) Act, 1992; the Customs Act, 1962
Article 5: manufacturing processes in which mercury or mercury compounds are used	Obligations to prohibit and restrict use of mercury and its compounds in manufacturing processes listed in Part I and II of Annex B	The Manufacture, Storage and Import of Hazardous Chemical Rules, 1989, 1994, 2000; the Drugs and Cosmetics Act, 1940
Article 7: artisanal and small-scale gold mining	Obligations to take steps to reduce and/or eliminate the use of mercury and its compounds in ASGM activities	The Indian Mines Act, 1952; the Mines and Minerals (Development and Regulation) Act, 1957
Article 8: emissions	Obligations to control and/or reduce emissions of mercury and its compounds to the atmosphere from the relevant point sources	The Air (Prevention and Control of Pollution) Act, 1981; the Environment (Protection) Act, 1986
Article 9: releases	Obligations to control and/or reduce releases of mercury and mercury compounds to land and water from the relevant point sources	The Water (Prevention and Control of Pollution) Act, 1974; the Environment (Protection) Act, 1986
Article 10: environmentally sound interim storage of mercury, other than waste mercury	Obligations to insure environmentally sound interim storage of mercury and mercury compounds as defined in Article 3 and do not fall within the category of mercury wastes as defined in Article 11	The Manufacture, Storage and Import of Hazardous Chemical Rules, 1989, 1994, 2000
Article 11: mercury wastes	Obligations to take appropriate measures to manage (in environmentally sound manner) waste containing mercury and its compounds	The Hazardous and Other Wastes (Management, Handling and Transboundary Movement) Rules, 2016; the Bio-Medical Waste (Management and Handling) Rules, 2016; the Municipal Solid Waste (Management and Handling) Rules, 2016; the E-waste (Management and Handling) Rules, 2016
Article 12: contaminated sites	Obligations to develop appropriate strategies for identifying and assessing sites contaminated by mercury or its compounds. (Does not include obligations for remediations of such mercury contaminated sites)	The Hazardous and Other Wastes (Management, Handling and Transboundary Movement) Rules, 2016; the Environment (Protection) Act, 1986
Article 16: health aspects	To promote the development and implementation of strategies and programmes to identify and protect populations at risk, particularly vulnerable populations	The Factories Act, 1948; the Mines Act, 1952; the Municipal Solid Waste (Management and Handling) Rules, 2016; the Chemical Accidents (Emergency Planning, Preparedness, and Response) Rules, 1996; the Public Liability Insurance Act, 1991; the Prevention of Food Adulteration Act, 1954; the Food Safety and Standards Act, 2006

NAP interventions for mercury pollution management and control, depending on the national circumstances, include establishing a coordinating mechanism and organization process; developing a national overview of the ASGM sector (including baseline estimates of mercury use and practices); setting goals, national objectives and reduction targets; formulating an implementation plan; and developing an evaluation mechanism for the NAP [36]. To do so, some of the suggested measures are to control emissions from point sources such as coal-fired power plants, coal-fired industrial boilers, smelting and roasting processes used in the production of non-ferrous metals, waste incineration facilities, and cement clinker production facilities. In fact, these are the major sources of mercury emissions in India and account for more than 50% of the total mercury emissions to the environment. If effectively implemented, the already existing relevant Indian regulations will play an important role in reducing such large mercury emissions. The Air (Prevention and Control of Pollution) Act, 1981, in India confers and assigns power and functions to Pollution Control Boards (at the National and State level) for the prevention, control, and abatement of air pollution. Under the provisions of this Act, the Central Pollution Control Board (CPCB) sets national ambient air quality standards and is responsible for both testing air quality and assisting the government in policy implementation to meet set standards. In addition to the Air Act, the Environment (Protection) Act, 1986, in India serves as an umbrella act for a variety of environmental issues and empowers the central government to establish authorities charged with the mandate of preventing environmental pollution in all its forms and tackle specific environmental problems nationwide [37]. Article 9 of the MC concerns controlling and reducing the release of mercury and its compounds to land and water. The relevant Indian regulation to manage and control mercury released to the water resources in India is the Water (Prevention and Control of pollution) Act, 1974. This regulation aims to prevent and control water pollution in any form and to maintain/restore wholesomeness of water in India by establishing Pollution Control Boards at the National and State levels which monitor and enforce policies and water quality standards in this regard.

Mercury release from wastes (industrial, municipal, electronics and electrical equipment, and biomedical) is a prominent issue in rapidly transiting economies like India which requires a well-structured and modern waste management capacity as well as regulations. The primary regulation related to the management of hazardous wastes (generated during the manufacturing processes of the commercial products such as petroleum, paints, pharmaceuticals, electronics, etc.) in India is the Hazardous and Other Wastes (Management, Handling and Transboundary Movement) Rules, 2016. This regulation defines hazardous wastes based on their characteristics, generation processes, and quantity. Within the scope of this regulation, mercury is listed among hazardous wastes generated in one of the listed 36 industrial processes. Some of the components of this regulation related to transboundary movement of hazardous wastes and their disposal are in line with India's commitment to the Basel Convention that lists mercury waste among hazardous wastes prohibited either for import and export or import only with a prior-informed consent by the responsible authorities. In addition, this regulation also lists mercury-containing waste in the list of hazardous wastes which require registration for recycling/reprocessing. The regulation also describes the responsibilities of the waste generator for the handling of hazardous waste and procedures for the management of waste generated. Moreover, it also specifies the guidelines for identifying the contaminated sites where discharge of any environmental pollutant in excess of the prescribed standards occurs or is apprehended to occur due to any accident or other unforeseen act or event [38]. Identification of contaminated sites using appropriate strategies by the signatory parties is advised in Article 12 of the MC. Another regulation which is related to mercury waste management in India and seems aligned to Article 11 of the MC is the Municipal Solid Waste (Management and Handling) Rules, 2016, which shall apply to every municipal authority responsible for collection, segregation, storage, transportation, processing, and disposal of municipal solid wastes (MSWs). In relation to mercury pollution, this regulation provides specifications for the landfill sites in terms of groundwater quality, which should be periodically monitored to ensure that there is no contamination beyond the acceptable limits decided by the National/State pollution control boards or committees. A regulation important from the point of mercury waste management is the Bio-Medical Waste (Management and Handling) Rules 2016, which include 17 rules related to duties of a person having administrative control over the institution and the premises generating bio-medical waste; they also include rules that specify the responsibilities of concerned authorities and guidelines for various stages of bio-medical waste management. The E-waste (Management and Handling) Rules, 2016, another regulation related to mercury waste management in India, describes the responsibilities of e-waste producers, dealers, collection centers, refurbishers, dismantlers, recyclers, auctioneers and bulk consumers involved in the manufacturing, sales, purchasing and processing of electrical and electronic equipment or components as described in one of its Schedules [39].

The MC, in addition to controlling and managing mercury pollution from point sources, also obliges parties to take necessary steps to ensure the control and restriction in trade of mercury and mercury products such as compact fluorescent lamps, thermometers, dental amalgams, etc. Concerning the trade of mercury and its compounds, which is under the obligations of Articles 3 and 4 of the MC, India's Foreign Trade (Development and Regulation) Act, 1992, and the Export Import policy (or Foreign Trade Policy; EXIM Policy 2015–2020) provide relevant guidance and procedures. The export policy only allows unhindered and free export of the goods that are not listed in the categories (specified by the ITC-HS) of restricted and prohibited goods and goods for exclusive trading through State Trading Enterprises. In addition, under the Customs Act, 1962, any imported or exported good can be subjected to chemical or other tests for the purpose of assessment of further decision on importation or exportation of the good. The import of mercury-based agro-chemicals is prohibited in India under the Central Insecticides Act, 1968, which regulates the import, manufacture, sale transport, distribution, and use of insecticides to prevent risk to humans.

The primary objective of the MC is to protect human health from mercury pollution. Article 16 of the MC encourages parties to promote the development and implementation of strategies and programs to identify and to protect populations at risk from mercury pollution. Indian regulations that can be linked to Article 16 do not necessarily identify the populations at risk, but they mostly regulate the safety of the human population in terms of either dietary exposure or occupational exposure. For example, the Prevention of Food Adulteration Act, 1954, seeks to prevent the adulteration of any article used as food or drinks for human consumption excluding drugs and water. In addition, the Food Safety and Standards Act, 2006, consolidates the laws relating to establishing food safety standards to regulate manufacturing, storage, distribution, sale, and import of food items. According to this regulation, the maximum acceptable quantity of mercury in fish and other food items is 0.5 ppm (by weight) and 1.0 ppm (by weight), respectively, whereas the acceptable quantity of methylmercury (a more toxic form of mercury) in all food items is 0.25 ppm (by weight).

Concerning the occupational exposure, the Factories Act, 1948, and the Mines Act, 1952, have provisions to ensure the health, safety, and welfare of all workers while they are at work. These regulations include provisions for arrangements to ensure safety and absence of risk to health in connection with use, handling, storage, and transport of articles and substances, as well as provisions to provide information, instructions, training, and supervisions to workers to ensure their safety and health. The description of occupational safety has been also advocated in regulations which are related to waste management, such as the Municipal Solid Wastes (Management and Handling) Rules, 2016, which specifies the safety provisions including periodic health inspections of workers at the landfill sites.

To safeguard the health of the general public from chemical accidents, following the recommendations of the Chemical Accidents (Emergency Planning, Preparedness, and Response) Rules, 1996, Crisis Groups at the National, State, District, and local levels have been formed in India. Some of the important functions of these groups are to provide expert guidance for handling major chemical accidents, to monitor the post-accident situation, etc. The Public Liability Insurance Act, 1991, a regulation which plays a role in the aftermath of a chemical disaster, provides relief (mostly in financial forms) to the victims of chemical disasters due to handling of hazardous substances and obliges the industry/factory owner to obtain a Public Liability Insurance Act Policy before they commence to handle any hazardous substance.

To support India's obligations under Articles 3 and 7 of the MC, related to mining activities consuming mercury (for example, the ASGM activities), the Mines Act, 1952, and the Mines and Minerals (Development and Regulation) Act, 1957, in India regulate and manage any type of mining operations through Mining Boards and Committees. These Acts provide provisions that prescribe the duties of the owner to manage mines and mining operations and the health and safety in mines. Although India does not have mercury mines, the role of Indian mining regulations is vital in management and restrictions of mercury usage in ASGM activities which have been reported in many regions of India and have been found responsible for up to 115,000 estimated disability-adjusted life years (DALY) [30, 40]. The effective implementation of Indian mining regulations that are more than a half-century old might need a reassessment so that they would be better aligned with the needs of the MC.

The MC sets out a range of measures related to the management of mercury pollution and of exposure of humans and the environment. It is obvious that not all these measures are covered within the existing national environmental and health regulations. Fundamentally, the existing relevant Indian regulations lack enforcement of a system that clearly identifies the important sources of mercury emissions and release in India. This is evident by the fact that only estimates and no real-time measurements of mercury emissions and releases from various primary and secondary sources are available from India. The same situation exists for the data on trade and consumption of mercury and its compounds in different sectors in India. The availability of such datasets is in fact the foremost necessity in planning the management and mitigation of any environmental crisis. Similarly, environmental and human biomonitoring to map the extent of mercury exposure has not been given enough priority by the executing agencies of various environmental and health regulations. The MC advises to develop mercury-free alternatives in industrial, domestic, and health sectors that are technically and economically feasible, but this is far away from the direct jurisdiction of the Indian regulatory system, which is largely engaged in enforcing laws. At the same time, even if some of the existing national regulations overlap with some of the provisions of the MC, their poor execution does not effectively contribute to the MC's success. The episode of the mercury spill from a thermometer manufacturing unit in Kodaikanal in Southern India in 2001 [41, 42] and how the mercury pollution caused by this episode has been handled is an example that demonstrates the corporate negligence and the inadequacy of management actions that are typical of a developing country [43].

Challenges, opportunities, and the scope of immediate actions in implementing the MC in India

India, as a large low-income developing country and one of the major contributors to global mercury emissions, appears to be a proving ground for the MC's success. To exhibit a strong position internationally and domestically, the coming years are crucial for India in terms of setting up relationships between domestic and international mercury management efforts as well as defining the target areas for further work concerning the management and monitoring of mercury use, trade, stockpiles, emissions, and releases. Moreover, this is an opportunity to harmonize mercury management programs in India with ongoing efforts to implement other global environmental agendas such as the Sustainable Development Goals (SDGs) "towards building an inclusive, sustainable, and resilient future for people and planet" [44]. Mercury management programs in India, if comprehensively designed, can be aligned with actions to implement various SDGs, specifically those related to achieve better health and well-being, clean water, investments in industrial innovations and infrastructure, responsible consumption and production of various industrial products that contain mercury or involve mercury consumption in the manufacturing process, protect life on land and water, gender equality, and climate actions. In this section, we summarize challenges, opportunities and scope of immediate actions in different sectors related to mercury management in India. Adequate arrangements to overcome these challenges and transforming them into opportunities will ultimately lead to informed and knowledge-based actions on the implementation of the MC and help India to successfully meet its obligations under the MC.

Mercury emissions and sources

One of the most challenging issues regarding mercury management in India is to control atmospheric emissions of mercury from coal-burning. Coal-fired power generation still accounts for more than 50% of India's total energy generation capacity [45]. Since 2015, however, a slowdown in the growth of coal-fired power plants has been observed that is accompanied by falling renewable energy cost and steady demand for energy. However, these trends of the last few years do not necessarily indicate a significant decline in energy demands in the near future and of coal consumption in the energy sector, until strict national policies are implemented. The transition from coal-fired energy generation to renewable energy generation is expected to face several constraints as historically there has been a strong economic interest in coal and its downstream industries [45, 46]. Moreover, the uncertainty about future coal consumption (and resulting mercury emissions) is largely attributed to the developmental strategies and choices related to the energy sector that India will make. Overall, the future of India's energy sector is significant for global as well as national mercury management and crucial in determining the success of the MC. Along with coal-fired power plants, cement production, primary production of ferrous and non-ferrous metals, and smelting industries are the relevant sectors responsible for atmospheric mercury emissions. Controlling mercury emissions from these industries is a challenging task considering the fact that the capacity of these industries is dependent on coal combustion, their contribution to Indian economy is substantial, adoption of environmentally friendly technologies is slow, and monitoring of mercury pollution in their surrounding environment is insufficient.

Concerning the management of mercury emissions associated with coal-burning and other sources in India, an important step would be to identify the regions and industries that are leading in atmospheric mercury emission levels. For this purpose, a national strategic mercury monitoring network is needed to be established that could be based on similar schemes and principles as in some of the developed nations, such as the Canadian Air and Precipitation Monitoring Network, European initiatives under the EU Directive 2004/107/EC, the United Kingdom's National Metal Network, etc. [47]. The existing national air quality monitoring program in India, which consists of 731 operating stations in 312 cities, does not include mercury within the list of regularly monitored pollutants and is mostly limited to common/criteria air pollutants [48]. The MC does not oblige the parties (under its Article 8) to necessarily establish mercury monitoring networks. It requires establishment of a NAP in this regard and also the application of Best Available Techniques (BAT) and Best Environmental Practices (BEP). The BAT/BEP guidances are prepared by UN Environment (UNEP) to assist parties in fulfilling their obligation under the MC [49]. The adoption of these BAT/BEP guidances by the existing and new industries contributing to mercury emission/release is quite complex in India, the reasons being the large scale of some industries (for example, the coal-based energy sector), limited coordination between monitoring and implementation of regulations to support the BAT/BEP, and limited capacity and financial resources. This, in fact, is being experienced in implementing BAT/BAP for the Stockholm Convention in India [35], and the approach to the development of BAT/BEP for the MC to control and, where feasible, reduce mercury emissions is quite similar to that for the Stockholm Convention in the case of POPs. To support implementation of BAT/BAP, the existence of a well-planned monitoring network in India is necessary that sets up mercury emission limit values, identifies the non-compliant industries/emitters, maps the populations at risk of mercury exposure, and ultimately supports the development of an inventory of mercury emissions from relevant sources. The availability of a mercury emission inventory will ultimately contribute to developing India's NAP setting out the measures to be taken to control mercury emissions/releases and its expected targets, goals, and outcomes. The mercury monitoring networks will also help in knowledge-based implementation of already existing environmental management regulations in India.

Management of mercury-related waste and contaminated sites

The issue of mercury-containing waste management is as important and challenging as the mercury emissions from large industries. India generates about 5500 tonnes of e-waste per day, of which only 1.5% is recycled [50]. The collection and recycling of e-waste is mostly done by the informal sector, which is largely unorganized and often bypasses the waste management policies and guidelines. In such a situation, it becomes difficult to recover mercury from e-wastes due to improper handling and dismantling of waste by low-cost techniques and poorly skilled workers, ultimately leading to serious environmental burdens and health implications. The environmental imprints of such activities have been shown in a recent study which demonstrates high mercury contamination levels (up to 16 mg/kg) in soils from e-waste dismantling, shredding, and dumping sites in four major Indian cities [22]. Over time, continuous accumulation of pollutants including mercury at such dumping sites turns them into the category of designated contaminated sites. These contaminated sites receive recognition from the Ministry of Environment, Forest and Climate Change (MoEFCC), which initiated projects on the remediation of hazardous waste-contaminated dumpsites in the country with CPCB as an executing agency under the National Clean Energy Fund. One of the challenges in managing and remediating such contaminated sites is in terms of mercury pollution control. The CPCB of India concisely lists severely contaminated sites and provides guidelines for their remediation, but the scope of these guidelines is broad and does not provide specifications for individual pollutants including mercury. In particular, these guidelines and regulations for waste management in India appeared rather ineffective in handling accidents such as the Kodaikanal mercury poisoning. It took around one and half decade to do justice to the affected environment and people impacted by the mercury emissions from the thermometer factory in Kodaikanal in Tamil Nadu: the State Pollution Control Board recommended remediation of the soil at the contaminated site in Kodaikanal, however, concerns were raised about the target remediation standard (20 mg/kg) that was accepted in the process of de-contaminating this site, which is 20 times higher than what would have been required in many developed countries. In addition, former workers of the thermometer factory who were exposed to the toxic mercury vapor were given compensations by the employer in the form of financial support and benefits of long-term health and well-being [43]. This incident typically highlights the corporate negligence regarding pollution management and environmental justice in developing countries like India. The case not only illustrated the lack of coherence between corporations and the regulatory system, but also failed to gain the support of systematic research studies monitoring mercury contamination in the environment and human population residing in this area. Overall, to better manage labeled contaminated sites, it is necessary to upgrade existing guidelines by specifying the baseline conditions (of contamination levels and risks to the environment and the human population) and by providing a systematic scheme to prioritize and remediate the contaminated sites. In addition, a scheme for proper channelization of funds especially for better infrastructure, development and adoption of appropriate technology to remediate the contaminated sites, training facilities for waste-handlers at each level, and developing and implementing strategies to transform the unorganized and informal waste management sector into an organized and formal sector should be well established [51]. This calls for cooperation with developed nations and international agencies in terms of transfer of expertise, technology and policy advisory, providing financial aid, and eliminating double-standards for waste management practices including waste offloading in developing countries. Several incidences of illegal waste inflow to developing countries including India have been reported in the past [52, 53]. The implementation of the MC demands phasing-out of mercury-containing health-care equipment and proper management of bio-medical waste that contains traces of mercury from either disposed health-care instruments or pharmaceuticals and personal care products. In India, the amount of bio-medical wastes generated (an estimate of about 520 tonnes per day in 2016) is by several orders of magnitude smaller than the MSWs and e-wastes [54]. Nevertheless, it is a substantial source of mercury pollution due to the significant use of mercury in healthcare instruments, dentistry, and pharmaceuticals in India. Considering the seriousness of the matter, the MoEFCC of the Government of India amended the bio-medical waste management rules in 2016. However, the amendment is not specially focused on the mercury pollution from bio-medical wastes, but more on the structure and capacity of the existing bio-medical waste management system in India. The new rules have simplified the categorization of the bio-medical wastes and authorization system to improve the coverage, collection, segregation, transport, and disposal of bio-medical waste. In the context of mercury management, the rules do not provide specific strategies for handling mercury-containing bio-medical wastes, for example specification about the standards for mercury emissions at Common Bio-Medical Waste Treatment Facility (CBMWTF) are missing. This leaves a further scope to manage mercury emissions from CBMWTF, ultimately requiring steps to eliminate mercury sources and to adopt alternatives of mercury-based products (including alternate dental fillings) in health care facilities. This is especially relevant for the dental-care facilities in India. It was estimated that in India annually about 66 tonnes of mercury waste can be generated as a result of removal of mercury containing dental fillings [55]. Managing mercury waste from dental-care units requires different approaches for rural and urban settings in India, considering that the rural areas lack awareness of mercury toxicity, modern dental care facilities, and availability of mercury-free alternatives. Moreover, the appropriate handling of bio-medical waste should be carried out by the dental practitioners, which can be achieved through regular monitoring and training programs for practitioners, adequate resource availability for the handling, segregation, collection and disposing of bio-medical waste [56–58].

Mercury inventories and monitoring

The availability of detailed and systematic inventories of mercury supply, trade, and consumption (in any form) would be an important asset for mercury management programs, especially in developing countries [59]. Although the MC does not necessarily oblige its parties to prepare an inventory of mercury trade, supply, or consumption, in the case of India such an inventory would be effective in controlling and managing illegal marketing and use of mercury, its unidentified stockpiles, risk of its accidental releases, and would help reduce the large uncertainties in the estimation of sector-wise mercury emissions and releases. Currently the information on mercury trade in India is limited to mercury import and export, whereas the information on within-country movement of mercury (and its products) among different sectors is missing. The proposed inventory should not be limited to mercury trade, but also focus on mercury (and its compounds) use, stockpiles, and emissions and releases in different sectors. This will also assist in prioritization of sectors with respect to local and regional mercury management actions.

Evaluating the effectiveness of the MC (as required by Article 22) in terms of curbing mercury pollution is an important component to ensure that the Convention meets the objective of protecting human health and environment from mercury pollution. There are several complexities in assessing the changes in mercury concentrations in the environment and humans [60]. This calls for an effectiveness assessment which is based on multiple metrics in the environment and human population that complement each other. The general perception is that mercury is widespread in the Indian environment and causes human exposure through several pathways to the local populations [23–26]. Unfortunately, this perception lacks a solid research ground based on which an accurate evaluation of environmental and human health implications of mercury pollution in India can be done and later used for scientifically informed policy reforms. The effective evaluation of the MC requires contributions from various stakeholders unlike the current situation where the nexus between scientists, policy-makers, and industries is in imbalance. At present, only selected researchers and environmental agencies in the country are accountable for mercury monitoring in the environment and humans in India, whereas the mercury polluting industries usually appear to neglect or sidewalk their share of reporting the environmental damage being done by them. The lack of mercury monitoring in the past has not only contributed to partially obscuring the extent of mercury pollution in India, but also resulted in mismanagement and delayed management of mercury pollution incidents such as the Kodaikanal case.

To protect the human population and the environment from mercury pollution in India, there are several research areas which urgently need systematic and well-planned long-term actions. One important route of mercury exposure in the Indian context is through fish consumption. India is the second largest producer of fish as well as in aquaculture and inland capture fisheries in the world [61]. However, there is no official advisory on mercury-containing species and contaminated coastal zones. There are few studies available from India which demonstrate mercury levels in seafood and inland fish [62, 63], however, communication of such research studies to the local population in rural areas along the coastline of India or in inland regions is often neglected. Demonstration of such studies to locals and, thereby, raising awareness might be one of the effective ways to reduce the exposure of mercury especially to vulnerable populations, particularly children, pregnant women, breast-feeding mothers, and women who intend to become pregnant. Public awareness is not only needed in order to reduce dietary exposure to mercury, but also to minimize its environmental release and exposure through other pathways. For example, mercury emissions and release from e-wastes, healthcare instruments, and pharmaceuticals can be reduced by raising public awareness about proper ways of waste segregation and disposal.

In terms of environmental justice, importance of public awareness on this subject is also crucial for those communities which either live in pristine areas or are exposed to rapid modernization and industrialization in recent years such as some of the indigenous populations in India. It is important to acknowledge that a large number of indigenous communities in India live in some of the locations which are known for heavy industrial activities such as mining, metal smelting, and ASGM [64].

Countrywide systematic mercury monitoring action in India should be initiated by defining appropriate biological and environmental matrices, geographical locations of interests covering the steep gradient of economic status as well as of pollution, and the populations to be monitored. Recently, the World Health Organization (WHO) has published the design of a survey for assessment of prenatal exposure to mercury using human biomonitoring [65]. Such strategies should be applied for biomonitoring in India. The WHO survey protocol addresses the selection of target populations and biological matrix, planning of the survey, recruitment and fieldwork, data management and communication, community involvement strategies and ethical considerations in conducting a large-scale biomonitoring of mercury exposure [65]. One important population group which should be given adequate attention for mercury bio-monitoring is occupationally exposed populations. These include workers handling municipal waste and e-waste, working in manufacturing units of mercury products and other industries which involve mercury uses and release. Mercury bio-monitoring of such groups will help identify those who need immediate attention in terms of medical supervision, training programs, and awareness. A well-planned environment and human bio-monitoring of mercury along with an established inventory of mercury-material flows to keep track of the mercury supply and trade will be crucial for taking scientifically informed actions for mercury management in India.

Conclusions

Successful implementation of the MC in India will be a difficult task in the absence of a balanced interface among research, policy, and economy. Foremost, mercury management action plans need to be developed for selected industries (largely responsible for mercury emissions) along with a national roadmap that facilitates the development of a NAP for the MC, especially to fulfill the obligations under Articles 7, 8, and 9 of the MC. The new mercury management policy developments warrant an update of the existing mercury management regulations and policies for implementing the MC in the country. Further steps that should be taken at the national level include: adopt lessons from international experiences of implementing selected provisions of the MC; provide knowledge-based support to the MC's implementation at the local, regional, and sector level; develop regulatory and policy options for an effective implementation of the MC; capacity building of pollution control boards and government officials, research institutions, and NGOs working on issues related to mercury pollution at National (and State) level; and systematically monitor mercury uses, emissions, and exposure of the environment and humans. This would bring about a paradigm shift in the pollution management in India from a retrospective approach to one based on risk management and policies formulated in the light of scientific knowledge. A sound and effective management of mercury pollution in India would be a complement to ongoing efforts to achieve the SDGs, in particular those focusing on better health outcomes (SDG 3), keeping surface and groundwater bodies clean (SDG 6), protecting marine ecosystem from mercury contamination (SDG 14), and protecting terrestrial ecosystem from mercury contamination (SDG 15). Mercury management in India requires a strong national framework that integrates management efforts with development plans, sustainable business practices, and consumer behavior. Should this integration fail, the complex and interlinked range of hazards and risks of mercury contamination will continue to cause adverse impacts on the environment, human health, and economic development in India. On the other hand, if the MC is successfully implemented in India, its mercury pollution management actions/programs could also be of interest for other developing countries with similar economic status and/or regulatory system. The relevant lessons for other developing countries could be from how India uses its fragmented and over-regulatory system, limited financial and knowledge resources and capacity, and the nexus between policy and development priorities in favor of its mercury pollution management agenda.

Abbreviations

MC: Minamata Convention; MEA: multilateral environmental agreement; ASGM: artisanal and small-scale gold mining; CPCB: Central Pollution Control Board; MSWs: municipal solid wastes; ITC-HS: Indian Trade Clarification Based on Harmonized System; NAP: National Action Plan; BAT: Best Available Techniques; BEP: Best Environmental Practices; ppm: parts per million; DALY: disability-adjusted life years; EU: European Union; EC: European Commission; MoEFCC: Ministry of Environment, Forest and Climate Change; CBMWTF: common bio-medical waste treatment facility; WHO: World Health Organization; SDGs: Sustainable Development Goals; UNEP (UN Environment): United Nations Environment Programme; NGO: Non-Governmental Organization.

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Authors' contributions

BMS initiated and conceptualized the study. All authors made contribution to the development of the content. BMS wrote the first draft of the manuscript. All authors contributed to the writing process. All authors read and approved the final manuscript.

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Competing interests

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