GLOBAL REVIEW OF MERCURY MONITORING NETWORKS

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Disclaimer:

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List of Abbreviations

AMAP	Arctic Monitoring and Assessment Programme
AMNet	Atmospheric Mercury Network (part of National Atmospheric Deposition Program)
APMMN	Asia-Pacific Mercury Monitoring Network
ASGM	Artisanal Small Scale Gold Mining
CAPMoN	Canadian Air and Precipitation Monitoring Network
CDC	US Centre for Disease Control and Prevention
CEM	(Vietnamese) Centre for Environmental Monitoring
CEMP	Coordinated Environmental Monitoring Programme
CETESB	Companhia Ambiental do Estado de Sao Paulo (Environmental Agency of the State of São Paulo)
CHMS	Canadian Health Measures Survey
CIEMAT	(Spanish) Research Centre for Energy, Environment and Technology
CLRTAP	Convention on Long-range Transboundary Air Pollution
CNR	Italian National Research Council
COPHES	Consortium to Perform Human Biomonitoring on a European Scale
DEMO-COPHES	Demonstration of a study to Coordinate and Perform Human biomonitoring on a European Scale
EMEP	European Monitoring and Evaluation Programme
E-PRTR	The European Pollutant Release and Transfer Register
ESB	Environmental Specimen Bank
EU	European Union
FAO	Food and Agriculture Organization
FNBI	(Canadian) Fist Nations Biomonitoring Initiative
FNFNES	(Canadian) First Nations Food, Nutrition and Environment Survey
GBMS	Global Biotic Mercury Synthesis
GEF	Global Environment Facility
GEM	gaseous elemental mercury
GerES	German Environmental Survey
GFC MMP	Global Fish and Community Mercury Monitoring Project
GMOS	Global Mercury Observation System
GOM	gaseous oxidized mercury
HBM	Human Biomonitoring
HELCOM	Helsinki Commission - Baltic Marine Environment Protection Commission
ICES	The International Council for the Exploration of the Sea
ICP Waters	The International Cooperative Program on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes
IESB	International Environmental Specimen Bank
JAMP	Joint Assessment & Monitoring Programme
KONEHS	Korean National Environmental Health Survey
MDN	Mercury Deposition Network (part of National Atmospheric Deposition Program)

MeHg	methylmercury
MIREC	(Canadian) Maternal Infant Research on Environmental Chemicals
NADP	National Atmospheric Deposition Program
NCP	Northern Contaminants Program
NHANES	United States of America National Health and Nutrition Examination Survey
NIES	Japanese National Institute for Environmental Studies
NIER	(Korean) National Institute of Environmental Research
NIMD	National Institute for Minamata Disease
NPI	(Australian) National Pollutant Inventory
OSPAR	"OS" for Oslo and "PAR" for Paris Conventions – mechanism to protect the marine environment of the North-East Atlantic
PBM	particulate-bound mercury
PBMS	(UK's) Predatory Bird Monitoring Scheme
SAICM	Strategic Approach to International Chemicals Management
SOPs	standard operating procedures
UNECE	United Nations Economic Commission for Europe
UN Environment	United Nations Environment
US EPA	United States of America Environmental Protection Agency
WFD	The Water Framework Directive
WHO	World Health Organization

Introduction

Mercury is a naturally occurring chemical element that cannot be destroyed. It is a heavy metal that is released to the environment from natural sources and as a result of human activities. Once it has been released, mercury persists in the environment, cycling between air, land and water. Mercury is highly toxic, especially affecting the nervous system, the brain and the kidney. It is particularly dangerous for children and pregnant women (UNEP/WHO, 2008). People might be exposed to mercury by inhalation of mercury vapors, ingestion, and absorption of mercury through skin. Mercury exists in three main forms: as elemental mercury, inorganic or organic salt. The organic compound – methylmercury (MeHg) – is particularly dangerous as it bio-accumulates in the food chain and thus its poisonous effects are magnified when digested by humans (UNEP/WHO, 2008).

The risks that mercury poses for human health and the environment have been acknowledged by the global community. In 2013, governments adopted the Minamata Convention on Mercury, whose objective is to protect human health and the environment from anthropogenic emissions (to the atmosphere) and releases (to land and water) of mercury and mercury compounds. In order to effectively control and reduce mercury globally, baseline information regarding mercury emission, releases, deposition, distribution and concentrations in humans and in the environment is indispensable. Effective monitoring systems covering all geographical regions and communities at risk are essential to gather meaningful baseline data, set and adjust the targets and limits, and monitor the progress and success of international efforts.

This review compiles and synthesizes available information on existing mercury monitoring networks, including (i) air monitoring, (ii) human biomonitoring, and (iii) biota monitoring. It also seeks to highlight gaps in the coverage and scope of the monitoring networks, in particular in terms of geographical distribution and institutional organization (global, regional, national and local studies). The report also aims to provide a basis for further coordination and cooperation between the various networks. It is expected that the results presented here will contribute to and guide the ongoing efforts to improve the geographical coverage of global mercury monitoring systems, thus allowing for better assessment, baseline data gathering and evaluation of projects aiming to reduce mercury pollution worldwide. It is important to note that the objective of the report is not to assess the quality of the presented monitoring networks or initiatives. Such evaluation is critical and should be performed as a follow-up action. Furthermore, the authors of the report acknowledge the importance of mercury monitoring efforts in other essential media not included here, such as water and soil. The comprehensive review of the monitoring efforts in those media is therefore elements to be included.

The review is being developed within the framework of the Global Environmental Facility (GEF)-funded project "Development of a Plan for Global Monitoring of Human Exposure to and Environmental Concentrations of Mercury". The project is executed by the United Nations Environment (UN Environment) Chemicals and Waste Branch, in close cooperation with the World Health Organization (WHO) and the Italian National Research Council - Institute of Atmospheric Pollution Research (CNR-IIA). In addition, within the framework of the project, a global Mercury Laboratory Databank is being established. The Databank aims to list laboratories from all UN regions capable of identifying and quantifying mercury species in biotic and abiotic samples. Both outputs, the review of the mercury monitoring networks (presented here) and the databank of mercury laboratories will contribute to the objective of the project, i.e. to harmonize approaches for monitoring mercury in humans and the environment, and strengthen the capacity for mercury analysis in humans and the environment to accurately determine their concentrations globally.

Methodology

Approach

The development of the report is being completed in four steps (details provided below):

1. Data collection and classification
    a. Initial screening of the key documents on the subject
    b. Secondary data collection
2. Compilation and evaluation of data
3. Review of the preliminary results and consultations

Data collection and classification

The first and second step towards the compilation of the global review of mercury monitoring networks focused on the identification, collection and classification of available information on the subject.

First, informal discussions with UN Environment staff and the leads of the UN Environment Global Mercury Partnership Area on Fate and Transport (the Biodiversity Research Institute (BRI) and CNR-IIA) led to a preliminary identification of key sources of information and approaches for data collection. The thus identified information and reports were then screened and reviewed.

Second, following the initial screening and assessment of potential sources of information, a collection and review of the vast amount of published and publically available information was undertaken. This was done via (i) references mentioned in reports (based on the initial screenings), (ii) website of partners and other institutions and groups working in the field of mercury monitoring (identified based on initial screening), and (iii) google and google scholar searches for relevant publications and initiatives. The most frequently used search terms were the following: “mercury monitoring in air/biota”, “human-biomonitoring” (or HBM), and “mercury monitoring networks”.

The main sources of information identified via the above steps include the following: (i) reports and websites[1] of scientific institutions, international organizations and NGOs, (ii) peer-reviewed scientific publications, including local studies and initiatives, and (iii) official documents submitted by Governments (including activity report submissions to the Interim Secretariat of Minamata Convention).

In order to collect information on the presence of the national mercury monitoring networks a survey was sent to the Strategic Approach to International Chemicals Management (SAICM) and Minamata Convention focal points. The survey probed whether the network is present in the country, and if so, since when, who has been operating it, and what kind of media are analyzed within the framework of the network. From seventy-six countries that submitted the answers, thirty-two indicated the presence of mercury monitoring network within their territories, five out of which are not included in this review because of incomplete information. The details concerning the national networks are presented in the following chapters.

Compilation and Data evaluation

The collected information was then classified based on the following two main criteria: (i) type of matrix analyzed (air, human or biota), and (ii) scope of the monitoring efforts (global, regional, national or local).

[1] See Annex for detailed information regarding reviewed websites

Next, the information was visualized in order to map the distribution of global mercury monitoring networks as well as to help in the identification of potential gaps and challenges.

In order to arrive at a more qualitative reading of the observation generated through the review, the results were compared against existing baseline information. For example, the distribution of the air monitoring networks was read in light of the geographical distribution of the mercury emissions to the air (on a country by country basis), in order to identify gaps in monitoring activities and networks in those regions with significant emissions of mercury to the air. Likewise, the distributions of human-biomonitoring and biota monitoring networks were compared with the geographical distribution of the major fish consuming populations in order to identify populations at risk and highlight potential needs for additional human-biomonitoring initiatives.

Review of the preliminary results and consultations

An additional step in the data evaluation includes consultations on the preliminary results with recognized experts in the field (based on the initial screening and secondary review) as well as other interested stakeholders, including governments, intergovernmental organizations, the private sector, civil society and academia. For this purpose, a draft has been circulated for comments and additional input. Furthermore, the draft document was presented during different meetings, including a consultation meeting of Fate and Transport partnership area of the UN Environment Global Mercury Partnership, in Portland, where comments received from the participants. All the above-mentioned comments were addressed and, to the extent possible, incorporated in this version of the document.

Challenges and limitations

The report seeks to present available information on the presence of the mercury monitoring networks. Several challenges were encountered in gathering, compiling and analyzing this information, resulting in some noteworthy limitations to the report and its findings.

Firstly, the objective of the report is not to assess the quality of the presented monitoring networks or initiatives. Such evaluation is critical and should be performed as a follow-up action. Secondly, the UN Environment recognizes the importance of mercury monitoring efforts in other media not included in the report, such as water and soil, and highlights the importance of compiling such information in the future.

Furthermore, certain information might have been overlooked due to limited accessibility via publicly available sources, especially in case of national or local monitoring networks and efforts. Moreover, various national and local initiatives could have gone unnoticed. To date, 11 countries and 3 International organizations and NGOs have submitted their activity reports ahead of Seventh session of the Intergovernmental Negotiating Committee on Mercury (INC 7)[2]. In addition, in some countries and regions, mercury monitoring efforts are relatively recent. Therefore, the development of monitoring networks might not yet be well documented. Moreover, certain considerations may render some countries or groups hesitant to undertake monitoring efforts and/or to make collected information publicly available. Finally, it is important to note that the screening and search for the information included in this report was restricted

[2] http://www.mercuryconvention.org/Negotiations/INC7/INC7submissions/tabid/4754/Default.aspx

to the documents and sources available in English, Spanish and French. This limitation likely resulted in an oversight of information available in languages other than those specified above.

PART 1

Atmospheric Monitoring Networks

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Background

Mercury is present in the atmosphere either as gaseous elemental mercury (GEM), gaseous oxidized mercury (GOM, also known as reactive gaseous mercury) or particulate-bound mercury (PBM). GEM is by far the most common mercury species in the atmosphere. It is not water soluble and can be transported over long distances due to its long atmospheric lifetime – ranging from several months to a year (AMAP/UNEP, 2013). GOM has high water solubility and is removed from the air phase by dissolution rapidly at the air-water interface. Due to its higher density, PBM is easily removed from the atmosphere by wet and dry deposition (AMAP/UNEP, 2013).

Although monitoring mercury levels in the air (dry deposition) is essential to understand its fate and transport in the atmosphere, it is information on mercury wet deposition that provides the key contribution. Wet deposition can track mercury input to sensitive ecosystems, where it can be further transformed into bioavailable MeHg, which bio-accumulates in the food chain and results in significant mercury exposure among frequent sea food consumers (AMAP/UNEP, 2013). Thus monitoring of mercury in the precipitates, ocean and sea (at the air-water interface) is of particular importance due to the mercury transformation that occurs in the aquatic environment. In addition, data concerning vertical distribution of mercury in the atmosphere is particularly important for validating chemical transport models and mercury transformation, e.g. oxidation of GEM to GOM. The monitoring networks presented below focus on at least one (or combination of) type of mercury measurements in the atmosphere. The specific information is provided in the sections describing each monitoring network.

Mercury emissions to the atmosphere come from two main sources: natural sources and anthropogenic sources. Natural sources include mercury releases as a result of Earth crust weathering. This constitutes approximately five to thirty percent of total mercury emissions (Corbitt et al., 2011; Pirrone et al., 2009). The remaining emissions to air come from anthropogenic sources, which can be divided into two categories: (i) by-product emissions and (ii) emissions from intentional use of mercury. The biggest by-product source of mercury emissions is the burning of fossil fuel. Coal contains mercury impurities and during the process of burning mercury is released to the air (AMAP/UNEP, 2013). The second category, emissions from intentional use, includes mercury use in artisanal and small-scale gold mining, or ASGM (yielding the highest emissions among all anthropogenic sources), use in industrial and chemical processes and production of mercury-added products.

Initial overview of atmospheric networks

Coordinated monitoring networks have been established in various regions of the world to measure mercury concentrations in ambient air and wet deposition. Europe and Northern America maintain multiple sites, as part of national monitoring networks, that have been monitoring mercury continuously since the 1970´s (AMAP/UNEP, 2013). Based on a result of the initial and secondary screening (see the methodology section for more details), this review comprises several national and 6 global networks actively engaged in atmospheric mercury monitoring. The national networks discussed below include: the Canadian Air and Precipitation Monitoring Network (CAPMoN) together with Environment Canada operated by Environment and Climate Change Canada, Canadian Northern Contaminants Program, Australian National Pollutant Inventory (NPI), the Japanese Agencies, including the National Institute for Minamata Disease (NIMD), the National Institute for Environmental Studies (NIES) and the Ministry of Environment, Korean National institute of Environmental Research (NIER) and Brazilian, Chinese (Taiwan), Vietnamese, UK's, Hungarian, Polish, Andorran, Austrian and Romanian national projects, as well as European Union initiative. The regional and global monitoring networks discussed below include: The Global Mercury Observation System (GMOS), European Monitoring and Evaluation Programme (EMEP), the National Atmospheric Deposition Program (NADP), the Asia-Pacific Mercury Monitoring Network (APMMN), the Arctic Monitoring and Assessment Programme (AMAP), and The European Pollutant Release and Transfer Register (E-PRTR).

National networks

1. The **Canadian** Air and Precipitation Monitoring Network (CAPMoN), operated by Environment and Climate Change Canada, was established in 1983. It is designed to monitor and study atmospheric pollutants, including total gaseous mercury and mercury in precipitation (wet and dry deposition). The monitoring data records reach back to 1978, whereas mercury monitoring initiated in 1996. Currently there are 3 CAPMoN monitoring stations measuring mercury air concentrations (Figure 3). New stations are planned to be developed in the west. Environment and Climate Change Canada operates an additional 7 mercury air monitoring stations outside of CAPMoN. Measurements of mercury in precipitation at 5 CAPMoN sites are contracted out to NADP – MDN (Fig. 3).

   The Canadian Northern Contaminants Program (NCP) measures continuously atmospheric mercury at two remote stations, Alert (Nunavut) since 1995 and Little Fox Lake (Yukon) since 2007. The stations are also part of Arctic Monitoring and Assessment Programme (AMAP). The measurements at the remote locations contribute to the understanding of long-range transport of mercury.

2. The **Australian** National Pollutant inventory (NPI) has been in operation since 1996 and is part of Australian Department of the Environment and Energy[3]. The NPI contains data on 93 substances, including mercury that have been identified as important pollutants due to their possible effect on human health and the environment. The data is derived from facilities including mines, power stations and factories, and from other sources such as households and transport. The mercury emission to air, water and soil are monitored.

3. **Japan** has two national mercury monitoring networks. These are operated by the National Institute for Minamata Disease (NIMD) and the National Institute for Environmental Studies (NIES)/Ministry of Environment (MOE). Monitoring stations are presented in Figure 3. Moreover, MOE collects monthly atmospheric mercury data since 1998 in collaboration with local governments. This data is based on measurements from 281 monitoring stations across Japan[4].

4. In **Republic of Korea**, the National institute of Environmental research (NIER) in the Ministry of Environment operates 12 total gaseous mercury monitoring stations continuously since 2009, located all over the country. Among 12 stations, there are 4 stations which monitor Hg in precipitation and 1 station that measure atmospheric Hg.

5. In 2014, the **Vietnamese** Centre for Environmental Monitoring (CEM) of the Vietnam Environment Administration (VEA) installed a monitoring station capable of measuring mercury wet deposition[5]. The pilot monitoring station is located in No 556 Nguyen Van Cu, Long Bien District, Hanoi. Since October 2014, CEM has collected monthly rain water samples and sent to the lab of National Central University in Taiwan for analysis. Within the APMMN activity, CEM will be provided 3 more samplers for installing in the cities in central and southern of Vietnam. CEM also is designing a network for mercury monitoring in the ambient air in Vietnam. The network is going to be operational in 2017

6. In **China (Taiwan), Taiwanese** Environmental Protection Administration operates a wet Hg deposition monitoring network, consisting of 11 sampling sites all over the main island of Taiwan and a remote islet site in subtropical Northwest Pacific Ocean (Sheu and Lin, 2013). The stations collect weekly rainwater samples for total Hg analysis since 2009. The purpose of this network is to establish a national database of the total Hg concentration in precipitation and the associated wet deposition fluxes, and to develop information on spatial and seasonal trends in wet Hg deposition and to evaluate the contribution of regional/long-range transport.

7. **Brazil** has also undertaken mercury monitoring. CETESB [6](Companhia Ambiental do Estado de Sao Paulo), the environmental agency of the State of São Paulo, undertakes continuous monitoring of various matrices, including water, air, soil, sediment and fish. The data collected is publicly available.

[3] http://www.npi.gov.au/about-npi
[4]http://www.mercuryconvention.org/Portals/11/documents/technicalsubmissions/Japan.pdf
[5]http://www.mercuryconvention.org/Portals/11/documents/technicalsubmissions/Vietnam.pdf
[6] http://www.cetesb.sp.gov.br/2014/10/27/cetesb-realiza-treinamentos-internacionais-sobre-pops-e-mercurio/

8. In **United Kingdom**, National Metals Network monitors the concentrations of metallic elements in air, and the deposition rates at urban, industrial and rural sites. As part of the network measurement of ambient vapor mercury is performed at 2 stations (Runcorn Weston Point and London Westminster)[7]. In addition, Uk's Department for Environment, Food and Rural Affairs operates National Atmospheric Emissions Inventory. The inventory estimates annual pollutant emissions from 1970. To deliver these estimates, the Inventory team collect and analyses information from a wide range of sources – from national energy statistics to data collected from individual industrial plants. As part of the Inventory, mercury estimates are reported since 1984[8].

9. Within the framework of **Hungarian** Air Quality Monitoring Network, atmospheric mercury is monitored in Hungary since 2010. The network is operated by the Hungarian Meteorological Service. The sampling point is situated next to Kecskemét town.

10. The **Polish** State Environmental Monitoring programme was established in June 1991 by the Inspection of Environmental Protection to provide reliable data on the state of the environment[9]. Within the framework of the programme, the system measures, collects, process and disseminates information regarding the state of the environment. As part of this programme, atmospheric mercury is being monitored since 2000 at 5 monitoring stations (Figure 3).

11. In **Andorra**, Department of Environment and Sustainability is operating Andorran Air Quality network that monitor atmospheric mercury since 2011.

12. In **Austria**, the Austrian Federal Research Centre for Forests controls mercury impacts annually in forest foliage on more than 750 plots[10]. This monitoring is a part of the Austrian Bio-Indicator Grid2[11], which has started in 1983. The aim of this program is to identify the impact of air pollutants, to detect the nutrition status and identify nutrient imbalances and to show their temporal and spatial variation in Austria.

13. In **Romania**, Ministry of Environment, NEPA and the National Environmental Guard monitor atmospheric mercury since 2000 in 41 counties of the countries.

14. Moreover, within the **European Union** measurements of total gaseous Hg and bulk deposition of Hg are performed at rural background sites under EU Directive 2004/107/EC (e.g. in Austria in Illmitz).

Regional networks

1. **GMOS**[12] was established in 2010 with financial support by the European Commission. It is coordinated by the Institute of Atmospheric Pollution Research of the National Research Council of Italy (CNR-IIA), and involves over 40 partners from all over the world. GMOS consists of > 40 ground-based (permanent monitoring stations) monitoring sites located in the Northern and Southern Hemispheres,

[7] https://uk-air.defra.gov.uk/networks/network-info?view=metals
[8] http://naei.defra.gov.uk/overview/pollutants?pollutant_id=15
[9] http://www.gios.gov.pl/en/state-of-the-environment/state-environmental-monitoring
[10] http://bfw.ac.at/ws/bin_online.hg
[11] http://bfw.ac.at/rz/bfwcms2.web?dok=3687
[12] http://www.gmos.eu/

and ad-hoc oceanographic campaigns overseas and oceans and promotes tropospheric studies to assess the global distribution of mercury and its compounds.

Figure 1 presents the localization of the GMOS and associated sites.

The **oceanographic campaigns** aim to measure over-water atmospheric, deep water and top-water micro-layer mercury concentrations. Several oceanographic expeditions were conducted over the oceans and regional seas (Figure 2). The monitoring of mercury in the ocean and sea regions (at the air-water interface) is of particular importance due to the mercury transformation that occurs in the aquatic environment. After mercury is deposited in the water, under reducing conditions it transforms into methylmercury that bio-accumulates in the food chain and result in direct mercury exposure among frequent sea food consumers.

The **aircrafts campaigns** were deployed to measure vertical profiles of mercury concentrations and speciation through the troposphere (mid-upper troposphere and lower stratosphere. These vertical profiles have been very useful to modelers to validate regional and global scale models.

In order to assure data comparability Standard Operating Procedures (SOPs) were developed for ambient air mercury monitoring and precipitation by wet scavenging. The SOPs have been implemented at all GMOS sites. A Quality Assurance/Quality Control (QA/QC) system was developed and is available online for all GMOS sites operators. Almost all GMOS stations are providing near-real time raw data that are archived in the GMOS Spatial Data Infrastructure (SDI). A great effort has been made to implement a centralized system, named GMOS-Data Quality Management (G-DQM) able to ensure, control and report the quality of mercury datasets coming from the GMOS network providing reliable and useful globally-based data for both the scientific and policy communities (D'Amore et al., 2015).

2. The European Monitoring and Evaluation Programme (**EMEP**)[13] is a scientifically based and policy driven programme that was established by the Convention on Long-range Transboundary Air Pollution (CLRTAP) that was signed in 1978. The main objective of EMEP is to regularly provide governments and subsidiary bodies under the LRTAP Convention with qualified scientific information on atmospheric pollutants. As part of the network atmospheric mercury is measured since 1990. The operation of EMEP focuses on three main elements: (1) collection of emission data, (2) measurements of air and precipitation quality and (3) modelling of atmospheric transport and deposition of air pollutions. The combination of these components provides a good basis for the evaluation and qualification of the EMEP estimates.

3. The National Atmospheric Deposition Program (**NADP**) was established in 1977 by U.S. Agricultural Experiment Stations to monitor atmospheric deposition and to study its effects on the environment[14].

   NADP provides, among others, long-term records of total mercury concentrations and precipitation in the USA and Canada. It consists of several networks, two of which focus on mercury pollution: The

[13]http://emep.int/index.html
[14] http://nadp.sws.uiuc.edu/mdn/

Mercury Deposition Network (**MDN**), which joined NADP in 1996, delivers information on the role of precipitation as a source of mercury in water bodies. The Atmospheric Mercury Network (AMNet), which joined NADP in 2009, measures atmospheric mercury fractions, which contribute to dry and total mercury deposition.

There are more than 100 MDN stations in the USA and Canada, and over 20 AMNet stations, most of which can be found in North-East USA, Alaska, North-East Canada and Hawaii (Figure 3). All MDN and AMNet sites follow standard operating procedures (SOPs) and have uniform collectors and gauges. Automated wet-deposition collectors and precipitation gauges measure total mercury concentrations and wet deposition. Optional measurements include monitoring of MeHg. MDN and AMNet provide consistent data to researchers, policymakers, and the general public.

4. The Asia-Pacific Mercury Monitoring Network (**APMMN**) was established in 2013 as a partnership between scientific institutions and governments. Scientific experts from the National Central University in Taiwan together with the Indian Institute of Technology in Hyderabad and governmental officials from eight countries agreed to develop a standardized pilot network to monitor wet deposition and atmospheric concentrations of mercury in the region.

   Currently, ten operating monitoring stations exist (Figure 3). Plans to expand the network by additional twenty to thirty stations in the region are being discussed[15]. The structure, scientific principles, SOPs, including for the analysis of samples, and instrumentation used by APMMN are consistent with those developed by NADP.

5. The Arctic Monitoring and Assessment Programme (**AMAP**) was established in 1991 as one of the six Working Groups of the Arctic Council. Its aim is to monitor and assess climate change and pollution issues, including mercury, in the region. AMAP's participating countries include: Canada, Denmark (Greenland and Faroe Islands), Finland, Iceland, Norway, Russian Federation, Sweden, and the United States. AMAP's monitoring program is largely based on the ongoing national and international monitoring initiatives. In order to develop global inventories of mercury emissions to the atmosphere, AMAP has collaborated with a number of partners, including the Norwegian Institute for Air Research and the Arctic Centre, University of Groningen. In 2005, AMAP started a collaboration with UN ENVIRONMENT on the development of global mercury emission inventories[16].

   The main areas of focus include the following: air monitoring (six monitoring stations), monitoring of mercury levels in arctic wildlife, and modelling of long-range transport of mercury to the Arctic from global sources.

6. The European Pollutant Release and Transfer Register (**E-PRTR**) is the Europe-wide register that provides easily accessible key environmental data, including measurement of mercury releases to the air, water and soil as well as off-site transfers of waste, from industrial facilities in European Union Member States and in Iceland, Liechtenstein, Norway, Serbia and Switzerland. The database contains

[15] http://rsm2.atm.ncu.edu.tw/apmmn/AboutAPMMN.html
[16] http://www.amap.no/mercury-emissions

data reported annually by over 30,000 industrial facilities across Europe[17]. The information in the database is publicly available and undergoes verification by The European Environment Agency. The information is compared with (i) the data reported under the Convention of Long Range Transboundary Air pollution, United Nation Framework Convention on Climate Change and EU Emission Trading Scheme (for releases to Air), (ii) with data reported to Eurostat and EEA (for waste data and transboundary movement of waste), (iii) with data reported to EEA and (iv) to the Water Information System of Europe WISE (for release to Water).

Distribution of monitoring networks

Figure 3 shows the geographic distribution of atmospheric mercury monitoring stations operated by the majority of above discussed monitoring networks. A to the information gathered as part of this review, the distribution of monitoring activities and networks is imbalanced across regions. Three clusters can be identified: North America, Europe and East Asia region.

In North America, a high number of monitoring stations are operated by the USA and Canada (national networks and regional networks including: NADP and CAPMoN. Env. Canada). The high number of monitoring stations might be a result of the long period of operation for both networks (NADP operates since 1977, CAPMoN since 1996). Notwithstanding, even in this well-covered region, some imbalances can be observed. The eastern part of the United States is slightly better covered than the central, southern and western regions. Similarly the south-eastern region of Canada, which is characterized by the high density of population and more significant emission sources, has the best coverage, while coverage in the northern territories and Mexico is slightly weaker.

In Europe, atmospheric mercury is monitored by European Union (EU) Member States building on the existing national air quality monitoring stations. In total, there are more than 8000 stations across the EU[18]. There is also a significant number of GMOS stations in central, southern (mainly Italy) and northern territories (Scandinavia and the United Kingdom/Ireland), including the Arctic. Combined, the European region has a high coverage of monitoring stations compared with other regions.

In Eastern Asia, Japan and Taiwan (China), have a high coverage of the mercury monitoring stations compared to other countries in the region. Individual monitoring stations, which are part of APMMN, operate in Japan, Republic of Korea, Vietnam, Thailand, the Philippines and Indonesia. Although overall the coverage in this region seems lower than in Europe and North America, joint efforts to establish a uniform monitoring network based on national systems in the region are ongoing. Additional stations are under development. These will contribute to enhanced monitoring capacity in the region in the coming years[19].

A global effort to establish a coordinated and harmonized worldwide atmospheric mercury monitoring network within the framework of GMOS triggered the establishment of monitoring stations and the

[17] http://prtr.ec.europa.eu/#/home

[18] http://www.eea.europa.eu/data-and-maps/data/airbase-the-european-air-quality-database-8#tab-figures-proapterduced,

[19] http://rsm2.atm.ncu.edu.tw/apmmn/AboutAPMMN.html

generation of data in regions that previously had little capacity to measure mercury concentrations in the atmosphere. Within the framework of GMOS, there are six monitoring stations in Latin America and Caribbean, three in Africa, six in Central and South Asia and three in Antarctica. Moreover, the monitoring stations operated by AMAP cover the Artic region.

Gaps

In agreement with the objective of this study that aims to present the overview of monitoring networks, the quality assessment of the networks is not covered here and should be evaluated in a separate study. Moreover, the limited accessibility of the publicly available sources and language limitation of the search (limited to English, Spanish and French) likely resulted in an oversight of certain information.

When comparing estimated levels of global mercury emissions (Figure 4) with the coverage in atmospheric mercury monitoring stations identified in this review (Figure 3), it becomes evident that a large share of the countries with emissions at the high end of the range have monitoring coverage at the low end of the range. The US is a notable exception. In particular, the Asian region has relatively fewer monitoring activities, while accounting for relatively high emissions (with an exception for Japan and Taiwan in China). The African region is also equipped with little coverage, lacking national and international monitoring networks in most parts of the continent. Again, some of the countries with the highest emissions have the least monitoring initiatives. Overall, however, the African region has relatively low levels of emissions. South American countries that emit high amounts of mercury as a result of ASGM operations also lack regional and national monitoring networks (with the exception of four GMOS stations and the Brazilian national network).

As mercury can travel long distances in the atmosphere before it is transformed and bio-accumulated in the animal and human tissues, it is important to monitor mercury concentrations in distance of point sources of emissions To some extent international networks addressed this by undertaking atmospheric mercury measurements in Antarctica and the Arctic (as part of the GMOS and AMAP networks).

In order to further improve our understanding of the fate of atmospheric mercury, it may be advisable to establish additional monitoring stations as part of existing networks, or establish new national networks, in particular in Africa, Asia and Latin America and Caribbean. Such efforts could take into considerations whether national meteorological networks capable of monitoring air quality exist. In such cases, the focus could be placed on collaboration and updating relevant SOPs to ensure consistency with the international procedures and requirements, as that developed and adopted by GMOS partners. If existing air monitoring stations do not have the capacity to measure mercury, technical upgrades may have to be considered. Modeling and estimations can be another tool to determine levels of atmospheric mercury pollution. Where feasible, an accurate model may need to be developed (similar to AMAP's Artic region models[20]) to close knowledge gaps on atmospheric mercury concentration and global transport. However, in order to produce reliable models and predictions, sufficient experimental data has to be collected and contrasted

[20] http://www.amap.no/mercury-emissions

with the model. Ensuring that sufficient atmospheric mercury monitoring networks are operational is therefore an ongoing challenge for the future.

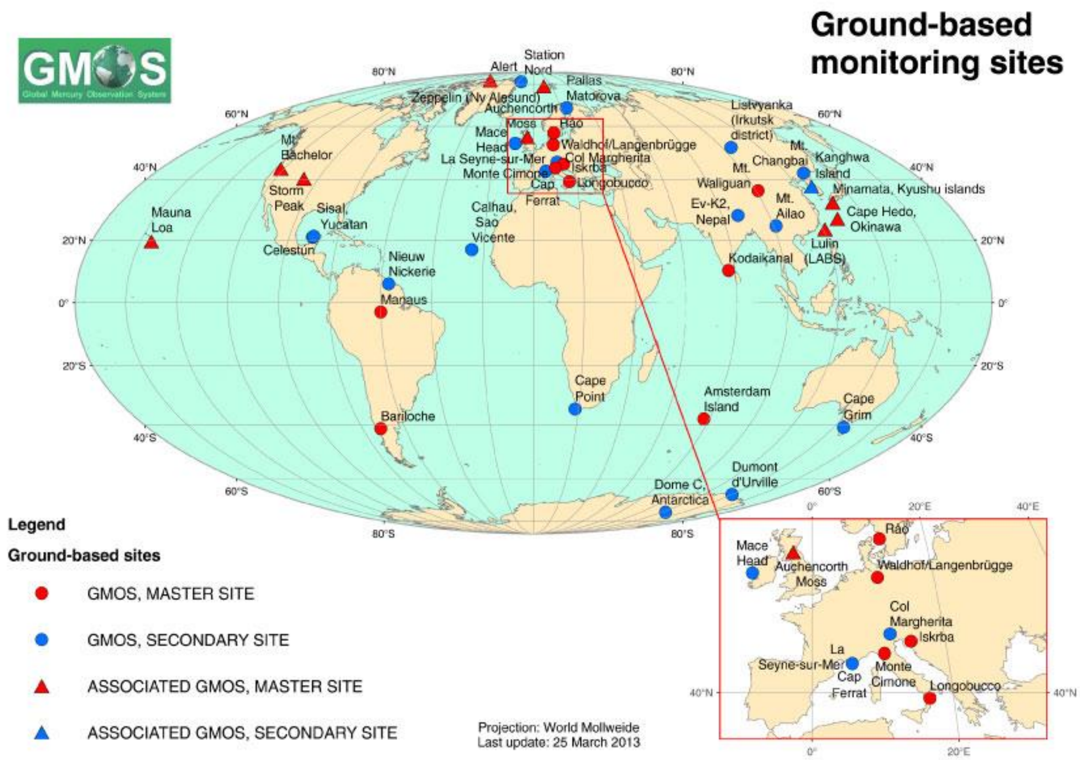

Figure 1. Global Mercury Observation System (GMOS) and GMOS-associated ground-based monitoring sites. (source: http://www.gmos.eu/)

Figure 2. GMOS Aircraft and marine monitoring campaigns (source: http://www.gmos.eu/

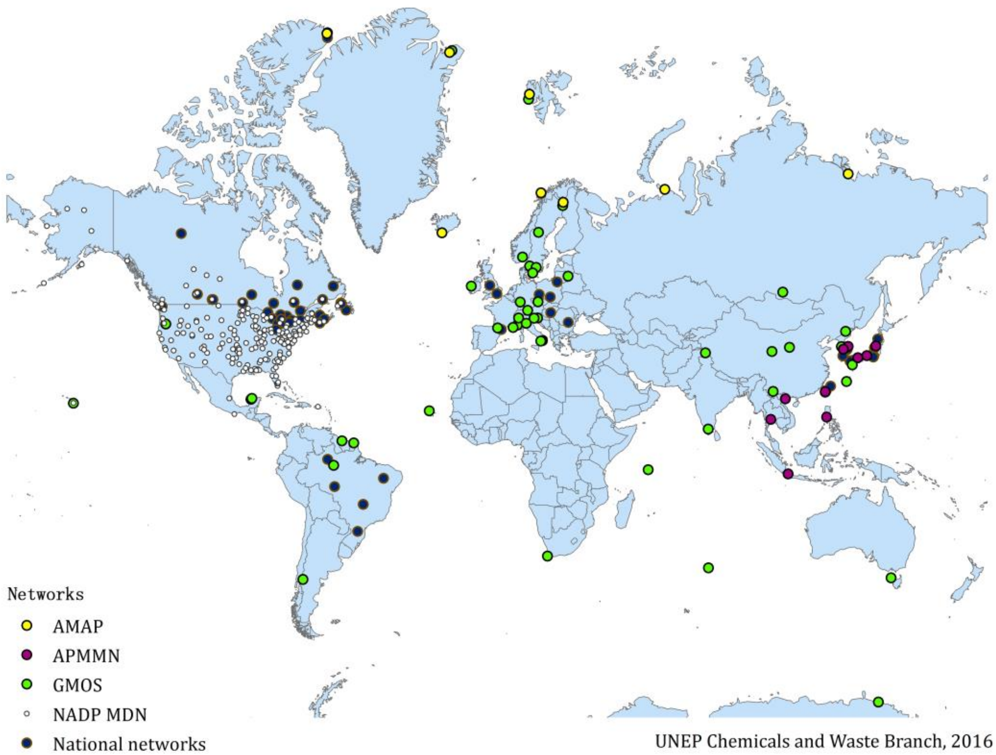

Figure 3. Location of atmospheric mercury monitoring stations from the networks identified in this report

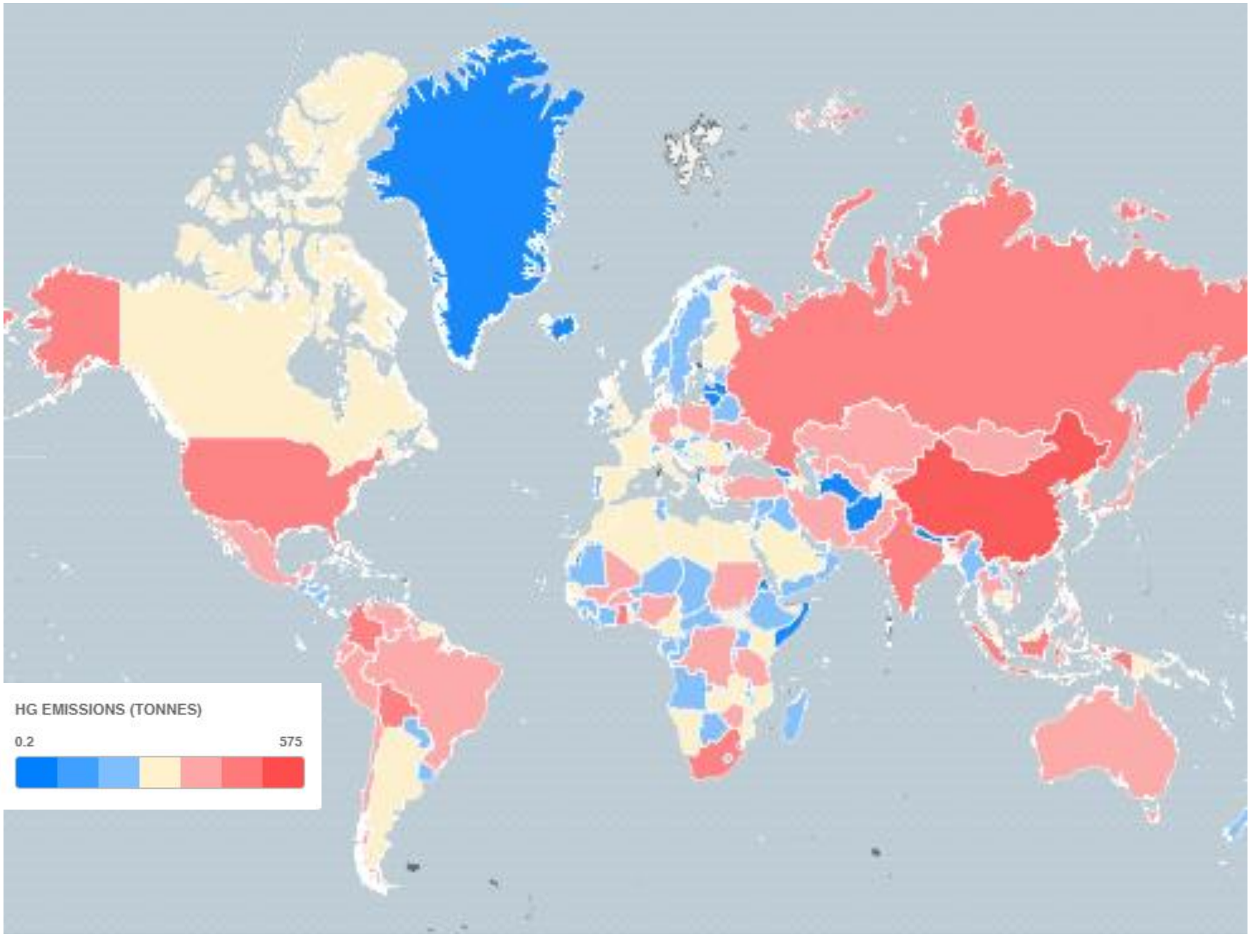

Figure 4 . Global mercury emissions by country (in tons) (data source: UNEP, Technical Background Report for the Global Mercury Assessment 2013)

PART 2

Human Biomonitoring Networks

Photo credits: Usman Tariq

Background

Mercury is a toxic and persistent chemical that accumulates in the food chain. The majority of populations has at least trace amount of mercury in their tissues. Generally, low exposure does not have significant adverse effect on human health (Ha et al., 2016; Schober SE et al., 2003; US Center for Disease Control and Prevention (CDC), 2005). However, new study indicated that there is a possibility that the methylmercury at low exposure levels might affect fetal and infant growth among susceptible sub-groups (Karagas et al., 2012). The intensification of the exposure to mercury, either medium level exposure over a long time or high level exposure over a short time, results in increased accumulation of the poisonous metal in the body, which may lead to various health complications (UNEP/WHO, 2008). At the individuals level symptoms might include: tremors, nervousness, neuromuscular changes, headaches, and at higher concentration kidney, lungs and thyroid dysfunction, changes in vision and deafness. Inorganic mercury compounds affect directly internal organs, for example kidneys (UNEP/WHO, 2008).

People are exposed to mercury mainly through consumption of methylmercury accumulated in seafood and fish, and ingestion or inhalation of elemental or inorganic mercury mainly through occupational exposure. Fish and other marine species are an important, nutritious and beneficial component of the human diet. Due to the bioaccumulation of mercury along the food web, the higher the trophic level, the higher the concentration of mercury in the marine species. Older and/or larger predators (e.g. king mackerel, shark or tuna) and fish consuming mammals (e.g. seal, whale) among other, exhibit increased level of accumulated methylmercury (UNEP, 2002; US Environmental Protection Agency (EPA), 2003).

Methylmercury negatively affects the nervous system, especially during its development phase. Once ingested, methylmercury forms an aggregate with cysteine, which can pass through the blood-brain barrier.

Exposure to metylmercury therefore has particularly adverse effects on pregnant women and their fetus. Children exposed to methylmercury (either during pregnancy or during their early years of development) might have various neurological abnormalities (e.g. delayed onset of walking and talking) that is evident by reduced neurological test scores (Ha et al., 2016; UNEP, 2002). In adults, methylmercury poisoning may result in neurological loss, visual disturbance, impaired hearing, paralysis or death (WHO, 2004).

Occupational exposure may occur during the use of mercury or mercury compounds in certain processes, or the production of mercury-added products. Main areas with an increased risk of exposure include the following: ASGM, primary mercury mining, chlor-alkali plants, industries producing mercury-added products (thermometers, laps, batteries etc.) and dental clinics with poor mercury handling practices (UNEP, 2002). A common significant occupational exposure has been observed in ASGM, where miners burn (often indoors or in open spaces in residential areas) an amalgam of mercury and gold to vaporize mercury and recover gold.

The susceptible population can be dived into those who are more sensitive to the toxic effect of mercury (e.g. fetus), and those who are exposed to higher level of mercury (e.g. ASGM miners), or combination of both (a pregnant women working in the ASGM sector). In order to effectively monitor the mercury level in susceptible populations as well as the general public, it is crucial to choose adequate indicators. The main biomarkers for mercury exposure in humans are: blood, hair and urine, which are efficient indicators for general screening of populations. For more specific screening of populations at risk (e.g. mining community) the choice of indicator has to be carefully adjust to explicit case.

The levels of mercury found in blood indicate current and recent exposure to methylmercury, which, in turn, is correlated with the consumption of fish products contaminated with mercury. Levels of mercury in hair can also be used as an indicator of exposure to methylmercury, which, in turn, is correlated with its levels in the blood. Since mercury cannot return to the blood once it is integrated in the hair, the analysis of hair samples may provide a reliable signal of long-term exposure to methylmercury. In contrast, urine sample generally indicate exposure to inorganic and elemental mercury in kidneys (UNEP/WHO, 2008).

Initial overview of the HBM networks

The following review presents national and international/regional networks as well as local studies identified as part of this review. The report present several national networks operating in Europe, North America, Asia and South America. Three regional network could be identified, namely (i) the international survey component of the Global Fish and Community Mercury Monitoring Project (GFC MMP) (ii) the Demonstration of a study to Coordinate and Perform Human biomonitoring on a European Scale (DEMO-COPHES) and (iii) Arctic Monitoring and Assessment Programme (AMAP). Finally, the review presents over 70 sample local studies monitoring human exposure to mercury at a specific location

National surveys

Various countries, including Austria, Belgium, Czech Republic, France, Germany, Italy, Slovenia, Spain, Sweden and Canada, USA, Republic of Korea, Colombia and Brazil, have undertaken efforts with respect to the human biomonitoring of exposure to mercury. The selected surveys are presented below and depicted in Figure 5. Detailed information is provided for the networks with highest amount of publicly available information.

1. In **Germany**, a survey and a network analyze total mercury content in human blood and urine alongside DEMO-COPHES: The German Environmental Survey (GerES)[21]and the German Environmental Specimen Bank[22] (ESB). Up to 5000 people took part in GerES in five time periods. First GerES took place between 1985 and 1986. The most current one is under execution and targets exposure to mercury (among other chemicals) in adolescents aged 3-17 from more than 160 German cities and municipalities.

2. **Swedish** Environmental Protection Agency, as part of its National Monitoring Programme, monitor the mercury levels in human blood, urine and hair since 1990[23].

3. Within a European transnational project[24] mercury and methyl mercury has been measured in blood of mothers and their newborn in Austria and Slovakia, confirming that newborns are exposed to a higher extent with methylmercury than their mothers (Umweltbundesamt, 2016).

4. In **Canada**, the Canadian Health Measures Survey (CHMS), which started in 2007 and initiated its fifth cycle in January 2016, is a national survey on the general health and lifestyles of Canadians between the ages of 3 and 79 years. The aim of the survey is to provide information on chronic and infectious disease, physical fitness, nutrition, and other factors that influence health. A biomonitoring component is included in the survey, and mercury (including total, inorganic, and methylmercury) is monitored in the blood, hair and urine of survey participants[25].

   Canada also conducts human biomonitoring for environmental contaminants, including mercury, in vulnerable populations through the Northern Contaminants Program (NCP). NCP undertakes biomonitoring and human health research in the Canadian Arctic and evaluate the impacts of contaminants found in traditionally harvested foods for Indigenous communities. Mercury in blood is measured among men, women, and children living in northern Canada. Moreover, time trend data has been collected for Inuit pregnant mothers over the period 1992-2013.

   Blood mercury has also been measured in vulnerable populations in southern Canada through the Maternal Infant Research on Environmental Chemicals (MIREC) study for mothers and children. The First Nations Food, Nutrition and Environment Study (FNFNES) measured mercury in hair of First Nations living on reserves in Canada and the First Nations Biomonitoring Initiative (FNBI) measured mercury in blood and urine of First Nations living on Canadian reserves.

[21]http://www.umweltbundesamt.de/en/topics/health/assessing-environmentally-related-health-risks/german-environmental-survey-geres
[22] www.umweltprobenbank.de
[23] Personal communication with Swedish Environmental Protection Agency
[24] http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0578.pdf
[25] http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/chms-ecms-cycle3/index-eng.php#s5c

5. In **the United States**, the National Health and Nutrition **Examination Survey (NHANES)**[26] **initiated its operation in 1960 with the aim of assessing the health and nutritional status of adults and children across the country. Within the framework of the project, mercury is measured in blood, hair** and urine.

6. In **Japan**, the Office of Environmental Risk Assessment of the Environmental Health Department of the Ministry of the Environment carried out a project entitled "Survey of the Exposure to Dioxins and other chemical compounds in Humans"[27]. So far, within the framework of the project mercury levels are measured in blood. Moreover, Ministry of Environment has conducted the Japanese environment and children's study (JECS) since 2014.

7. Since 2009, in **Republic of Korea**, 'Korean National Environmental Health Survey (KoNEHS)' has taken place every 3 years. As part of the survey, 26 environmental pollutants, including mercury, has been measured in urine and blood sample of more than 5,000 people. Korean Children's Environmental health Study (Ko-CHENS), a birth cohort study, started in 2015 and mercury levels in hair, blood and urine will be monitored for 5,000 children.

8. In **Colombia**, the National Health Institute (El Instituto Nacional de Salud) and the Ministry of Health and Public Security (Ministerio de Salud y Protección Social) have undertaken several national surveys on the effect of mercury on human health. The human biomonitoring, including measurements of mercury levels in blood, urine and hair, took place between 2007 and 2011 as part of the Public Health Monitoring System (Sistema de Vigilancia en Salud Pública)[28]. Moreover, the mercury has been monitored as well among affected population – artisanal and small-scale gold mining communities - in several department of Colombia[29].

9. Finally, the **Brazilian** environmental agency CETESB reported its capacity to monitor mercury in human matrices[30].

Regional surveys

1. The Global Fish and Community Mercury Monitoring Project - **GFC MMP** - is a result of the joint efforts of BRI and the International POPs Elimination Network (IPEN)[31]. The sampling sites represent all UN regions and are associated with releases of mercury to air, land and water. Hair samples were analyzed in 8 countries, namely: Cameroon, Cooks Islands, Indonesia, Japan, Mexico, Russia, Thailand and Tanzania. The selection of sampling sites has been guided by the presence of point sources of mercury emissions. In Tanzania and Indonesia, populations living in the vicinity of ASGM operations were monitored. In Thailand, the focus was placed on human exposure to mercury from coal-fired power plants. In Mexico and Cameroon, the effect of exposure from mixed-use chemical industry sites was

[26] http://www.cdc.gov/nchs/nhanes.htm
[27] https://www.env.go.jp/chemi/dioxin/pamph/cd/en_full.pdf
[28] http://www.ins.gov.co:81/iqen/IQUEN/IQEN%20vol%2018%202013%20num%204.pdf
[29] http://www.ins.gov.co:81/iqen/IQUEN/IQEN%20vol%2018%202013%20num%2022.pdf, http://www.ins.gov.co/Noticias/Paginas/Exposici%C3%B3n-a-mercurio.aspx#.WBr0G_orLIV
[30] http://www.mercuryconvention.org/Portals/11/documents/technicalsubmissions/Brazil.pdf
[31] http://www.briloon.org/uploads/BRI_Documents/Mercury_Center/gmhSummary.pdf

monitored, and in Russia exposure to mercury from chlor-alkali facilities was examined. In Cooks Island and Japan, effect of the global deposition of mercury was monitored. 82% of the hair samples collected within the framework of this project exceeded the maximum mercury concentration advised by the U.S. EPA (1.0 parts per million or 1 µg of Hg/g of sample).The highest exceeded values were reported for coal-fired power plant hotspot in Thailand (100% of the tested hair samples), ASGM hotspot in Indonesia (95% of the tested samples), and in the population associated with global deposition of mercury in Japan (95% of the tested samples) (see a note about comparability of data in gaps section).

2. The Consortium to Perform Human Biomonitoring on a European Scale (**COPHES**) project was launched in 2009, as a result of a collaboration between European scientists and stakeholders from 35 institutions in 27 European countries[32]. COPHES is an example of a coordinated and harmonized approach to human biomonitoring. Within the framework of the project standardized protocols that allow for comparable data collection across the European countries were developed. A demonstration project, referred to as **DEMO-COPHES** ran from September 2010 to November 2012, and proved the feasibility of the project[33]. 17 European countries participated in DEMO-COPHES (see Figure 5). The project monitored mercury concentration in almost 4000 hair samples obtained from pair: mothers and children (children age 6-11, equal number of boys and girls), coming from two distinct areas – urbanized vs. rural locations (equal distribution). The project provided insights into the harmonized approach to human biomonitoring surveys, which is a step towards standard European reference values. In this study, 1.4% of the children and 3.4% of the mothers have mercury levels above the FAO/WHO[34] health-based guidance value of 1.6 µg/kg of body weight/week, which translates into a value of 2.3 µg of mercury/g of hair (see a note about comparability of data in gaps section).
3. In 2015, **AMAP** published a Human Health Assessment Report [35] that summarizes and presents the results of current and previous AMAP assessment study on human health in the region since 1998. The report provides information regarding human biomonitoring for mercury in a number of Arctic communities, some including long-time series and several based on detailed cohort-study populations.

Local studies

In addition to coordinated regional and national biomonitoring initiatives, a large number of local studies have been carried out with the aim of determining the effects of mercury exposure among various populations. The main focus of the gathered here sample studies are populations at risk of high mercury exposure, e.g. fish consumers (Carta et al., 2003; Endo and Haraguchi, 2010; Mezghani-Chaari et al., 2011; Steuerwald et al., 2000) and ASGM communities (Baeuml et al., 2011; Barbieri and Gardon, 2009; Drasch et al., 2001; Rajaee et al., 2015). The relationship between mercury levels in mothers and its effect on their children during pregnancy and the early development stage was the focus of many of the local studies (Basu et al., 2014; Debes et al., 2006; Grandjean et al., 2001; Jedrychowski et al., 2006; Palkovicova et al.,

[32] http://www.eu-hbm.info/cophes
[33] http://www.eu-hbm.info/democophes
[34] Guidance value defined by JECFA (Joint FAO/WHO Expert Committee on Food Additives) at their 67th meeting in 2006.
[35] http://www.amap.no/documents/doc/amap-assessment-2015-human-health-in-the-arctic/1346

2008). Moreover, several local studies carried out monitoring surveys to determine the level of mercury in human tissue among communities without important point sources and significant exposure to mercury at the local level (Olivero et al., 2002; Paruchuri et al., 2010).

Distribution of monitoring networks

According to the information gathered as part of this review, the AMAP, COPHES and GFC MMP are unique international/regional networks aiming to monitor and compare human exposure to mercury in a systematic way, using common and standard procedures based on the experiences of the national networks. The GFC MMP project covers 8 countries from 5 continents, including Latin America and Caribbean, Europe and Australian and Oceania (one location each), Africa (two locations) and Asia (three locations). Moreover, in Europe, harmonized human biomonitoring efforts proved to be effective, with 27 countries participating in the DEMO-COPHES program. In addition several national surveys were successful in generating reliable source of information, e.g. in North America, Europe, and South America (Figure 5).

Distribution of the monitoring initiatives of the human exposure linked to ASGM is limited to the two sub-project within GFC MMP network framework (in Indonesia and Tanzania) as well as various local studies, carried out mainly by scientific community in several ASGM hotspot, such as Ghana, Amazonian region and Philippines (Baeuml et al., 2011; Barbieri and Gardon, 2009; Drasch et al., 2001; Rajaee et al., 2015).

Gaps

Firstly, it should to be recognized that the objective of the report is to present the overview of the mercury monitoring networks. Assessment of the quality of the networks is not covered here and it is hereby highlighted the importance of undertaking an evaluation in a separate study. Moreover, the limited accessibility via publically available sources and language limitation of the search (limited to English, Spanish and French) likely resulted in an oversight of information.

Existing regional and national surveys are currently not sufficient to provide geographically representative and balanced information on human biomonitoring. Limited efforts have been initiated at national and regional level in Latin America and the Caribbean (with the exception of Brazil and Colombia), Africa, Asia (with the exception of Japan and Republic of Korea), and Australian and Oceania. Meanwhile, various local studies, carried out primarily by the scientific community, have contributed to knowledge generation on human exposure to mercury in these regions (Sheehan et al., 2014).

Taking into account the current distribution of human biomonitoring networks, it becomes evident that there is a need for more harmonized and standardized approaches. Models such as DEMO-COPHES proved to be successful in the European region and thus could be replicated in other regions as well as at the global level. However the harmonized approached should be based on a strong national capacity and where possible on existing national monitoring programmes. In particular, human exposure to mercury should be monitored in more locations among high risk populations, including frequent fish consumers and ASGM communities.

According to the Food and Agriculture Organization (FAO), regions with the highest protein intake from fish consumption relative to total animal protein consumption are South-East Asia, West and Central Africa, and certain South American countries (Figure 7). When contrasted with HBM studies carried out in those regions, a clear lack of HBM networks is evident. In particular, it is advisable to increase efforts to monitoring the accumulation of mercury in human tissues in countries where consumption of fish constitutes more than 30% of total protein consumption.

The extent and magnitude of mercury emissions from the ASGM sector (Figure 6) and its significant effects on human health does not translate into coverage of HBM studies in those areas. In particular, African countries with high mercury emissions from ASGM, are relatively poorly covered by HBM networks/local studies (with the notable exception of Ghana, where several studies were carried out) (Basu et al., 2015a; Basu et al., 2015b; Rajaee et al., 2015; Adimado and Baah, 2002; Donkor et al., 2009; Kwaansa-Ansah et al., 2010; Paruchuri et al., 2010; Rajaee et al., 2015).

Based on the information gathered as part of this review, it is important to note that the vast amount of efforts to monitor human exposure to mercury and its effect on our health were in the form of local studies carried out by scientific community. Existing efforts by governments and collaborative screening projects may need to be enhanced. Thus, there is room for improvement with regard to national capacity and regional coordinated efforts addressing mercury monitoring in human tissues.

Joint efforts to monitor various environmental pollutants, such as COPHES and AMAP, are a valuable option to integrate HBM into a bigger scheme. This approach has a potential to be replicated in other regions as its standard operating procedures and practices can be shared among other the participating monitoring stations as long as national capacity is enhanced. The results obtained in DEMO-COPHES and GFC MMP however, cannot be directly compared due to public unavailability of raw data and difference in referencing system, i.e. U.S. EPA health-based value for GFC MMP and FAO/WHO health-based value for DEMO-COPHES. In order to coordinate and harmonize the approaches between the networks and obtained results, there is a need for enhanced data accessibility and coordination between initiatives and projects.

Developing new national human biomonitoring networks and/or expanding global networks in the hotspot regions as well as in remote regions far from the point source of mercury emissions would contribute to an improved understanding of the pathways of mercury exposure and accumulation in humans. Collaboration with local scientific expert centers specialized in HBM is critical in the development of global efforts. The expansion and the generation of baseline data would also allow for greater preventive measures to be applied in a more specific manner and thus contribute to the reduction and elimination of the mercury pollution issues worldwide.

In addition to the above mentioned elements, lessons learned from the DEMO-COPHES project[36] could help the process of harmonization and standardization of HBM approaches, i.e.

[36] http://www.eu-hbm.info/euresult/media-corner/press-kit

(i) “define inclusion and exclusion criteria that can be met in all countries,

(ii) measure one substance in one lab thus avoiding uncertainties regarding comparability of measurements of small doses between different laboratories,

(iii) provide user-friendly programmes for statistical analysis, to reduce the resources needed to perform them,

(iv) involve national social scientists from the start of the study, to help understand and take into account cultural differences,

(v) develop communication materials that are well adapted to the target groups allowing adaptations to national situations”.

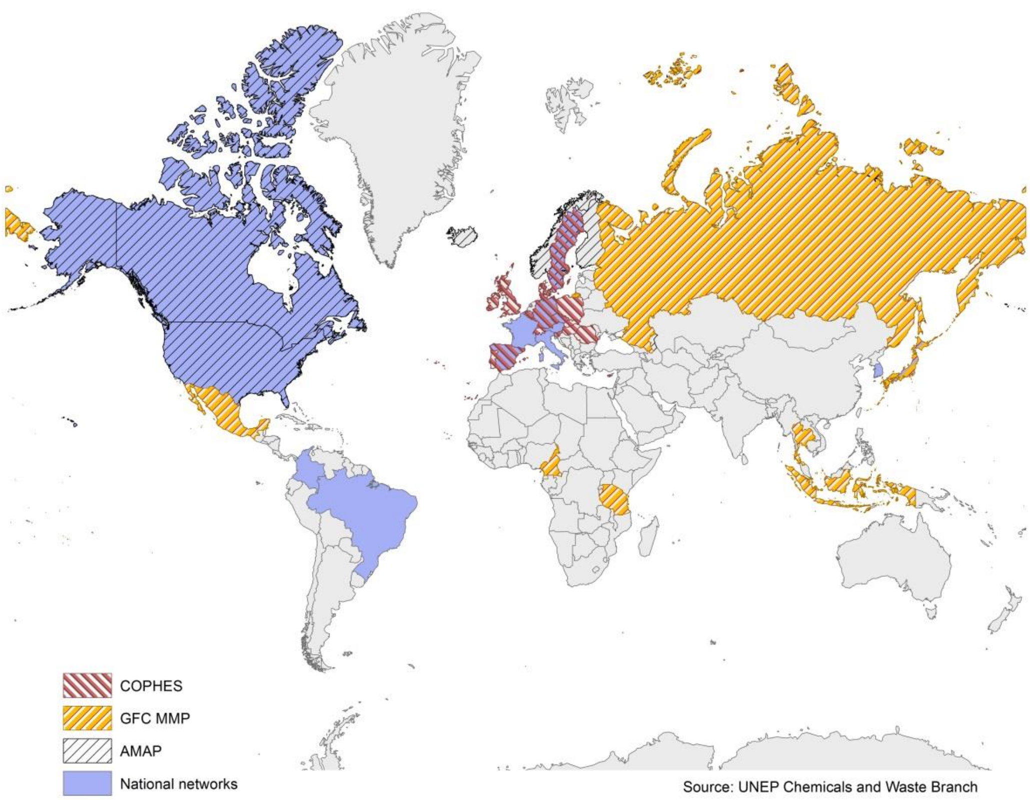

Figure 5. Distribution of the regional (international) and national human biomonitoring surveys and studies

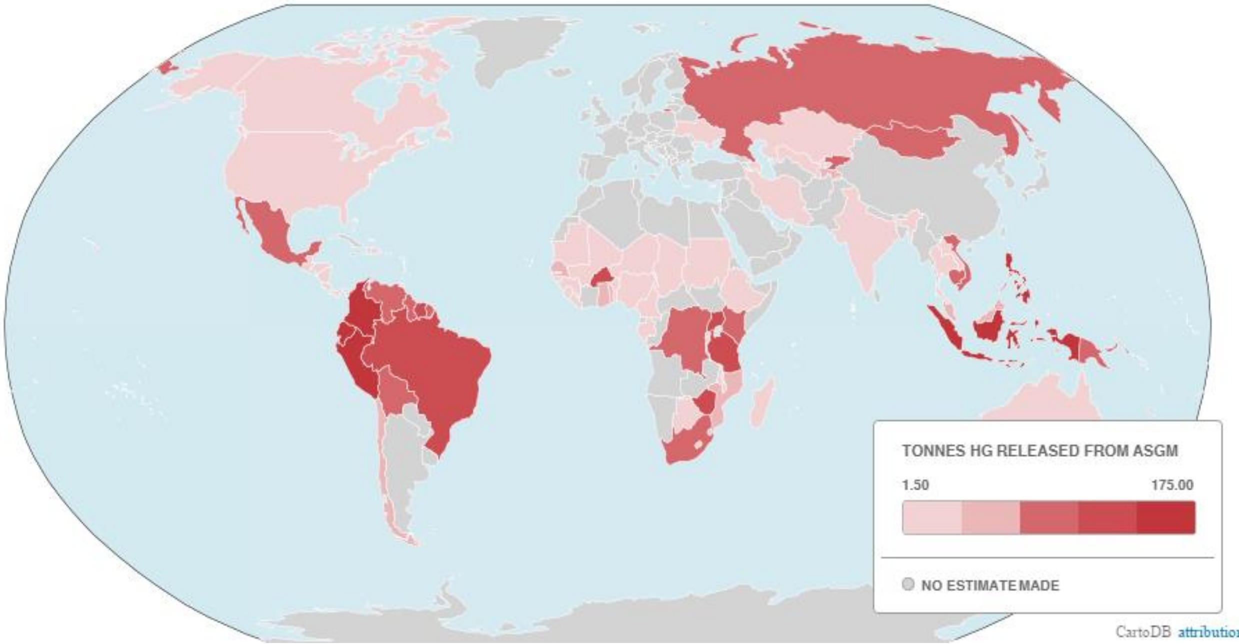

Figure 6. Global mercury releases to air, water and soil from the ASGM sector, in tones, per country. (This map was designed by the Chemicals and Waste Branch based on data from: http://www.mercurywatch.org/)

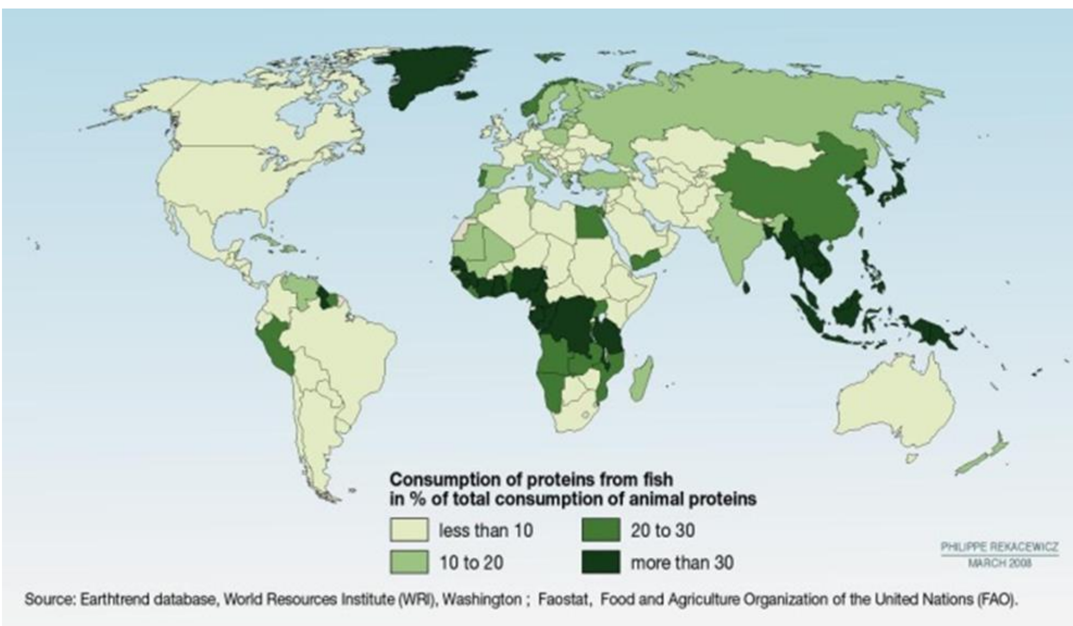

Figure 7. Global consumption of protein from fish in % of total consumption of animal protein, per country. (FAO, 2000)

PART 3

Biota Monitoring Networks

Photo credits: Luca Galuzzi

Background

The monitoring of mercury levels in biota is an essential element of global mercury monitoring efforts. This chapter focuses on the monitoring of biota, including fish and other marine species. Mercury accumulates and biomagnifies in the food chain, exposing fish-consuming populations to the risks associated with increased mercury exposure. Hence, baseline information regarding the levels of mercury accumulation in the world's biota is crucial to estimate those risks and take necessary preventive actions.

Methylmercury constitutes more than 95% of total mercury found in fish and seafood (Bloom, 1992). According to the U.S. EPA only fish at a concentration below 0.3 ppm of mercury per kilogram of body weight is safe to consume on a daily basis (based on a 17.5 g/day consumption). Above that value and below 1 ppm, certain restrictions of consumption should apply. The upper limit of consumption for mercury containing fish and seafood ranges between 0.5 and 1 ppm, depending on the recommending agency (WHO, U.S. EPA or European Commission) and the type of fish (to larger predatory species, such as shark, some tune and swordfish, the upper limit applies) (EPA 2001, EC 2002, FAO/WHO 2011). Above this limit, consumption is not recommended.

In general, mercury accumulation is lower in smaller, short-lived fish (including anchovies, sardines, salmon etc.), which can be consumed on a more regular basis. By contrast, large, long-lived species, many of which are pelagic[37], accumulate higher mercury concentrations.

Initial overview of biota monitoring networks

The review discusses, identified national networks, including EU initiative, Norway, Sweden, Spain, UK, Poland Canada, USA, Japan, Republic of Korea, Colombia and Brazil, and global or regional networks (i) an international survey that forms a part of the GFC MMP, (see the previous section for more details), (ii) the International Environmental Specimen Bank (IESB) Group, (iii) Arctic Monitoring Assessment Programme (AMAP), (iv) regional seas Convention OSPAR, and (v) Baltic Marine Environment Protection Commission - Helsinki Commission HELCOM, (vi) the International Council for the Exploration of the Sea (ICES), (vii) the International Cooperative Programme on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes (ICP Waters), and the Global Biotic Mercury Synthesis (GBMS) database, which is a collection of more than 200 local studies that monitor the level of mercury in biota at a specific location.

National surveys

Several countries monitor mercury levels in biota as part of the broader monitoring schemes.

1. Mercury is a priority hazardous substance in the **European Union** according to the European Water Framework Directive (WFD) and associated with a corresponding environmental quality standard. For compliance and trend assessment mercury has to be measured in fish. The WFD was adopted in 2000, but the approach to tackling chemical pollution of surface water is embedded in the wider strategic approach established in the 1970s, with Directive 76/464/EEC that sets out an ambitious programme to prevent and limit pollution from dangerous substances. The sample of the monitoring results from Austria are published and can be found in a report (BMLFUW, 2015). Furthermore, in the European Union within the Call for continuous collection of chemical contaminants occurrence data in food and feed mercury measurements are regularly reported to the European Food Safety Authority EFSA[38]. Monitoring activities in and studies e.g. from Austria are summarized in a recent report (Umweltbundesamt, 2016).

2. In **Norway**, the Norwegian National Institute of Nutrition and Seafood Research programme controls mercury levels in seafood[39]. Moreover, the Norwegian Institute for Air Research and Norwegian Institute for Water Research on behalf of Norwegian Environment Agency monitors mercury in the

[37] Pelagic fish live in the water column of the lake, sea or ocean – being neither close to the bottom nor near the shore; source: National Oceanic and Atmospheric Administration, US Department of Commerce (NOAA) - http://oceanservice.noaa.gov/facts/pelagic.html

[38] https://www.efsa.europa.eu/en/data/call/datex101217

[39] https://www.nifes.no/en/

biota as part of the programme "Environmental pollutants in the terrestrial and urban environment"[40] and "Environmental Contaminants in an Urban Fjord"[41].

3. **Swedish** Environmental Protection Agency, as part of its National Monitoring Programme, is as well monitoring the mercury levels in fish since late 1960' [42].

4. In **Spain**, the Spanish Research Center for Energy, Environment and Technology (CIEMAT) is monitoring the mercury in environmental samples, including biota, since 1999[43].

5. In **UK**, Centre for Ecology and Hydrology carries out two monitoring programmes "The Predatory Bird Monitoring Scheme (PBMS)" and "National Fish Tissue Archive". PBMS is a long-term, national monitoring scheme that quantifies the concentrations of contaminants in the livers and eggs of selected species of predatory and fish-eating birds in Britain. Under this scheme a study of Mercury concentrations in Predatory Birds has been undertaken (Walker et al., 2016). The second project "National Fish Tissue Archive" aims to assess the contamination of UK's rivers[44], including measurements of mercury in the fish tissues.

6. In **Poland**, the State Environmental Monitoring system measures and assess the state of the environment as well as collects, process and disseminates information on the environment. As part of this programme, mercury levels are monitored in biota – including marine mollusks, phytobenthos and herring – since 1998.

7. **Canada** executes several regional and national programmes, including (i) the Northern Contaminants Program (NCP), which monitors mercury in various arctic species that are important to the traditional diets of Northern indigenous people, including fish, marine mammals and seabirds, (ii) the Canadian Food Inspection Agency, which monitors mercury levels in retail seafood, (iii) the Canadian Fish Mercury Database, (iv) Seabird Egg Monitoring Program that operates on Canada's three coasts (Atlantic, Pacific and Artic), (v) Great Lake Herring Gull Egg Monitoring Program and (vi) the transboundary Gulfwatch Contaminants Monitoring Program (implemented in Canada and the USA), which monitors mercury levels in coastal waters and blue mussels.

8. In the **United States**, mercury is monitored in fish and wildlife within the framework of the National Contaminant Biomonitoring Program.

9. The **Japanese** Ministry of Agriculture, Forestry and Fisheries monitors fish as well as agricultural and canned products.

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[40] http://www.miljodirektoratet.no/no/Publikasjoner/2015/Oktober-2015/Environmental-pollutants-in-the-terrestrial-and-urban-environment/

[41] http://www.miljodirektoratet.no/no/Publikasjoner/2016/September-2016/Environmental-Contaminants-in-an-Urban-Fjord2015/

[42] Personal communication with Swedish Environmental Protection Agency

[43] http://www.ciemat.es/

[44] http://www.ceh.ac.uk/our-science/projects/national-fish-tissue-archive

10. The **Korean** National Institute of Fisheries Science continuously executes national monitoring programs, which monitor mercury levels in coastal waters (seawater, sediments, mussels and oysters) as well as seafood.

11. In **Colombia**, the National Institute of Pharmaceuticals and Food Monitoring (Instituto Nacional de Vigilancia de Medicamentos y Alimentos) is undertaking a monitoring of mercury level in the canned tuna fish for the period of 2015-2016[45].

12. The **Brazilian** Environmental Agency of the state of Sao Paulo (**CETESB**) and several research groups hosted mainly in Federal Universities in Brazil have also undertaken continuous monitoring of mercury in fish and bivalve mollusks[46].

Regional surveys

1. As part of the **GFC MMP**, fish samples were analyzed in 9 countries representing all UN regions namely Albania, the Czech Republic, Italy, Japan, Portugal, Russia, Thailand, Uruguay and the USA (Alaska). The sampling locations were chosen based on the proximity of a point source of mercury emissions. The effect of the chlor-alkali industry on biota was monitored in the Czech Republic and Russia. Exposure to mercury from coal-fired power plants was monitored in Thailand and contaminated site vicinity was taken into account in Albania. The global deposition effect on biota was monitored in the USA, Italy, Portugal, Uruguay and Japan. 84% of the fish sampled as part of the initiative were deemed unsafe for consumption more than once per month according to U.S. EPA standards. More than 13 % of the fish samples would not be recommended by the WHO or the European Commission for commercial sale.

2. Environmental Specimen Banks, which together form the **IESB** group[47], collect and archive biotic and abiotic environmental samples in a systematic and long term manner. The samples are used for variety of purposes, including of medical and clinical nature, as well as for the preservation of genetic diversity. Another important objective of the IESB group is to measure the levels of environmental contaminants, including mercury, in the collected samples. The objective is to control the mercury concentration level in the fish in order to assess the human health risk related to the consumption of seafood.

   Among the 15 established ESBs, 10 are reported to monitor mercury levels in the biological samples, including fish and other seafood. Those include the Swedish Environmental Specimen Bank, the U.S. Environmental Specimen Bank Group, Canada's National Aquatic Biological Specimen Bank and Database and National Wildlife Specimen Bank, the German Environmental Specimen Bank, the Japanese Environmental Specimen Time Capsule Program and Japanese Environmental Specimen Bank for Global Monitoring, the Norwegian Environmental Specimen Bank, the Italian Mediterranean

[45] https://www.invima.gov.co/images/pdf/inspecion_y_vigilancia/direccion-alimentos/Documentotecnicomercuriopublicar1.pdf
[46] http://www.mercuryconvention.org/Portals/11/documents/technicalsubmissions/Brazil.pdf
[47] http://www.inter-esb.org/

Marine Mammals Tissue Bank, the Korean National Environmental Specimen Bank, the French Environmental Specimen Bank, and the Chinese Yangtze Environmental Specimen Bank.

3. Arctic Monitoring Assessment Programme (**AMAP**) conducts as well regularly measurements of mercury levels in arctic biota. "The AMAP Assessment 2011: mercury in the Arctic"[48] report presents analysis of temporal trends from 83 long time-series for mercury in biota monitored at 60 sites around the Arctic. The study reports time series of mercury levels in various tissues and organs of a range of species (including shellfish, freshwater and marine fish, marine mammals, terrestrial mammals, and seabirds).

4. **OSPAR** is the regional seas Convention that aims to protect the marine environment of the North-East Atlantic[49]. It has two associated monitoring programmes, the Coordinated Environmental Monitoring Programme (CEMP) and Joint Assessment & Monitoring Programme (JAMP). OSPAR time-series of mercury monitoring in biota go back to the late 1970s and cover the coastal areas of Europe from southern Spain to the Norwegian-Russian border and some offshore monitoring sites. OSPAR monitoring is increasingly aligned with monitoring under the EU Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC[50])

5. Baltic Marine Environment Protection Commission - Helsinki Commission (**HELCOM**)[51] is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. HELCOM coordinates a long-standing regional marine monitoring programmes (active since 1979), including measurements of mercury levels in biota. Since 1992 the programmes have been integrated into one Cooperative Monitoring in the Baltic Marine Environment (COMBINE).

6. The International Council for the Exploration of the Sea (**ICES**)[52] is an international organization that support the sustainable use of the oceans through scientific and advisory services. ICES is a network of more than 4000 scientists and its work extends into the Arctic, the Mediterranean Sea, the Black Sea, and the North Pacific Ocean. As part of their projects ICES monitors the mercury levels in marine biota and track the mercury transfer through the tropic levels.

7. International Cooperative Programme on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes (**ICP Waters**)[53] is a monitoring programme focused on the effects of acid rain and air pollution on water and water courses. It was established in July 1985 under the United Nation Economic Commission for Europe (UNECE) Executive Body of the Convention on Long-Range Transboundary Air Pollution. The Norwegian Institute for Water Research is the institutional programme centre for ICP Waters. 18 European countries, USA and Canada participate and supply

[48] http://www.amap.no/documents/doc/amap-assessment-2011-mercury-in-the-arctic/90
[49] http://www.ospar.org/about
[50] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN
[51] http://www.helcom.fi/about-us
[52] http://www.ices.dk/Pages/default.aspx
[53] http://www.icp-waters.no/

monitoring data to the programme's central database. Mercury is monitored as part of its monitoring project focused on heavy metal and POPs.

Global Biotic Mercury Synthesis database

The GBMS database project was launched by BRI as a response to an expression by UN Environment and Signatories of the Minamata Convention on Mercury of the necessity of consistent mercury data and monitoring. The database compiles and synthesizes existing data on mercury levels in marine mammals, fish, sharks, skates and rays. The database was assembled by gathering samples of more than 33 thousand species, derived from 72 countries and 457 unique locations. As a result, it allows for representative and comparable spatial coverage. The report "Mercury in the Global Environment: Understanding Spatial Patterns for Biomonitoring Needs of the Minamata Convention on Mercury"[54] can be consulted for further information.

Distribution of biota monitoring networks

According to the information gathered as part of this review, the GBMS database compiles the largest amount of information on mercury level in biota worldwide. The database has wide geographical coverage, with most of the data obtained from samples analyzed in the East Coast of United States, Northern and Southern Europe, Japan, Southeast Asia and the East Coast of Australia. In addition to coastal and inland data, several ocean samples from Pacific, the Atlantic and the Indian Ocean were analyzed.

In addition to the GBMS database, which is a collection of individual local studies, the Global Fish and Community Mercury Monitoring Project is an international network that aims to monitor and compare mercury levels in fish in a systematic and standardized way in 9 countries, expanding over 4 continents, namely Latin and North America (one location each), Europe (five locations) and Asia (two locations).

Moreover, the regional monitoring networks that commonly build on the national monitoring efforts, such as AMAP, OSPAR and HELCOM, operate actively in the Arctic and Northern European territory.

In contrast to the above mentioned network and database, the national ESBs and national networks are geographically limited to several regions, namely North America (USA, Canada), Europe (EU wide initiatives, Norway, Sweden, Spain Germany, France, Italy, and UK), East Asia (Japan, Republic of Korea and China) and Latin America and Caribbean (Brazil and Colombia) (Figure 9).

Gaps

In agreement with the objective of the report, which aims to present an overview of monitoring networks, the assessment of the quality of the networks is not covered here and it should be evaluated in a separate study. Moreover, the limited accessibility via publically available sources and language limitation of the search (limited to English, Spanish and French) likely resulted in an oversight of information.

[54] http://www.briloon.org/mercury-in-the-global-environment

The limited geographical coverage of national ESBs and other national networks reveals a lack of national initiatives in terms of mercury monitoring in biota. According to the information gathered as part of this review, there are no such national activities being undertaken in Africa and Australia. Most Asian countries also do not seem to engage in national initiatives to monitor mercury levels in biota, with the notable exceptions of Japan and Republic of Korea.

Meanwhile, local studies, which are part of the GBMS database, conducted by the global scientific community provide comprehensive and geographically balanced information regarding mercury levels in biota. However, the countries with the highest fish consumption (Fig. 7) are relatively poorly covered by these monitoring efforts (especially Western and Central Africa, with the exception of Tanzania, Uganda and Ghana). Additional efforts are therefore needed to develop and implement projects to fill those gaps. Although national efforts could provide for monitoring networks in the region, local scientific studies can make a significant and welcome contribution in the short term and would allow for knowledge generation in the region in the near future.

Enhanced efforts need to be applied in order to develop and implement project that will fill the above mentioned gaps. In order to provide the sustainable and long-term source of monitoring capacity in the regions, the focus should be placed on increasing number of national initiatives. Moreover, it is crucial to enable the collaboration and coordination between the national projects in order to create the harmonized regional approaches.

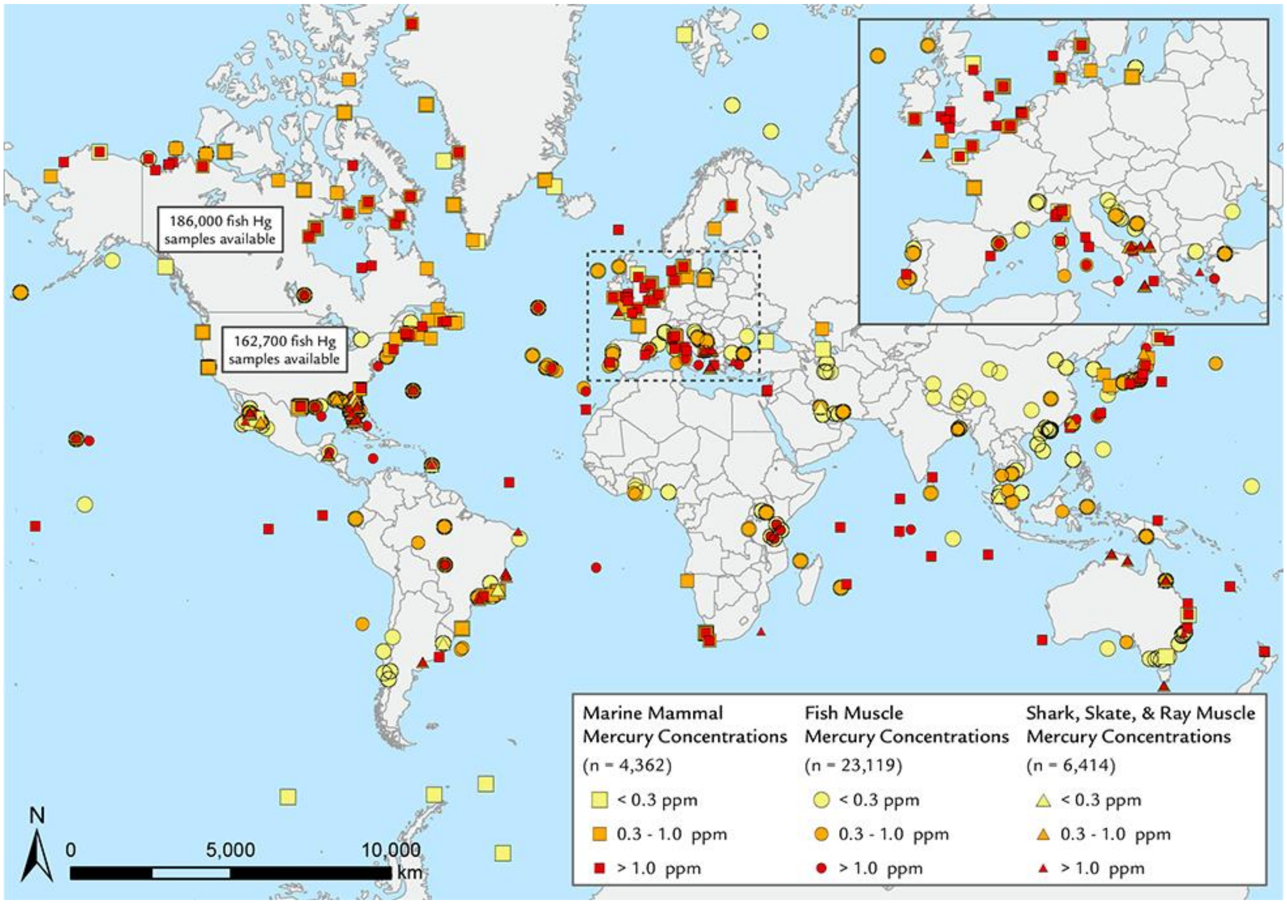

Figure 8. Global distribution of mercury concentrations in biota based on studies collected as part of the GBMS database (source: Evers et al., 2014)

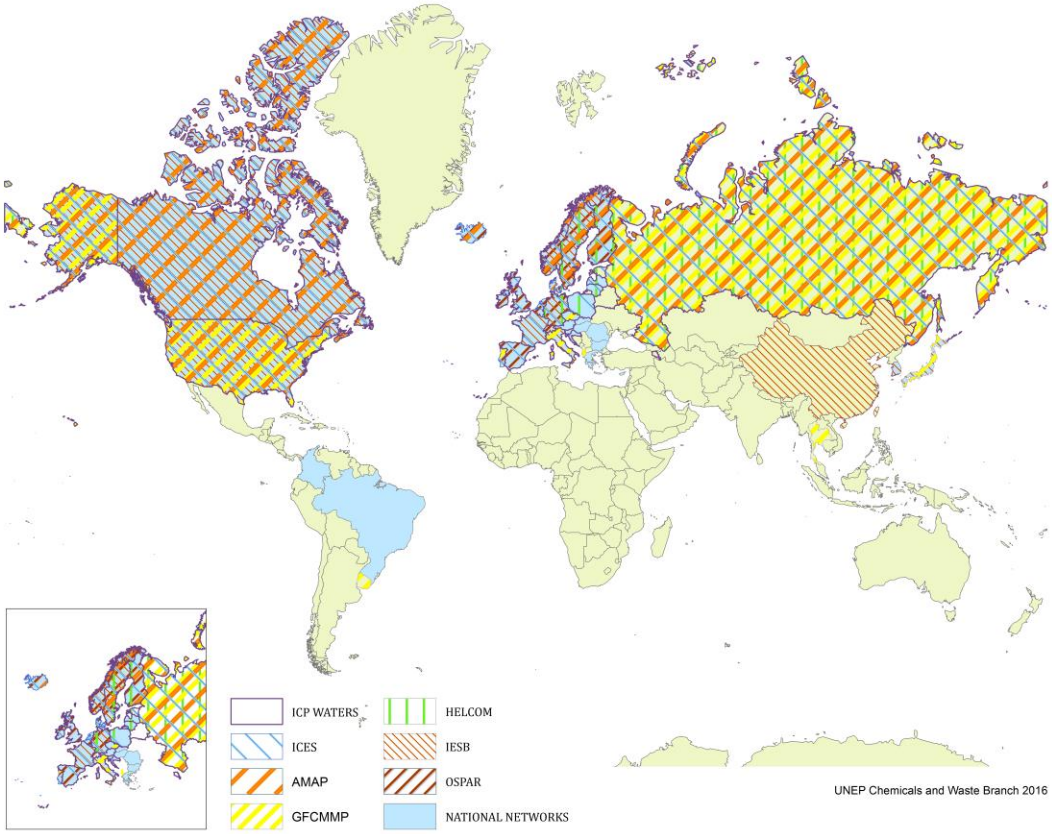

Figure 9. Distribution of the regional (international), and national biota monitoring surveys and studies

Summary and Closing Remarks

Mercury is a powerful neurotoxin of global concern due to its chemical properties. It is a universal contaminant that travels vast distances and accumulates in the environment, thus polluting ecosystems and posing significant risks to human health. It affects as well the populations that are exposed to the source of mercury emissions, such as ASGM and industrial sites. In order to take adequate preventing measures, it is of critical importance to upscale mercury monitoring networks and to enhance collaboration on this matter globally.

Currently, networks and initiatives that monitor atmospheric mercury and its levels in humans and biota show room for upscaling in most regions of the world, including Africa, Asia and Latin America and Caribbean. The regions with the highest mercury emission to the atmosphere are also those where atmospheric monitoring stations are scarce or information on existing monitoring initiatives is not well documented publicly and therefore the information or data is not easily available. Along the same lines, there is a lack of efforts to monitor mercury levels in humans and seafood for human consumption in the regions with the highest percentage of seafood consumption. Meanwhile, the existence of global or regional networks (e.g. GMOS, AMAP or DEMO-COPHES) and a number of local scientific studies (e.g. the GBMS database) attests to the ongoing efforts to upscale monitoring networks at the global level as well as to enhance collaboration and network development

Below, specific knowledge gaps are presented as identified for the three types of mercury monitoring.

Atmospheric Mercury Monitoring

- A large share of the countries with high mercury emissions has atmospheric monitoring coverage at the low end of the range. The US is a notable exception.
- Asia has relatively few monitoring activities (with exception of Japan and Republic of Korea), while accounting for relatively high emissions.
- Africa is also equipped with little coverage, lacking national and international monitoring networks in most parts of the continent. Again, some of the countries with the highest emissions have the least monitoring activities. Overall, however, the African region has relatively low levels of emissions.
- Countries from Latin America and the Caribbean that emit high amounts of mercury as a result of ASGM operations, lack regional and national monitoring networks (with the exception of the Brazilian national and GMOS stations)

Human Biomonitoring

- Existing regional and national surveys are currently not sufficient to provide geographically balanced information on human biomonitoring.
- Some limited efforts have been initiated at national and regional level in Latin America, Africa, Asia, and Australian and Oceania. Various local studies, carried out primarily by the scientific community, have contributed to knowledge generation on human exposure to mercury in these regions.

Biota Monitoring

- Limited geographical coverage of national ESBs and other national networks reveals a lack of national activities in major parts of Latin America and Caribbean (with exception to Brazil and Colombia), Africa, Australia and Oceania, and Asia (with exception to Japan and Republic of Korea) in terms of mercury monitoring in biota.

Highligts:

The objective of the report was to present the available information on the presence of mercury monitoring networks that measure mercury in the air, humans and biota. The quality assessment of the presented monitoring networks or initiatives is critical and should be performed as a follow-up action. Furthermore, the UN Environment acknowledge the importance of mercury monitoring efforts in other essential media not included in the report, such as water and soil, and highlights the need to develop such overview in the future.

The sustainability of the mercury monitoring networks is an important factor affecting the effectiveness of the monitoring efforts. Data comparability, quality assurance and data accessibility are key aspects of the monitoring network when determining its relevance for a global effectiveness evaluation scheme. The information on the long-term monitoring programs with a reliable funding source is a key factor when establishing a long-term monitoring system under the Minamata Convention. In many cases, the global and regional initiatives are built on previously established national monitoring network. In some cases, when developing an international or regional network, additional monitoring efforts or sites may be considered based on short-term support to fill the gaps. However, the majority of the successful, sustainable and long-term monitoring solutions are critically dependent on an ongoing national commitment and national arrangements when implementing monitoring activities. Nevertheless, the regional and international initiatives are crucial as they tend to add a degree of harmonization, coordination and justification (in some cases legal requirement) for continuing the national commitment. Strengthening or creating the national capacity is therefore highlighted as an essential step towards more unified and successful mercury monitoring efforts globally.

Below, as identified for the three types of mercury monitoring, specific issues are presented for further consideration.

Atmospheric Mercury Monitoring

- Strengthen the national mercury monitoring capacity and establish additional monitoring stations as part of existing national or regional networks, or establish new national or regional networks, in particular in Africa, Asia and Latin America and Caribbean.
- If national meteorological networks capable of monitoring air quality exist, place the focus on collaboration and updating relevant SOPs to ensure consistency with the international procedures and requirements.
- If existing air monitoring stations do not have the capacity to measure mercury, consider technical upgrades.

Human Biomonitoring

- Expand national and regional networks, both in regions with intense mercury releases and in regions remote from the point source of mercury (to account for the global deposition effect on the mercury accumulation n humans, especially among the frequent fish consumer).
- Enhance data accessibility and coordination between initiatives and projects in order to coordinate and harmonize approaches between the networks and the results obtained.

- Apply lessons learned from previous projects (such as DEMO-COPHES) for further harmonization and standardization of HBM approaches.

Biota Monitoring

- Enhance efforts to develop and implement projects to fill the above mentioned gaps.
- Rely on an increased number of national initiatives to provide a sustainable and long-term source of monitoring capacity in the region.
- Local scientific studies can make a significant contribution and allow for knowledge generation in the regions lacking national capacity in the near future as well as beyond.

Closing Remarks:

To the best of knowledge, this report is the first such attempt at undertaking the task of summarizing and presenting in a systematic way the available information on global mercury monitoring networks. As an initial overview, the report is not entirely exhaustive and should be seen as an initial starting point. The report is a living document that will remain open for comments and be periodically updated in the future. Support from the global community and governments is welcome and encouraged during the development of a more complete and exhaustive overview in the future. Moreover, the quality assessment of the presented here networks, as well as overview of mercury monitoring networks that track mercury levels in water and soil, are critical and should be performed as a follow-up actions.

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ANNEX

Table 1. List of the major mercury monitoring networks identified during an initial screening of the key documents on the subject and secondary data collection

Network	Link to the resources
Atmospheric	
GMOS	http://www.gmos.eu/
NADP	http://nadp.sws.uiuc.edu/mdn/
APMMN	http://rsm2.atm.ncu.edu.tw/apmmn/AboutAPMMN.html
AMAP	http://www.amap.no/mercury-emissions
CAPMoN	https://www.ec.gc.ca/rs-mn/default.asp?lang=En&n=752CE271-1
NIMD	http://www.nimd.go.jp/english/
NIES	https://www.nies.go.jp/index-e.html
NPI	http://www.npi.gov.au/about-npi
CETESB	http://www.cetesb.sp.gov.br/2014/10/27/cetesb-realiza-treinamentos-internacionais-sobre-pops-e-mercurio/
E-PRTR	http://prtr.ec.europa.eu/#/home
Human Biomonitoring	
GFC MMP	http://www.briloon.org/uploads/BRI_Documents/Mercury_Center/gmhSummary.pdf
DEMO-COPHES	http://www.eu-hbm.info/democophesV
GerES	http://www.umweltbundesamt.de/en/topics/health/assessing-environmentally-related-health-risks/german-environmental-survey-geres
ESB Germany	https://www.umweltprobenbank.de/de
Canada Human Biomonitoring	http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/chms-ecms-cycle3/index-eng.php#s5c
NHANES	http://www.cdc.gov/nchs/nhanes.htm
Japanese HBM Survey	https://www.env.go.jp/chemi/dioxin/pamph/cd/en_full.pdf
Biota Monitoring	
GBMS	http://www.briloon.org/mercury-in-the-global-environment
GFC MMP	http://www.briloon.org/uploads/BRI_Documents/Mercury_Center/gmhSummary.pdf
IESB	http://www.inter-esb.org/
OSPAR	http://www.ospar.org/about
HELCOM	http://www.helcom.fi/about-us