Note to reader

This draft version of Chapter 5 in the Technical Background Report to the Global Mercury Assessment 2018 is made available for review by national representatives and experts. The draft version contains material that will be further refined and elaborated after the review process. Specific items where the content of this draft chapter will be further improved and modified are:

1. Comparison of results with independent estimates for Hg releases to water.
2. Quantification of the uncertainties for sectors where this information is currently missing and update of for some others
3. Geospatial distribution of releases
4. Paragraph on the results of the inventory in the context of global Hg cycle will be added
5. Detailed harmonisation and cross reference with Chapter 2 including integration of Annexes (e.g. Annex on methodological approaches used for Hg-added products sector)

GMA 2018 Draft Chapter 5 Releases of Hg to the aquatic environment from anthropogenic sources.

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10030 ## Contents

10063
10064

Chapter 5 Releases of Hg to the aquatic environment from anthropogenic sources

5.1 Introduction

This chapter is an extension to work on the global inventory of air emissions discussed in Chapter 2. The results presented represent an attempt to compile a comprehensive global inventory of releases of mercury to water from anthropogenic sources for which sufficient information is available. The work builds on, updates and extends the aquatic Hg release inventory prepared as a part of the UNEP global mercury assessment 2013 (AMAP/UNEP, 2013).

This is the second time only that the content of the updated report has been expanded to include information on Hg releases to aquatic environments. General lack of data in the literature reporting Hg releases to aquatic systems and related information needed for estimation of the releases (e.g. waste-water amounts) is still an issue restricting accuracy and completeness of these estimates. Therefore, methods employed to derive the estimates are largely driven by the type and the amount of information available for various source category. Part of this work is directly linked to the air emissions inventory work and utilise factors employed in the UNEP Toolkit are used to derive releases to water from sectors responsible for emissions to air. Releases from other sectors not covered by the Toolkit but recognised as relevant with respect to releases to water, are also addressed, using independent methods and assumptions to derive the estimates.

To the extent possible, our estimates are compared with available national and other estimates/inventories of releases to water. For some of the release sectors covered in the 2015 inventory - to evaluate if obtained results are realistic - alternative release estimates were made using independent assumptions and information. Information regarding global releases of Hg to aquatic systems is still incomplete, and therefore a substantial part of this chapter is devoted to discussion on data sources and their availability, data gaps and associated uncertainties, as well as different methods and approaches/assumptions made for estimating the releases.

The focus of this chapter is on Hg released from current anthropogenic sources to adjacent freshwater systems. The exception is oil and gas production sector, where offshore releases with produced water are also included. If should be pointed out that this inventory does not represent the total global load of Hg to aquatic systems. Namely, in addition to primary anthropogenic sources for which lack of information prevented reliable quantification, diffuse releases associated with legacy Hg accumulated in terrestrial environments can also be important contributors. In this chapter, relative contribution and significance of sources quantified is assessed by comparing inventory results with magnitudes of sources and pathways of other components of the global Hg cycle as established before.

In contrast to air emission estimates (Chapter 2), the numbers presented here do not necessarily correspond to the year 2015. For example, the underlying assumptions for estimating Hg releases with industrial wastewaters are based on information corresponding to latest available information, while releases from point sources were derived from atmospheric inventory data for 2015 presented in Chapter 2.

Inventory results are summarised using two types of regionalisation. The first is distribution of the estimates according to sub-continental regions. The purpose of this regionalisation is comparability with air emissions inventory. However, in case of aquatic releases it is more relevant to track Hg from its source and through catchments all the way to its ultimate delivery into the oceans. Therefore, additional regionalisation is used based on major drainage basins of the world (see Section 2.5 for details).

It should be noted that the fate of terrestrial Hg once entering aquatic systems will largely depend on site-specific environmental conditions that govern its transport and transformation processes within catchments, and have the control over its ultimate delivery to downstream marine environments. This is not addressed in the inventory as the focus of this chapter is on quantification of releases only.

5.2 Estimating global anthropogenic mercury releases for 2010-2015: Methodology

A key component of this work to update the 2010 Global Atmospheric Mercury Assessment: Sources, Emissions and Transport report (AMAP/UNEP, 20013) is the production of a new global inventory of anthropogenic Hg releases to aquatic systems. This new inventory has the target year of 2015 – however

recognising that information required to produce such inventories may not yet be available for all countries and release categories the basis for most of this new inventory is latest available data which dates in the 2000–2015 period.

5.2.1 Methods for estimating releases

Various methods are employed to estimate releases of Hg at the plant/facility, national, regional and global level. The approaches used and underlying assumptions depend on the data availability. In general, they fall under one of the three main groups schematically shown in Figure 1. In order to avoid confusion with the atmospheric and other independent inventories, we named our inventory of global primary anthropogenic aquatic Hg releases *Global Mercury Assessment Aquatic Release* (GMAAR) inventory.

Often assumptions made to derive the estimates presented in this chapter are difficult to validate. For reasons of transparency, details on the approaches and assumptions made in the GMAAR to derive the estimates are given in Annex X., with a summary given in the following sections.

Group 1: This group comprise sectors covered by the UNEP Toolkit (chlor-alkali industry, oil refining, large scale Au and non-ferrous metal production) and for which the Toolkit (UNEP, 2017) provides 'distribution factors' that proportionally 'distribute' total Hg releases between emissions to air and releases to water and land. We use these factors together with the most recent Global Mercury Assessment (GMA) atmospheric Hg emission inventory (Chapter 2) to calculate the corresponding magnitudes of releases to water. Sectors included in this first group are those included also in 2010 inventory.

Group 2: This group is comprised of sectors for which estimates were derived based on measured Hg concentrations reported in the literature for selected case studies and associated volumes of wastewater released and other relevant activity data, respectively. Following the approach recently used by Liu et al. (2016) to develop aquatic Hg release inventory for China, sectors considered important in terms of their relative contribution and included in this inventory, in addition to those from the first group, are: Hg releases associated with produced municipal wastewater and several industrial activities – wastewater from coal-fired power plants, coal washing and produced water generated during oil and

gas production. All sectors from the second group are new addition to the global inventory and have not been addressed in the 2010 inventory.

Group 3: This group covers Hg releases from wastes associated with the use of Hg-added products: batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other uses. Releases are produced using approach comparable to that applied to calculate emission to air (See section 2.2.2. of Chapter 2 and Annex 3 for details), adjusted to aquatic Hg fate. The model used considers regional patterns of consumption of Hg and Hg-containing products and initially distributes Hg in products to different pathways using distribution factors. Releases to water are then assumed for breakage during use, waste recycling and from waste landfills, using fate-specific release factor (see Annex X.6 for details). This is a new methodological approach, as releases from the use of Hg-added products in 2010 inventory were derived using the UNEP Toolkit distribution approach.

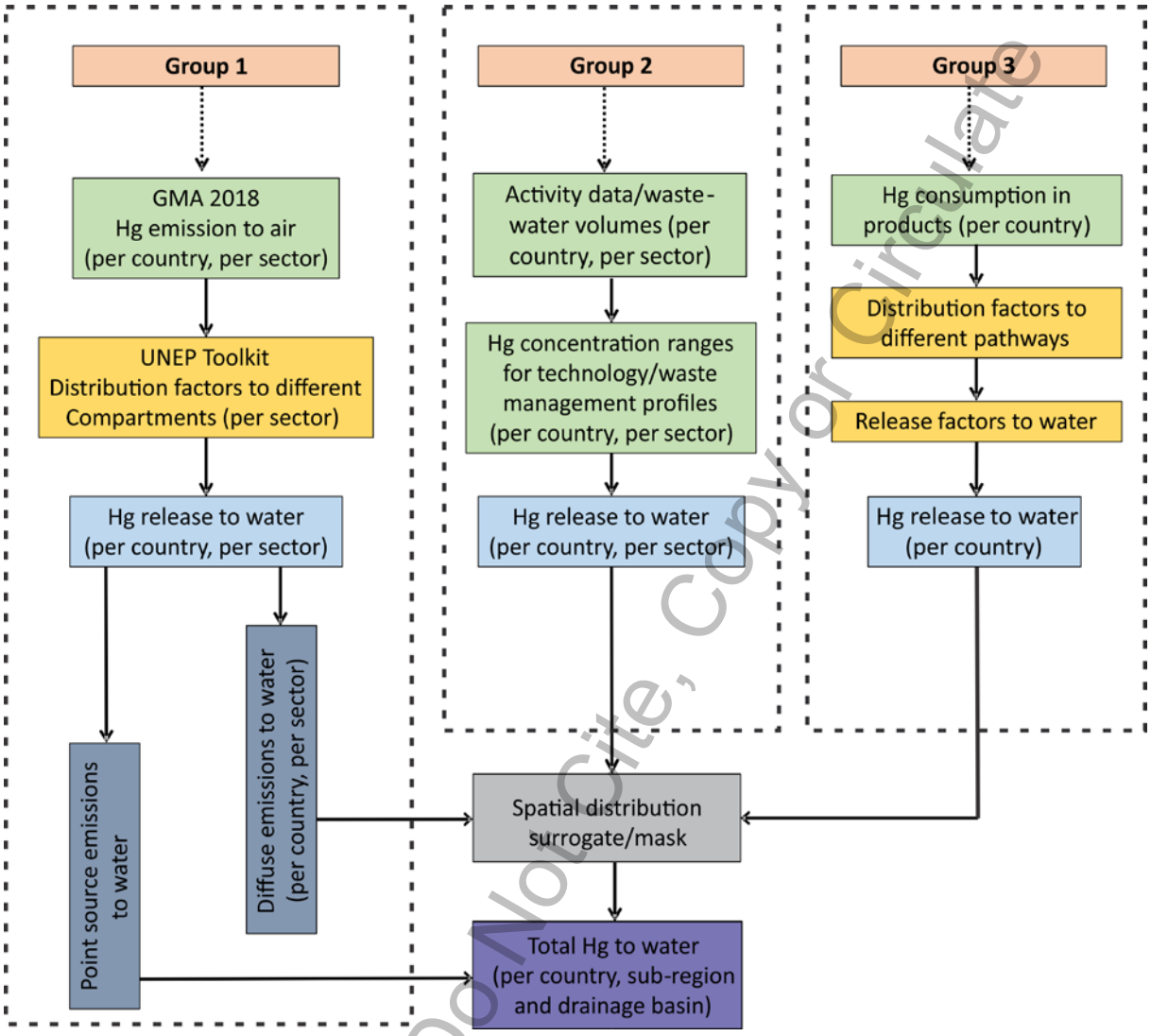

Figure 1. Methods for estimating releases

Initially, estimates of Hg releases for all sectors were made on the country level, as majority of input data used are country specific. Technology and waste-management profiles of individual country (cross ref.) were used for selection of Hg concentration ranges and other related activity data. Based on the country-level information, Hg release estimates were then summarised according to sub-continental regions, using the same regionalisation as that used for the air emission inventory.

In the next step, various methods were applied to geospatially distribute country scale releases, as described further in the Figure 1. Level of details of geospatial distribution vary from sector to sector, and depends mostly on distribution surrogate data availability. In case of Group 1 sectors, methods used

to geospatially distribute air emissions were applied also to the aquatic release estimates. The approach used is described previously in Wilson et al. (2006), AMAP/UNEP (2008, 2010) and Steenhuisen et al. (2015), and in summary assigns releases to point sources where possible, with the remainder being geospatially distributed according to distribution of appropriate surrogate parameter (see Section 2.3 and Annex X for details). In case of Group 2 and Group 3, several "distribution masks" were created for application to releases from different sectors: (i) population density mask for distribution of releases associated with municipal waste-water and use of Hg-added products; (ii) locations of coal-fired power plants (CFPPs) for distribution of Hg releases with associated wastewater; (iii) coal deposits mask for distribution of Hg releases from coal washing, and (iv) on-shore and off-shore oil fields mask for distribution of Hg releases during oil and gas production.

In the final step, in addition to sub-continental summary, Hg releases were summarised based on major drainage basins of the world (see Section 3.2). The above mentioned distribution masks were used along with the drainage basins mask to distribute country-level estimates for individual sectors into appropriate drainage basin.

5.2.2 Sectors and activities

5.2.2.1 Sectors and activities quantified in the inventory

Selection of the sectors and activities for the aquatic inventory is driven by previously established knowledge about their relative importance, while their categorisation depends mainly on the data and type of information available for individual sector/activity. To the extent possible, categorisation was kept comparable with that used for the air emission sectors. The release estimates in the new 2015 GMAAR inventory comprise the following release sectors:

- Production of non-ferrous metals (primary production of aluminium, copper, lead and zinc) (O1)
- Production of mercury metal (O2)
- Production of gold from large-scale mining (O3)
- Mercury releases from oil refining (E1)
- Production of gold from artisanal and small-scale gold mining (O4)
- Mercury releases from chlor-alkali industry (Hg cell technology) (W1)
- Mercury releases with municipal waste-water (W2)

- Mercury releases from coal-fired power plants (E2)
- Mercury releases from coal washing (E3)
- Mercury releases from Hg-added products (batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other uses) use and waste disposal (W3)
- Mercury releases during oil and gas extraction (E4)

In broader terms these sectors can be divided into three general categories: ore mining and processing sector (O), energy sector (E) and waste treatment and disposal (W). The first six items on the list are those included previously in the 2010 inventory. Among these the first four sectors are associated with by-product or unintentional Hg releases and latter two with intentional uses of Hg. Other items from the list are new addition to the 2015 inventory and comprise categories for which relative contribution of Hg releases to aquatic systems is considered to be significant, following mostly the example of Liu et al. (2016) and their release estimates for China.

5.2.2.2 Sectors and activities not quantified in the inventory

We recognise that there are additional sectors and anthropogenic activities, not taken into account in this inventory, but might be responsible for the delivery of additional Hg to local aquatic systems. For example, in the Hg release inventory from anthropogenic sources in China, releases from iron and steel industry, fabrication of textiles and apparel and printing industry were also considered, however estimated at less than 5% of total releases (Liu et al., 2016). Considering relative low importance of these sectors, especially in the light of the fact that there is no data available that would allow any reasonable global quantitative estimate, these sectors were not included in the 2015 inventory.

On the other hand, it should be pointed out that there are processes associated with some of the sectors covered in the inventory that might result in additional quantities of Hg released, however not accounted for in the current inventory due to lack of sufficient information to develop a global inventory. One such example is dental industry where Hg releases are only partly covered within the releases from Hg-added products sector, while there might be additional ones during production and preparation of Hg amalgams fillings. The same goes also for production stage of other Hg-added products (e.g. thermometers, lamps and batteries), as only releases associated with the use of these products are considered in this inventory. Similar, in the case of Hg releases from coal industry, large

quantities of water used during coal mining and transport, apart from those associated with coal washing, might release significant amounts of Hg.

5.2.3 Sources of data and information used in the inventory

Primary sources of data and information used in the production of the release inventory are described in Table 1. The following section briefly summarises data and information used to produce the estimates.

Table 1. Primary sources of activity and other related data used do derive release estimates

Release category	Activity data[a]	Distribution/release factors[b]	Hg content[c]	Other
Non-ferrous metal (Cu, Pb, Zn, Al, Hg, large-scale Au) production	GMA 2015 air emissions	UNEP, 2017a,b	-	
Chlor-alkali industry	GMA 2015 air emissions	UNEP, 2017a,b	-	
Oil refining	GMA 2015 air emissions	UNEP, 2017a,b	-	
Artisanal and small-scale gold mining	Artisanal Gold Council	Artisanal Gold Council/ UNEP Partnership on Reducing Mercury in ASGM	Artisanal Gold Council/ UNEP Partnership on Reducing Mercury in ASGM	
Municipal sewage	AQUASTAT, 2017	-	*To be added*	Sato et al., 2013 UNEP, 2006
Coal-fired power plants	Liu et al. (2016); GCPT, 2017;	-	Liu et al., 2016	Biesheuvel et al., 2016
Coal washing	Enerdata, 2016	UNEP, 2017b; Liu et al, 2016; ENM, 2016	Annex 6 and Hg in coal reported therein	Carbon Locker, 2017
Hg-added products use and waste disposal	P. Maxon, pers. Comm.	UNEP, 2017b; Lin et al., 2016	-	
Produced water during oil production	IOGP, 2016 BP, 2016	-	IPIECA, 2012 IKIMP, 2012 Gallup and Strong, 2008	Lujala et al., 2007

Group 1 sources: For release categories using UNEP Toolkit distribution factors (chlor-alkali industry, oil refining, large scale Au and non-ferrous metal production), respective air emissions developed in Chapter 2 of this report were used as input data to calculate corresponding releases to water. For the ASGM category, releases are discussed based on the amounts of Hg used in these activities and practices employed in individual country, as discussed in detail in Annex 2 of this report.

Group 2 sources*:* For estimation of Hg releases associated with municipal sewage, information on amounts of municipal wastewater generated and its treatment practices in individual countries were used. Amounts of municipal wastewater were obtained mostly from AQUASTAT, the FAO's global water

10237 information system, while waste-water treatment practices were obtained based on national data on
10238 waste-water generation, treatment, and use, as summarised by Sato et al. (2013). For countries with no
10239 data general regional averages were adopted from the UNEP report (UNEP, 2006). Ranges of Hg
10240 concentrations for untreated wastewater and water treated in treatment plants were selected based on
10241 ranges reported in literature, taking the waste management profile of individual country into account
10242 (see Annex X.1 for details).

10243 Releases associated with wastewater from coal-fired power plants were estimated based on amounts of
10244 waste-water generated per MWh of energy produced, as estimated from data presented by Liu et al.
10245 (2016). Hg concentration ranges applied were taken from the same source. Realized total energy output
10246 from CFPPs in individual country which was calculated from electricity generation capacities obtained
10247 from the Global Coal Plant Tracker database (GCPT, 2017) using country-specific capacity factors
10248 adopted from Biesheuvel et al. (2016).

10249 Global releases due to coal washing are estimated using information on production rates, Hg coal
10250 content, the Hg removal efficiency of coal washing and the coal washing rates. Activity levels of raw coal
10251 production for individual country were obtained from the global energy statistical yearbook (Enerdata,
10252 2016), information on type of coal produced from international energy statistics (EIA, 2017), Hg content
10253 of various coal types was selected based on ranges reported in scientific literature (see Annex 6), coal
10254 washing rates in major producing countries adopted from Energy News Monitor (ENM, 2016) and Hg
10255 removal efficiency from UNEP (2017) and Liu et al. (2016).

10256 Releases of Hg with water produced during oil and gas extraction are estimated based on global oil and
10257 gas production patterns, discharged produced water and Hg content in various oil and gas fields.
10258 Amounts of produced water discharged globally were estimated based on data from International
10259 Association of Oil and Gas Producers (IOGP, 2016) and BP Statistical Review of World Energy (BP, 2016),
10260 while ranges of associated Hg concentrations were selected considering regional differences in Hg
10261 content in oil fields throughout the world (IPIECA, 2012).

10262 **Group 3 sources:** For estimation of Hg releases associated with the use and disposal of Hg added
10263 products information consist of estimated Hg consumption in one year covering the product groups:
10264 batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other

uses (P. Maxon, 2017). The same distribution factors as in the case of air emissions were used to follow the fate of mercury through major pathways (see Annex 3 for details). Water specific release factors were selected and adjusted according to waste management profile of individual country based on factors from the Toolkit (UNEP, 2017) and Lin et al. (2016).

5.2.4 Relationship with independent inventories and approaches

In Figure 2 comparison of sectors for which releases to aquatic systems are being reported in various independent release inventories is shown schematically. Arrows indicate sectors comparable to various extent to GMAAR approach used in this study and which we use for comparisons with our estimates. In the following section, an overview of these independent inventories is given.

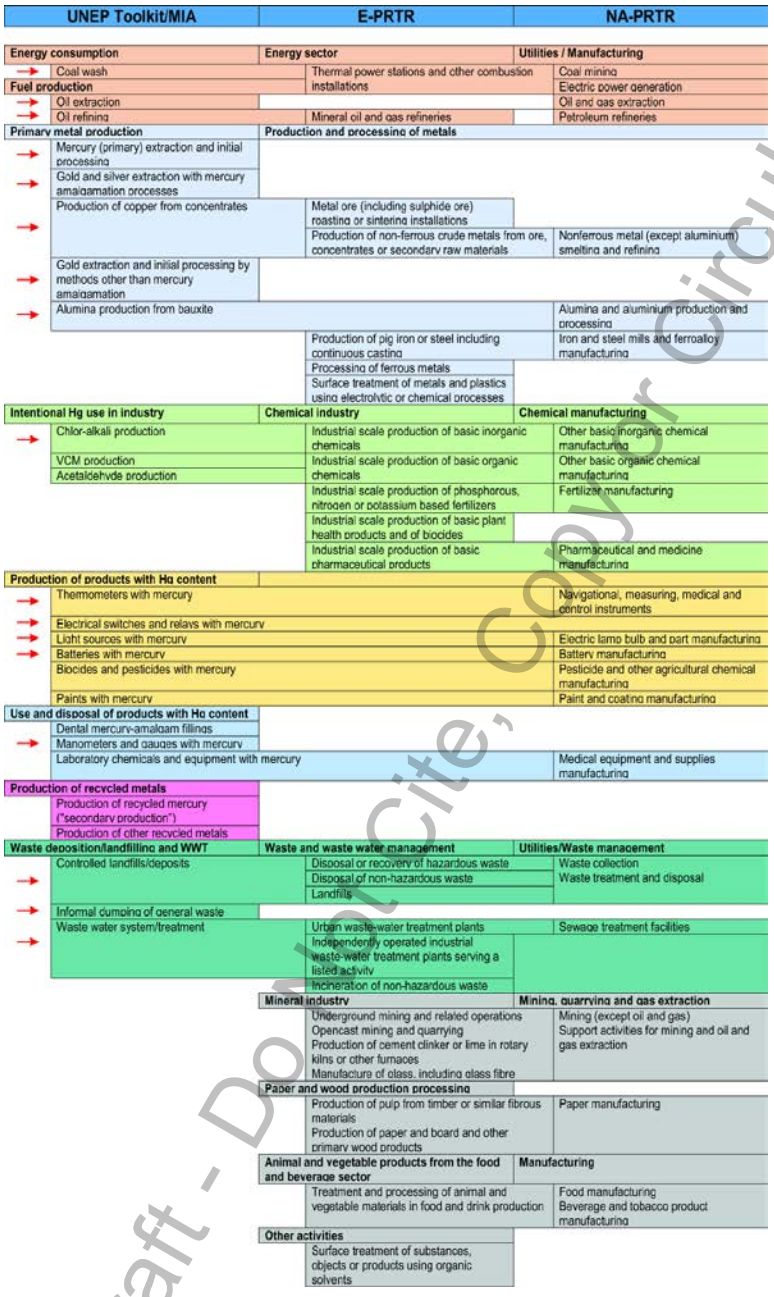

Figure 2. Comparison sectors used in various release inventories with arrows indicating sectors comparable (directly or indirectly) to GMA approach used in this study

For some countries independent inventories are available conducted as part of the Minamata Initial Assessments (MIAs) (ref.) and where UNEP Toolkit was used for identification and quantification of Hg releases.

The European Pollutant Release and Transfer Register (E-PRTR) is publically available Europe-wide register that provides key environmental data, including measurement of Hg releases to the air, water and soil as well as off-site transfers of waste, from by over 30,000 industrial facilities in European Union Member States and in Iceland, Liechtenstein, Norway, Serbia and Switzerland (UNEP, 2016). The following main sectors are covered in E-PRTR (http://prtr.ec.europa.eu) and data is available for 2007-2014 period: 1) energy sector, 2) production and processing of metals, 3) mineral industry, 4) chemical industry, 5) waste and wastewater management, 6) paper and wood production processing, 7) intensive livestock production and aquaculture, 8) animal and vegetable products from the food and brewery and 9) other activities. For each sector several sub-activities exist, however only those reporting Hg releases to water are shown in Figure 2. In case of E-PRTR it should be noted that reporting requirements are subject threshold which is set at the relatively high 1 kg Hg/yr.

NA-PRTR: Canada, Mexico, United States report data from 2006 to 2013 for states, provinces and territories on different levels (http://www.cec.org/) for different pollutant types including Hg within the North American Pollutant Release and Transfer Register (NA-PRTR). In the NA-PRTR inventory North American Industry Classification System (NAICS) is used, a system working on various levels of detail. In Figure 2, for the comparability reasons, sectors relevant for aquatic Hg releases from different NAICS levels are indicated. Similar as in the case of E-PRTR there is a threshold amount for reporting in NA-PRTR.

5.2.5 Regionalisation based on drainage basins

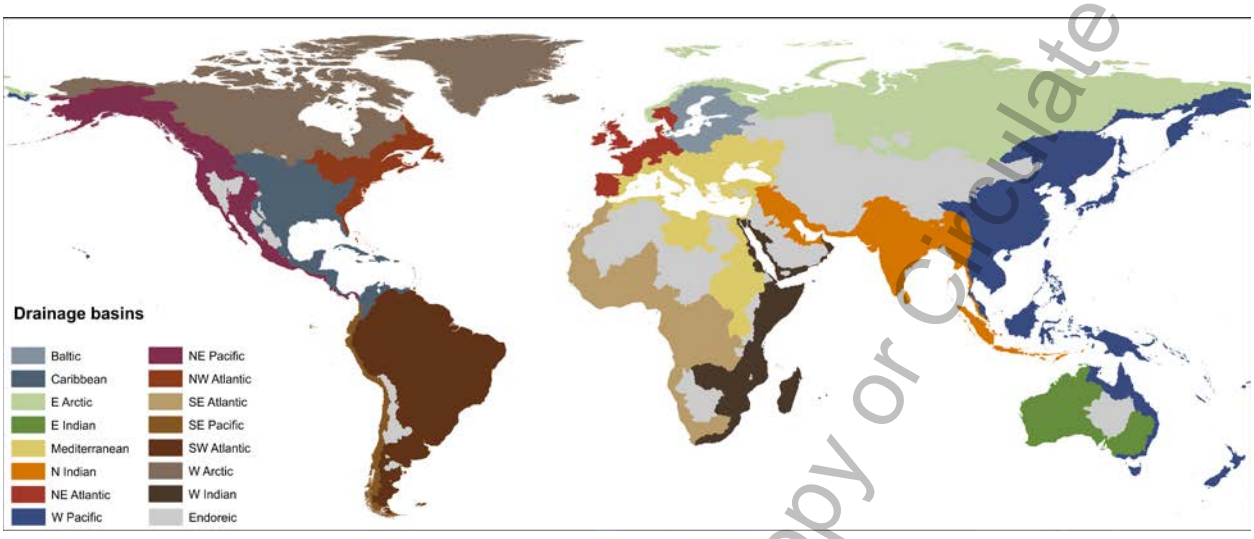

Figure 3. Drainage basins considered in the inventory (source: compiled by William Rankin (personal communication) based on USGS Hydro1k database (Garretson, SD, USA))

Additional regionalisation used to summarise inventory results is based on major global drainage basins map illustrated in Figure 3. The map comprises 15 basins draining to the principal oceans and seas of the world. An additional group of endorheic basins consists of several basins distributed in various parts of the world and that do not drain to the oceans. These basins used for the spatial distribution of Hg releases estimated in our inventory have quite different characteristics, e.g. in terms of land-use and population density. Important shares of crop land are present in NE Atlantic, N Indian, Caribbean and Mediterranean basins. The artificial surfaces have the highest shares in NE Atlantic and NW Atlantic basins, followed by Caribbean, Baltic and Mediterranean basins. On the other hand, drainage basins with the highest population density are N Indian, NE Atlantic and W Pacific.

5.2.6 Uncertainties and limitations

It should be pointed out that, given the global scope of this assessment, there are several limitations of this work and the estimates presented here are just that – the estimates. Numbers discussed in the following sections are derived using a number of different approaches and various assumptions, and the use of alternative approaches and assumptions might result in significantly different values. It was out of the scope of this work, however, to address these aspects into detail.

In order to provide some quantification of the uncertainties associated with the 2015 inventory, upper and lower range releases were produced for all sectors. For the sectors using the Toolkit approach, upper and lower range release estimates were calculated using the methodology used for emission inventory and described in Chapter 2 of this report. For the Group 2 and Group 3 sectors, upper and lower range releases were produced using the respective upper and lower ranges of Hg levels and associated activity data, respectively. Uncertainties related to the input data selected are further discussed for selected sectors in Section 3.4.

In addition to the above mentioned uncertainties, an additional limitation of this work is the possible double counting on one hand and the potential for underestimation of releases on the other. All sectors included in the inventory have a distinctive Hg sources and their pathways are clearly identified. The exception are releases associated with municipal waste-water which might contain a fraction of releases accounted for in the Hg-added products sector, releases resulting from breakage during use pathway to be specific. This latter pathway is however a minor share representing only 5% of releases from Hg-added products sector. As to the possible underestimation, a number of sectors and activities are identified in Section 2.2.2 that are not included in the current inventory, but might be important contributors to Hg releases on global scales. The current inventory of global anthropogenic Hg releases to aquatic systems is a work in progress, and an important step towards filling a major gap in inventories of anthropogenic Hg releases to the environment.

5.3 Estimating global anthropogenic mercury releases: Results

Given the specific nature of releases associated with artisanal and small scale gold mining (see section 3.3.6 for details), results for ASGM and non-ASGM sectors are discussed separately. In section 3.1 overall results are discussed considering releases summarised based on three general source categories (ore mining and processing, energy sector and waste treatment) and sub-regions. Section 3.2 presents inventory results spatially resolved according to major drainage basins of the world, while details for selected sectors are given in section 3.3, including discussions on trends where possible and the associated uncertainties.

Using the methods described above, the total estimated inventory of anthropogenic Hg releases from sources for which there was enough information to provide quantitative estimates, is 434 (x-y) t/y (ASGM not included).

5.3.1 Inventory results by region and sectors

Table 2 summarises the distribution of the estimates of global anthropogenic Hg releases to aquatic systems according to sub-continental regions. Table 3 presents the results per region on a per capita basis, for ASGM and other sectors.

Table 2. Global anthropogenic mercury releases to aquatic systems from different regions

Sub-continent	Releases[a] (range), t	%
Australia, New Zealand & Oceania	5.01 (x – y)	1.2
Central America and the Caribbean	19.9 (x – y)	4.6
CIS & other European countries	46.3 (x – y)	11
East and Southeast Asia	160 (x – y)	37
European Union	17.7 (x – y)	4.1
Middle Eastern States	14.9 (x – y)	3.4
North Africa	10.8 (x – y)	2.5
North America	22.3 (x – y)	5.1
South America	36.1 (x – y)	8.3
South Asia	54.2 (x – y)	12
Sub-Saharan Africa	46.7 (x – y)	11
Total	434 (x – y)	100

[a]Values rounded to three significant figures, ASGM not included

Table 3. Per capita anthropogenic mercury releases to aquatic systems in different regions

Sub-continent	Per capita releases from non-ASGM sectors, g	Per capita releases from ASGM [a], g
Australia, New Zealand & Oceania	0.16	0.00
Central America and the Caribbean	0.09	0.30
CIS & other European countries	0.14	0.03
East and Southeast Asia	0.07	0.19
European Union	0.04	0.00
Middle Eastern States	0.05	0.00
North Africa	0.06	0.00
North America	0.06	0.00
South America	0.09	0.95
South Asia	0.03	0.00
Sub-Saharan Africa	0.05	0.10
Global	0.06	0.14

[a]To both land and water

Figure 4 and Table 4 summarise the distribution of the estimates of global anthropogenic Hg releases to aquatic systems according to sector. Apart from combined releases to water and land resulting from ASGM activities, the majority of the global anthropogenic releases of Hg to aquatic systems are associated with the waste treatment sectors (52%), followed by energy sector (26%) and ore mining and processing group of sectors (22%). Overall, the new inventory is dominated by releases from two individual sectors, namely releases resulting from the use and disposal of Hg added products, and those associated with municipal wastewater. These two sectors alone contribute more than half (52%) of the total releases from all the sectors included. Other major release sectors include waste-water from coal fired power plants (13%), non-ferrous metals production (11%), coal washing (9.7) and production of gold from large-scale mining (9.4%).

The three newly added sectors (municipal wastewater, CFPPs and coal washing) are driving the relatively large difference between the 2010 and 2015 anthropogenic Hg release inventory (185 t/y in 2010 compared to 434 t/y in 2015). Here it should be noted that compilation of the global aquatic Hg inventory including identification of new sources is an ongoing activity, and as recognised in the 2010 inventory already, global releases are assumed to be underestimated due to the lack of information for some sources. In addition, there were some methodological changes incorporated in the 2015 inventory and as such both inventories cannot be directly compared. On the other hand, it must be pointed out that the three newly added sectors have the largest associated uncertainty among all included sectors. Methodological changes and uncertainties are further discussed in Section 3.3.

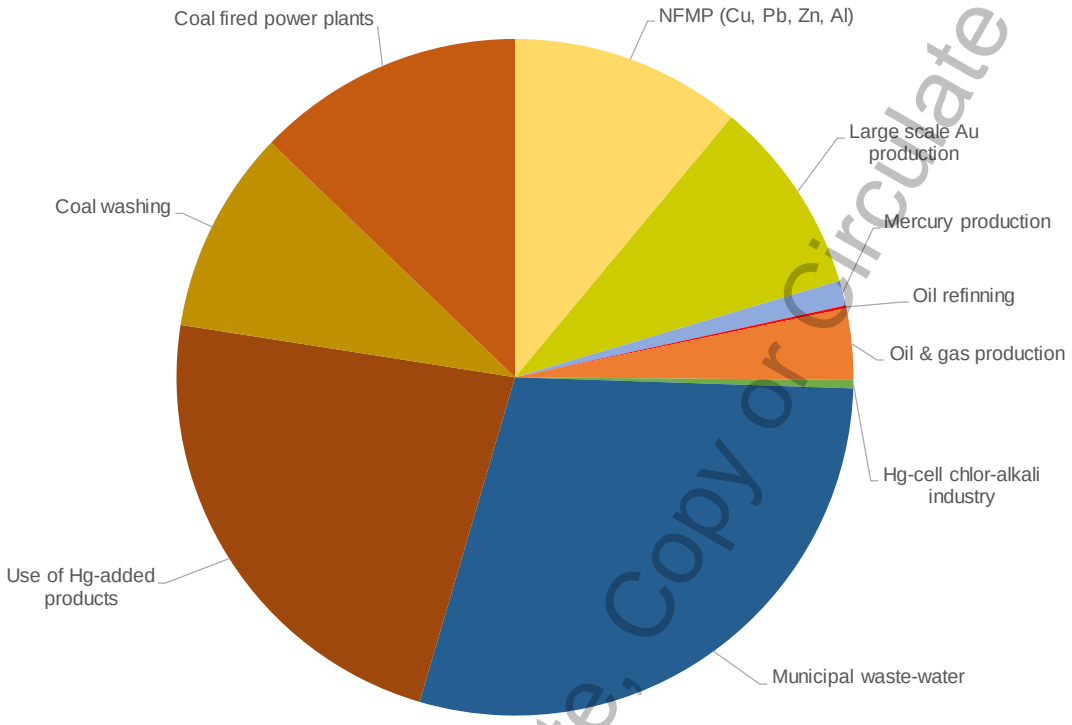

Figure 4. Proportions of global anthropogenic mercury releases to water in 2015 inventory from different sectors

Table 4. Global anthropogenic mercury releases to aquatic systems from different sectors

Sector	Releases (range), t[a]	%[b]
Production of non-ferrous metals (primary production of copper, lead, zinc and aluminium)	47.9 (x - y)	11
Production of mercury metal	5.18 (x - y)	1.2
Production of gold from large-scale mining	40.6 (x - y)	9.4
Mercury releases from oil refining	0.56 (x - y)	0.1
Mercury releases during oil and gas production	14.7 (x - y)	3.4
Mercury releases from chlor-alkali industry (Hg cell technology)	1.74 (x - y)	0.4
Mercury releases with municipal sewage	126 (42 - 210)	29
Mercury releases from coal-fired power plants	55.6 (12.3 - 123)	13
Mercury releases from coal washing	42 (23 - 65)	9.7
Mercury releases from Hg-added products use and waste disposal	99.4 (66.5 - 133)	23
Production of gold from artisanal and small-scale gold mining[c]	1011 (509 - 1513)	-
Total	434 (x – y)	

[a]Values rounded to three significant figures;, [b]ASGM not included;[c]Releases to both land and water

Figure 5 presents the 2015 inventory graphically by region and sector. It can be clearly seen from the illustration that relative contribution to the global anthropogenic Hg releases to water is by far the greatest in East and Southeast Asia. This is driven by large population and associated large industrial and other activities. As this region is a dominant source of Hg releases from all sectors, distribution of releases between sectors reflects the global one. On the other hand, relative contribution of Hg releases from different sectors varies a lot from region to region, clearly reflecting differences in technological and socio-economic status of the regions.

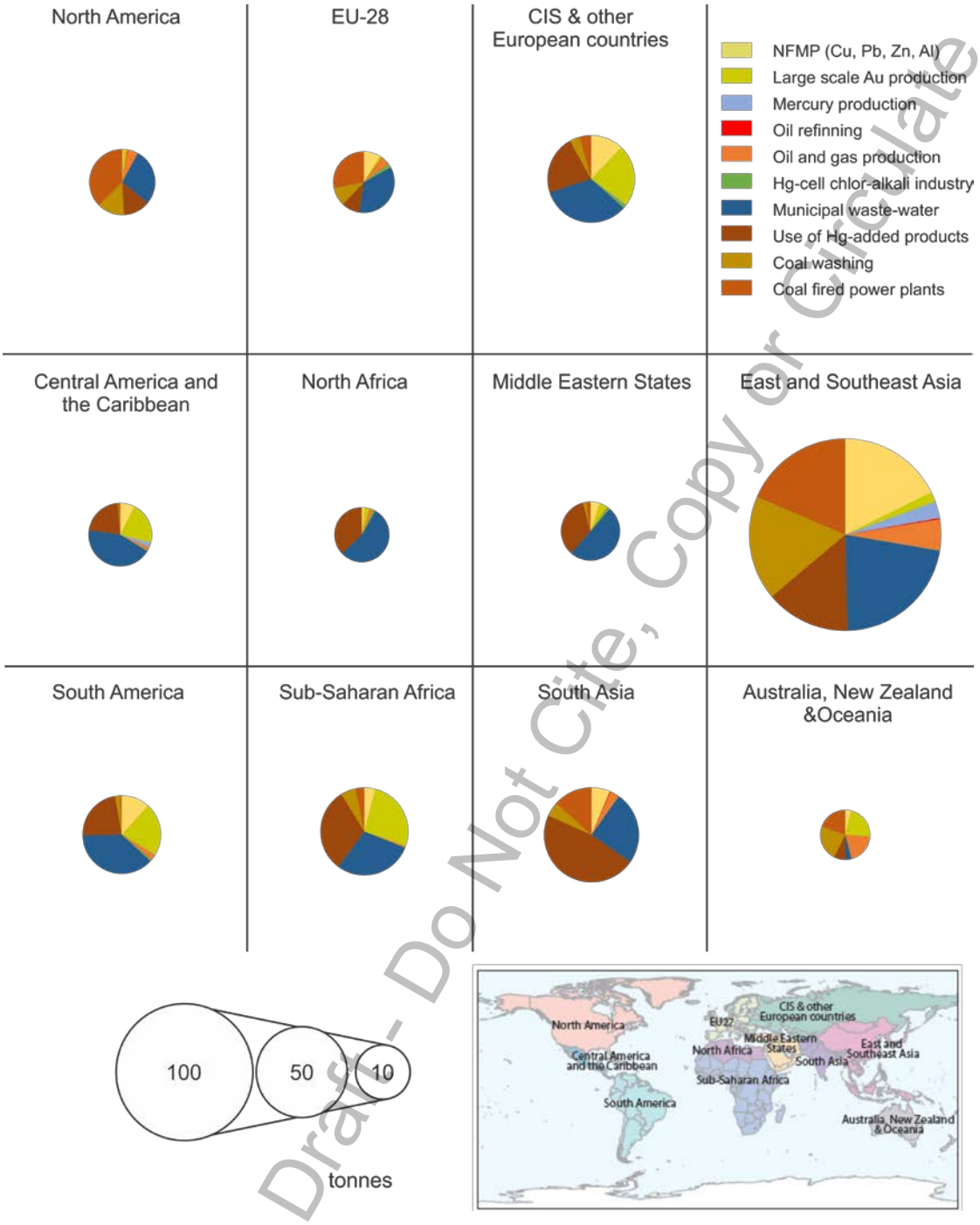

Figure 5. Regional pattern of global anthropogenic mercury releases to water in 2015 inventory from different sectors

5.3.2 Inventory results by drainage basin

To be added

5.3.3 Discussion of results for selected sectors

The following sections discuss details on Hg releases associated with major release sectors. For the sectors included in both 2010 and 2015 inventory, trends in releases are also addressed, as well as differences in methods used to derive the estimates.

5.3.3.1 NFMP including Cu, Pb, Zn, Al, Hg and large scale Au production

The estimates included in the current inventory for releases from copper (Cu), lead (Pb), zinc (Zn), aluminium (Al), mercury (Hg), large scale gold (Au) production were all included previously in the 2010 inventory. Sum of releases from these sectors is comparable between the two inventories (92.5 vs. 88.5t/y), with around half of it resulting from large-scale gold production. It should be noted however that this latter sector has large associated uncertainties.

5.3.3.2 Municipal sewage

Releases from municipal sewage have not been addressed in the 2010 inventory. Estimates suggest that this sector is an important sector contributing significant amounts (29%) to the total global inventory. Given the input data and approach used for estimating Hg releases (details in Annex X.2), Hg releases from this sector are linked closely to water-use patterns and wastewater treatment practices in individual countries. Substantial part of municipal waste-water results from domestic water uses, but also from commercial and industrial effluents and storm water. While developed nations have very large per-capita water use and efficient wastewater treatment, people in developing countries use much less water, however with poorly developed wastewater collection and treatment systems (Sato et al., 2013). It is expected that with increases in population of developing nation's water demand and associated Hg releases will increase in these regions. On the other hand, it should be noted that global distribution and consumption of Hg containing products as one of the most important sources of Hg for this sector, is not uniform, and will largely depend on individual country's economy, with more products being consumed in developed parts of the world. Phase out of many products that contain Hg under the Minamata Convention is expected to result in decreases of Hg releases with municipal sewage, and so is the anticipated increased treatment of wastewater.

While Hg concentrations in both treated and untreated municipal waste-water are relatively well documented in the literature, Hg release estimates for this sector depend largely on data on global water use patterns, information that is considered as the least reliable and most inconsistent of all

water resources information (Gleick et al., 2014). The major limitations are lack of reporting standards, differences in approaches used to derive the information on water usages, and large inconsistencies in reporting years (Gleick et al., 2014). Another source of uncertainties lies in the fact that country-scale wastewater treatment levels (i.e. primary, secondary, and tertiary), practices that have significantly influence on effluent Hg concentrations, are mostly unknown. In our estimates, different Hg removal efficiencies for treated water were assigned to individual countries based on their waste management profile (cross ref).

5.3.3.3 Coal industry

Releases from coal industry have not been addressed in previous global inventories. In the 2015 inventory we consider two types of releases resulting from associated water use: Hg releases with wastewater from coal-fired power plants and those resulting from coal washing. Together both releases are estimated to contribute 23% to the global inventory. Both types of release estimates are considered preliminary and have large associated uncertainties. In the case of coal-fired power plants, this reflects the fact that information on actual profiles of installations - water use practices, treatment and wastewater generation - is missing for most of the world's CFPPs and so is information on Hg concentrations in respective effluents. In case of coal washing the major uncertainties are the result of assumptions that had to be made regarding coal washing rates, removal efficiencies and especially selected share of Hg reaching aquatic systems in individual countries. Estimates are therefore made based on gross generic assumptions as described in Annexes X.3 and X.4.

Coal-fired power plants. CFPPs are recognised as one of the major anthropogenic Hg emission sources. However, due to the lack of quantitative information, Hg releases to water from this sector were neglected in previous inventories. Large releases are the result of the fact that coal industry is by far the greatest water demanding anthropogenic activity in the world, and it was estimated that in 2013 CFPPs alone consumed 19 billion m^3 of freshwater globally (Cheng and Lammi, 2016). While the vast majority of this water is used for cooling, and is usually not contaminated with Hg, additional water uses such as pollution control can also generate large amounts of Hg contaminated wastewater. Here, an attempt was made to quantify Hg releases with this latter non-cooling water-use types.

Despite many uncertainties, there is now much more evidence based on both measured and estimated data about the significance of Hg releases from CFPPs. It is known that plants using wet scrubbers can

discharge up to tens of kg of Hg to local surface waters per year (EIP, 2016, E-PRTR, 2014). In addition to discharges to surface water, even larger amounts of Hg (up to hundreds kg per year) are dumped into ash ponds which are prone to leaks (EIP, 2016). In a recent aquatic release inventory for China, wastewater discharged from CFPPs, although in gradual decline in the last decade, is recognised as one of the most important anthropogenic sources of Hg (Liu et al., 2016). Similar, according to European Pollutant Release and Transfer Register (E-PRTR, 2017), Hg releases from thermal power stations and other combustion installations are the second largest source – second only to urban waste-water treatment plants. Global Hg releases from this sector using assumptions described in Annex X.3 are based on information available for China (Liu et al., 2016) and are estimated in the 12-123 t/y range. Alternative to this approach would be an estimate made based on simple global upscaling of ratio of anthropogenic Hg released to water and air for China for this sector which is approximately 1:4. This would result in a global release of 50-110 t/y, which is a range comparable to the first approach.

Coal washing. In addition to water used in CFPPs, large amounts of water are used during coal mining and washing. The latter is used to remove impurities and ash from the coal and results in the generation of a slurry of toxic material (Cheng and Lammi, 2016). Here, in the absence of detailed information, we use the approach similar to that of Liu et al. (2016) and make a preliminary estimate of likely magnitude of global Hg releases due to coal washing based on global coal production, coal Hg content, assumed Hg removal efficiencies, washing rates and environmental fate in individual countries (see Appendix X.4 for details). Given the fact that coal washing results in higher caloric value of coal and consequently a higher economic value, coal beneficiation is increasing throughout the world. Available information suggests that a higher share of the coal produced is treated in more developed countries but is also in increase in developing economies (Budge et al., 2000). Estimates available for China, the major coal producer in the world, indicate rapid increase of Hg releases from coal mining and washing with an annual average growth rate of 25% in the 2001-2012 period, making this sector the second largest anthropogenic source of aquatic Hg in China (Liu et al., 2016). Overall releases from this sector are largely dominated by releases from China (>60%), followed by other important coal producing countries such as United States, India, Australia and Indonesia. In addition to high uncertainty of the approach and sensitivity of all input information used to derive these estimates, it should be pointed out that these numbers are obtained based on very gross assumptions regarding environmental fate of Hg once washed from coal. Nevertheless, even larger quantities of Hg in the magnitude of tens of tonnes per year are assumed to

accumulate in the slurry ponds at coal washing sites globally, representing a great environmental hazard for local aquatic systems, as these ponds are often very prone to brakeage and leaking (Cheng and Lammi, 2016).

5.3.3.4 Oil industry

The 2015 inventory includes two types of releases associated with oil industry. Hg releases from oil refining were included previously in the 2010 inventory, while releases with produced water during crude oil and gas production is a newly added sector. Given the fact that in 2015 oil refineries processed similar amounts of crude as in 2010, and that the same method was used to estimate releases, differences between the two inventories are negligible. Both release types, refining and crude processing, together contribute approximately 3.5% of the total inventory. Of that a vast majority (96%) is attributed to produced water, and of which ~85% is occurring off-shore. Using the approach described in detail in Annex X.5, almost 70% of these releases are attributed to Asian countries due to large amounts of produced water and more mercury contained in these regions oil and gas fields. There might be additional releases from this industrial activity such as releases during separation and transportation of crude oil and gas not accounted for in this inventory.

5.3.3.5 Hg-added products – use and waste disposal

Hg-added products sector comprise of releases from the following product groups: batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other uses (see Annex 3 for details). In the 2010 inventory, releases for this sector were estimated based on Hg emission inventory by using the distribution factors from the UNEP Toolkit to calculate the corresponding magnitudes of releases to water. The 2015 inventory adopts the model used to estimate mercury emission from waste streams associated with intentional use sectors and considers releases for three main pathways of Hg-added products: breakage during use, waste recycling and waste landfilling (see details in Annex X.6). In addition to the new method used to derive the estimates, there is a change in the models input data. In the 2010 inventory part of the mercury from Hg-added products (approx. 30%) was considered as "retained in use" and is now included in the waste streams and consequently in emission and release pathways, respectively.

Our estimates suggest significant Hg releases due to usage and disposal of Hg added products (66-133 t/y), a vast majority (91%) being associated with uncontrolled landfilling of waste which is primarily

occurring in developing countries, followed by releases during breakage (5%) and recycling (4%). Due to environmental regulations and new technologies available, the use of Hg in products is in decline and so are environmental releases of Hg, especially in developed countries. Substitution of Hg-added products with non-Hg containing alternatives, however, is also becoming evident in developing countries. An exception are products without the adequate Hg-free alternatives such as lightning devices which are also excluded from the Minamata Convention.

It should be noted that these estimates depend largely on estimates of regional consumption of Hg-added products. While this information is available for developed countries, very little information is available on the real consumption patterns for Hg-added products in developing countries.

5.3.3.6 Artisanal and small-scale gold mining (ASGM)

Given the fact that there is still not enough information and knowledge to separate terrestrial releases between water and land, releases associated with artisanal and small-scale gold mining (ASGM) remain a "special" sector in the inventory. The detailed reasoning for this is given in 2010 inventory (AMAP/UNEP, 2013). In summary, Hg releases for this sector are based on amounts of Hg used in ASGM activities and the characteristics of the mining practices applied in individual countries. The methodological approach used differentiates between emissions to air and releases to both land and water (details including example calculation is given in Annex 2). At this point, it is not possible to directly determine what the proportion is of Hg associated with this later pathway that will enter hydrosphere. In addition to the direct losses occurring during ore amalgamation, large quantities of Hg are accumulating in soils and sediments surrounding ASGM sites over the time. This accumulated Hg has potential to be remobilised and enter aquatic systems, however with a time-lag usually unknown, depending largely on site-specific environmental conditions. It is estimated that ASGM releases to water and land in 2015 are 1011 t/y (range, 509-1513 t/y).

5.3.4 Comparison of estimates with national reported inventories and other sources

To be added

5.3.5 Inventory in the context of global Hg cycle

To be added

5.4 Conclusions

5.4.1 Key findings

- The 2015 global inventory of Hg releases from anthropogenic sources is more complete and reinforces the importance of these sources in the global context.
- Global releases of anthropogenic Hg to freshwater, excluding ASGM, based on revised estimates are 430 t/y, compared to 180 t/yr in the 2010 estimate.
- New sectors were added to this inventory and include releases with municipal wastewater, from coal washing, coal fired power plants and with produced water during oil and gas production. Uncertainties for these sources are large (+/- X%). Better information about coal washing practices and fate of Hg during various water uses in coal fired power plants are needed, in particular.
- While levels of Hg associated with individual sectors included in the inventory are relatively well established, all other supporting information (e.g. production rates, waste-water generation, treatment practices etc.) is much more unreliable and inconsistently reported, and drives the uncertainties of the estimates.

5.4.2 Future gaps and needs

- Reduction of uncertainties for all the sectors included in the inventory is needed by using more systematic and harmonised approaches in data collection.
- Not only information on Hg content must be improved, but especially information on related activity data needed to derive the estimates.
- Additional sectors and anthropogenic activities, not taken into account in this inventory, as discussed in detail in Section 2.2.2, should be included in future inventories. Although recognised as less relevant in the global context in this work, some of these sources might be significant contributors of Hg to local aquatic systems.
- Estimates in the 2015 inventory are made based on country-level information. Future work would benefit from inclusion of more detailed facility-level information to improve the spatial distribution component of this work. Along these lines, more detailed knowledge on differences in technologies used, waste treatment practices and Hg consumption patterns in individual countries should be incorporated.

- Harmonisation of methodological approaches for estimating the releases is needed, e.g. something along the lines of the UNEP Toolkit approach but focused on aquatic Hg releases.
- Although out of the scope of this chapter, lack of knowledge regarding the fate of Hg once released from the source was recognised as a limiting factor for placing inventory results in the context of the global Hg cycle. Future work should focus more on establishing relationships between catchments characteristics, sources within individual catchments and the Hg outflows. Nowadays, techniques like isotope tracer experiments and isotope ratio measurements of Hg are available to address this issues.

Annex X

Given the global nature of the inventory and general lack of data/information on aquatic Hg releases and associated information, assumptions had to be made to derive the estimated presented in this work. Often these assumptions are difficult to validate. For the transparency reasons details on the data/information and assumptions made within individual release category are given here.

X.1 Group 1 sectors

Group 1 sectors use UNEP Toolkit distribution factors from Table X.1 to calculate releases to water from the 2015 air emission inventory. Details for compiling data and derivation of air emissions are given in Chapter 2 and Appendixes 1-6.

Table X.1. UNEP Toolkit distribution factors and scaling factors for water/air distribution

Sector	UNEP Toolkit distribution factor		Scaling factor (water/air)
	to air	to water	
Chlor-alkali industry	0.1	0.01	0.1
Oil refining	0.25	0.01	0.04
Large scale Au	0.04	0.02	0.5
Non-ferrous metal production (Cu, Pb, Zn)	0.1	0.02	0.2
Non-ferrous metal production (Al)	0.15	0.1	0.67
Non-ferrous metal production (Hg)	0.25	0.06	0.24

X.2 Municipal wastewater

The 2015 inventory for Hg releases associated with municipal wastewater is based on information regarding volumes of municipal wastewater produced, wastewater treatment practices and reported Hg concentrations measured in wastewater before (influent) and after the treatment (effluent). Municipal wastewater is water that has been used for municipal use and is afterwards released back to the environment. Treatment of this released water mostly depends on prosperity of the country and consequently its capacities and number of wastewater treatment plants. Bulk of the information for individual countries was obtained from the AQUASTAT database of the Food and Agriculture Organisation of the United Nations (FAO). AQUASTAT reports amounts of municipal wastewater generated within urban areas. Since not all countries are reporting their amounts of municipal wastewater on regular yearly basis, the last available data for each country was used. For countries with no data available, waste-water was calculated based on assumed water use per person per day. Water use averages for individual continent were selected and assigned to the countries with missing data: 230 for Asia, 50 for Africa, 200 for Europe, 100 for Oceania and 100 l/person/day for Caribbean countries. Percentage of treated waste-water has been then assigned to each country. Treatment data are based on the numbers from Sato et al. (2013). For the countries with no specific values on treatment, general regional ratios from UNEPs state of the marine environment report were adopted (UNEP, 2006), assuming similarities within regions and between the neighbouring countries.

Magnitude of Hg releases from this sector will depend greatly on the amount of Hg products used, general waste handling practices and especially level of waste-water treatment - information lacking for most of the countries. In absence of such information, generic waste management profile of a country was used and different ranges of Hg concentrations applied for untreated wastewater and wastewater treated in treatment plants, to estimate releases for individual country. These estimates are based on an assumption that Hg concentrations in untreated wastewater are lower in more developed countries compared to those in developing nations, as seen from values reported in scientific literature. Further assumption is that Hg removal is more efficient in developed countries due to greater levels of waste-water treatment (Table X.2).

Table X.2 Ranges of Hg concentrations in untreated and treated sewage used to derive the estimates

Profile	Hg in untreated wastewater [ng/L]	Hg removal efficiency [%]	Hg in treated wastewater [ng/L]
1	100-500	95	5-25
2	300-1500	80	60-300
3	300-1500	70	90-450
4	300-1500	60	120-600
5	300-1500	50	150-750

X.3 Coal-fired power plants

The 2015 inventory for Hg releases with wastewater from coal-fired power plants uses a very coarse approach for a first preliminary estimate of global magnitudes associated with this sector. In the absence of more detailed country-specific information, the approach largely relies on information available for China and work carried out by Liu et al. (2016), by upscaling globally relationships between CFPPs electric capacities, amounts of wastewater produced and associated reported ranges of Hg concentrations reported in their work.

The method applied is based on an assumption that on average global water use patterns in CFPPs are similar to those in China, country that is the single largest user of coal-derived electricity in the world. This is of course a rough generalisation, however inevitable in order to perform harmonised global calculation approach.

Based on wastewater volumes reported by Lie et al. (2016) and total electricity generation capacity of CFPPs in China, wastewater generation was estimated at 0.25-0.5 m^3 per MWh of energy produced. For the purpose of this wastewater generation estimate, realized energy output from CFPPs was calculated using the capacity factor of 0.55 (Biesheuvel et al., 2016). In order to estimate generation of wastewater in each country of the world with CFPP, wastewater generation rate from China was then used along with the information on country-wide CFPPs total capacity based on information provided in Global Coal Plant Tracer database (GCPT, 2017). Capacity factors used for calculation of the amount of energy produced in individual country were adopted from Biesheuvel et al. (2016). Final amounts of Hg releases

per country were estimated using Hg concentrations in CFPPs generated wastewater in 5-25 mg/m^3 range (Liu et al., 2016 and references therein).

X.4 Coal washing

The 2015 inventory for Hg releases associated with coal washing is based on global coal production, coal Hg content, Hg removal efficiency and coal washing rates, following the approach of Liu et al. (2016).

Total coal production in 2015 for individual country was obtained from the Global Energy Statistical Yearbook 2016 (Enerdata, 2016). In the absence of detailed per-country information on amounts of different coal types, regional information on coal type produced (anthracite, metallurgical, bituminous, subbituminous and lignite) was obtained from International Energy Statistics available for the year 2014 (U.S. Energy Information Administration, 2017b). Regional ratios were then applied to individual country. For countries where information on Hg content in various Hg coals was available as summarised in Annex 6, country specific average Hg content was used, while for countries where this information is missing generic values were applied. Information on coal washing rates in individual countries is available for world's major coal producers only, China, United States, India and Australia, and varies in the 20-90% range. For the rest of the world we assume that higher percentages of coal produced are being washed in developed countries and assign the following washing rates using technology profiles (TP) of the country: TP1-80%, TP2-65%, TP3-50%, TP4-35% and TP5-20%. The Hg removal efficiency of coal washing is selected in 20-30% range (UNEP, 2017; Liu et al, 2016). It is further assumed that only part of Hg released during washing will reach local aquatic systems, the rest being deposited in slurry ponds. Using waste management profiles of individual country, following percentages for Hg reaching water courses were selected: WP1-20%, WP2-30%, WP3-40%, WP4-50% and WP5-60%.

X.5 Releases with produced water during oil and gas production

The 2015 inventory of Hg releases with produced water during oil and gas production is based on information on global oil and gas production patterns and knowledge about associated amounts of discharged produced water and Hg content in various oil and gas fields.

Initially, amounts of produced water discharged globally were estimated using amounts and knowledge regarding percentage of global coverage as reported for various regions of the world (Africa, Asia/Australasia, Europe, FSU, Middle East, North America and South & Central America) by the

International Association of Oil and Gas Producers (IOGP, 2016) for the target year 2015. Information on produced water discharged is available separately for onshore and offshore oil and gas production.

Total per region amounts were then used together with selected Hg concentration ranges to derive regional Hg releases. Publically available information on Hg concentration in produced water is very scarce. It is known, however, that there can be significant differences in Hg content in different oil and gas fields throughout the world. Limited data available indicate Hg levels in produced water can vary from less than 1 ppm (IKIMP, 2012) to tens of ppm in some of the oilfields in the gulf of Thailand (Gallup and Strong, 2008). In the absence of detailed information on Hg concentrations in produced water from oil and gas fields of the world, different Hg concentrations were assigned to different regions of the world, using the regional breakdown for crude oil Hg concentrations by IPIECA (2012) (Table X.3).

In the next step, regional releases divided to onshore and offshore share were proportionally downscaled to per country level, using information on oil and gas production in individual country as reported in BP Statistical Review of World Energy (BP, 2016) for the target year 2015. In the absence of detailed information on onshore and offshore production in individual country, PETRODATA, a spatially distributed dataset on global oil and gas fields (Lujala et al., 2007) was used to identify the countries with both or just one type of production.

Table X.3. Regional breakdown of mercury median crude oil concentrations and assigned produced waste-water Hg concentrations

Continent	Median crude oil concentrations [ppm]	Produced water concentrations [µg/l]
Africa	1	3.0
Middle East	1	3.0
Europe	1.2	3.5
North America	1.2	3.5
South America	1.4	4.0
Pacific and Indian	3	9.0

[a]IPIECA, 2012

X.6 Hg added products

In 2015 inventory mercury releases to water from Hg added products are produced using methodology comparable to that applied to estimate emissions to air (see Annex 3 for details). The approach uses regional patterns of consumption of Hg and Hg-containing products. Mercury releases at various points

in the life-cycle of these products are estimated using assumptions regarding rates of breakage, waste handling, and factors for releases to water. The input data consist of estimated Hg consumption in one year (2015) covering following product groups: batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other uses. These amounts are then distributed to four different initial pathways (safe storage, breakage and releases of Hg during use, paths to the waste stream, products remained in use) using distribution factors. Waste pathways are further differentiated among waste recycling, waste incineration and waste landfill. This latter pathway is further distributed between two levels of waste management, controlled and uncontrolled waste landfill. Within these pathways, releases to water are assumed for breakage/release during use, recycling and from waste landfills. Releases to water are then estimated by applying release factors (RF) according to Table X.4 to the distributed individual amounts of Hg. For releases resulting from breakage during use, waste recycling and controlled landfills, release factors are the same for assigned generic profiles of waste management. A differentiation is introduced for releases from uncontrolled landfills by using different release factors for individual profiles. Using this approach, estimates were made for individual countries, while global population density/distribution map was then used to spatially distribute and summarise the estimates according to major drainage basins of the world.

Table X.4. Release factors (fraction released) applied to distributed amounts of mercury in Hg-added products

Profile	Break/release during use	Waste recycling	Landfill	
			controlled	uncontrolled
1	0.1	0.05	0.0001	0.05
2	0.1	0.05	0.0001	0.10
3	0.1	0.05	0.0001	0.15
4	0.1	0.05	0.0001	0.20
5	0.1	0.05	0.0001	0.25

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