Chapter 4

Persistant toxic substances (PTS) sources and pathways

4.1. Introduction

In general, the human environment is a combination of the physical, chemical, biological, social and cultural factors that affect human health. It should be recognized that exposure of humans to PTS can, to certain extent, be dependant on each of these factors. The precise role differs depending on the contaminant concerned, however, with respect to human intake, the chain consisting of 'source – pathway – biological availability' applies to all contaminants. Leaving aside the biological aspect of the problem, this chapter focuses on PTS sources, and their physical transport pathways.

Contaminant sources can be provisionally separated into three categories:

- **Distant sources:** Located far from receptor sites in the Arctic. Contaminants can reach receptor areas via air currents, riverine flow, and ocean currents. During their transport, contaminants are affected by the combined effects of physical and chemical factors. Persistence in the environment is, therefore, one of the most important characteristic in determining the ability of contaminants to reach the Arctic. In this respect, PTS, due to their low degradation rates, are often considered to be 'global contaminants' subject to long-range transportation.

- **Local sources:** These are located in receptor region, often in the vicinity of indigenous communities. Although transport of contaminants from local sources to recipients is determined by the same physical and chemical processes as contaminants from distant sources, there are a wider range of pathways and mechanisms that may be involved in the case of local sources. For example, mechanisms of soil contamination from local sources can differ significantly, such that effects of local contamination can be much greater than those resulting from contamination from distant sources. In contrast to distant sources, local sources can also affect recipients through contamination by more readily degradable substances as well as the persistent contaminants. Although non-persistent contaminants are beyond the scope of this project, it is important to note that the effects of PTS, when combined with those of other types of contaminants originating from local sources, may be substantially increased. Similarly, humans exposed to and affected by PTS may be more sensitive to the acute toxic effects of other less persistent contaminants from local sources.

- **Contact sources:** These comprise the intentional or unintentional use of chemicals by recipients in everyday household and occupational uses. For example, the health of individuals using PTS-containing insecticides for pest control or for the treatment of reindeer may be directly affected by the products. A typical example of an unintentional contact contaminant source would be the use of paints and insulating materials containing PTS in the indoor environment.

4.2. Assessment of distant sources: Long-range atmospheric transport

Due to the nature of atmospheric circulation, emission sources located within the Northern Hemisphere, particularly those in Europe and Asia, play a dominant role in the contamination of the Arctic. Given the spatial distribution of PTS emission sources, and their potential for 'global' transport, evaluation of long-range atmospheric transport of PTS to the Arctic region necessarily involves modeling on the hemispheric/global scale using a multi-compartment approach. To meet these requirements, appropriate modeling tools have been developed.

Extensive efforts were made in the collection and preparation of input data for modeling. This included the required meteorological and geophysical information, and data on the physical and chemical properties of both the selected substances and of their emissions. It should be noted that reliable and relatively comprehensive information on emission sources is currently not available for most PTS. Therefore, an assessment of long-range atmospheric transport was undertaken for substances for which emission source information is sufficient to meet modeling requirements, namely, mercury (Hg), polychlorinated biphenyls (PCBs) and γ-hexachlorocyclohexane (γ-HCH). It was considered that modeling results obtained for these contaminants could be extrapolated to give a general overview on the situation with respect to long-range atmospheric transport of other PTS in the study.

An assessment of mercury, PCB and γ-HCH pollution arising from emission sources in the Northern Hemisphere and affecting regions of the Russian North inhabited by indigenous peoples, was carried out for the reference year 1996. This assessment included an evaluation of air concentrations and deposition levels, as well as source-receptor relationships for selected regions and for the Arctic as a whole. Particular attention was given to the fate of contaminants in different environmental compartments (air, soil, water, etc.). The effect of PCBs and γ-HCH transport via ocean currents, ice cover dynamics, and 'Mercury Depletion Event' (MDE) (Schroeder *et al.*, 1998) chemistry on Arctic pollution were also examined.

4.2.1. Climate conditions and atmospheric circulation patterns

The climate of the Russian Arctic is characterized by a lack of solar radiation during the winter, which leads to very low temperatures. In contrast, solar radiation flux in the summer is significant, but temperatures are still not high, as most incoming solar energy is utilized in the melting of ice and snow. Atmospheric circulation is characterized by cyclonic activity in all seasons, which promotes the exchange of air masses between the middle and high latitudes. As a result of the prevailing westerly airflows, the Russian Arctic experiences the mod-

erating influence of the Atlantic (North Atlantic Current). This influence is stronger in western parts than in central and eastern parts. The western Russian Arctic is therefore warmer, with a much lower temperature variation between winter and summer than that found in the eastern part of the Russian North, which is characterized by the more severe climatic conditions.

Atmospheric circulation in the Arctic region differs between winter and summer (Figure 4.1) with the prevailing atmospheric currents in the lower Arctic troposphere depending upon the location of quasi-stationary pressure systems in the Northern Hemisphere, the Icelandic and Aleutian Lows, and Siberian and North American Highs.

In winter, due to the geographical position of these systems, air masses move into the Arctic from Europe in a northeasterly direction, or from central Asia and Siberia. Western regions of the Russian North – Murmansk Oblast and the Nenets Autonomous Okrug (AO) – are affected mainly by southwesterly or westerly airflows, bringing air masses from Eastern and Central Europe, as well as from central Russia. In the central regions – Yamalo-Nenets AO, Taymir AO, and the Republic of Sakha (Yakutia) – southerly airflows prevail, transporting air masses from central Russia, the Urals, the south of Siberia and central and eastern Asia. Over the easternmost region – the Chukchi AO – northerly airflows predominate in winter.

In summer, the continental high-pressure systems disappear and oceanic low-pressure systems weaken. Over the Arctic Ocean, high-pressure systems occur more frequently than in winter, causing an outflow of Arctic air in the meridional direction. The European region comes under the impact of the Azores anticyclone. Over central Eurasia and the central part of North America, low-pressure systems dominate. The influx of air masses to the Arctic mainly occurs over the Aleutian Islands/Bering Sea region in the east, and from the North Atlantic, along the north-western periphery of Azores anticyclone, in the west. Compared with winter, the northerly component is more frequent in atmospheric transport in summer across all regions of the Russian Arctic except for Chukotka. Chukotka, during the summer, is predominantly affected by transport either from the Pacific Ocean, or from Eastern Asia and the Russian Far East, some transport from the north still occurs however.

Atmospheric circulation is also responsible for the precipitation pattern in the Russian Arctic. The most abundant annual precipitation takes place in the western part and can reach 500-600 mm/y. Annual precipitation decreases from the west towards the east, and over the north of the Republic of Sakha (Yakutia) is mainly within the range of 100-150 mm/y. In the easternmost part of the Russian Arctic, precipitation is relatively high (300-600 mm/y), and caused by the southerly transport of air masses from the Pacific Ocean, especially during summer.

Figure 4.1. Mean position of the Arctic air mass in January and July, and the winter and summer frequencies of winds (AMAP, 1997).

4.2.2. Emission sources

Emission sources of Hg, PCBs and γ-HCH were divided into several groups according to their geographical location (Figure 4.2). The key criterion used for the selection of a specific region as an aggregate emission source was the possible influence of emissions from this region on the Russian North.

Figure 4.2. Source regions of the Northern Hemisphere considered in the source-receptor analysis.

The number of the selected regions varies for different pollutants. For simplicity, generalized names were used for some regions, e.g., the region identified as 'Central Asia' actually includes central, western, and southern Asia. Selected emission sources regions for the pollutants under consideration are presented in Table 4.1. Source region boundaries also vary depending upon the contaminant in question. For example, China and Japan are con-

sidered as separate sources for mercury, but included in larger Asian source regions for the other contaminants. For γ-HCH, China and India are important enough sources to consider their emissions separately, whereas Northern Europe was omitted as γ-HCH emissions in this region in 1996 were insignificant. The Americas (North and Central) are included as a single source region, due to their greater distance from the Russian North.

Hg	PCBs	γ-HCH
1. Russia	1. Russia	1. Russia
2. Northern Europe	2. Northwestern Europe	2. Western Europe
3. Western Europe	3. Southeastern Europe	3. Eastern Europe
4. Eastern Europe	4. Americas	4. Southern Europe
5. Southern Europe	5. Southeastern Asia (including China and Japan)	5. Americas
6. Americas	6. Central Asia (including India) and Africa	6. China
7. Central Asia (including India)		7. India
8. China		8. Asia (Central and South-eastern Asia)
9. Japan		9. Africa
10. Southeastern Asia		
11. Africa		

Table 4.1. Regions of the Northern Hemisphere selected as source areas for long-range transported pollutants.

Due to their proximity to the Russian North and the significant polluting influence of some regions of the Russian Federation, the territory of Russia was subdivided into twelve source regions according to current administrative boundaries and to their potential impact on Arctic ecosystems. The Location of these regions and abbreviated identification codes is shown in Figure 4.3. The first five regions (MUR, NEN, YNT, YAK, and CHU) are also considered as the receptor regions.

MUR – Murmansk Oblast;
NEN – The Nenets AO;
YNT – The Yamalo-Nenets AO and Taymir AO;
YAK – The Republic of Sakha (Yakutia);
CHU – The Chukchi AO;
NRT – Northern region;
NWK – North-Western region and Kaliningrad Oblast;
CVV – Central and Volgo-Viatsky regions;
CVN – Central-Chernozem, Volga and Northern Caucasus regions;
URL – Ural region;
WSB – West Siberian region;
ESB – East Siberian and Far-Eastern regions.

Figure 4.3. Aggregated regions of the Russian Federation chosen for source-receptor analysis. The first five regions listed (MUR, NEN, YNT, YAK, and CHU) are considered as both source and receptor regions, the rest are considered as source regions.

Mercury

The industrial and urbanized regions of the world account for the majority of anthropogenic mercury emissions to the atmosphere. To evaluate the anthropogenic input of mercury to the Northern Hemisphere, the most recently available global emission inventory, that for 1995, (Pacyna and Pacyna, 2002) was used. The original global emissions dataset has a resolution of 1°x1° lat./long., with mercury emissions speciated into three chemical forms: gaseous elemental mercury (Hg^0), gaseous oxidized mercury (Hg^{2+}), and particulate mercury (Hg_{part}). These emission data were redistributed to a lower resolution (2.5°x2.5°), suitable for input to the air transport model employed, assuming uniform distribution over each grid cell.

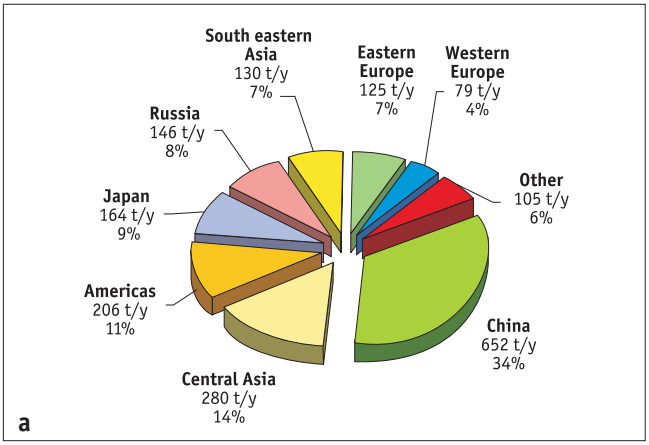
The most significant emission sources are in Eastern Asia, Europe and the eastern part of North America. Considerable emissions also occur in the Indian subcontinent and the Arabian Peninsula. The total amount of anthropogenic mercury emissions in 1995 from the Northern Hemisphere was estimated as 1887 tonnes.

In order to assess the impact of different mercury emission sources on the contamination of the Russian North, the entire hemispheric emission field was divided into 11 regions: Russia, China, Central Asia, the Americas, Japan, Southeast Asia, Africa, Eastern Europe, Western Europe, Southern Europe, and Northern Europe. The relative contribution of each region to total mercury emissions in the Northern Hemisphere is presented in Figure 4.4(a).

This diagram shows that more than one third (34%) of the total mercury emissions originate in China. Considerable emissions also originate in Central Asia (14%), the Americas (11%), Japan (9%), and Russia (8%). The contribution of other regions specified does not exceed 7%.

Figure 4.4(b) shows total mercury emissions from different regions of the Russian Federation. The most significant emission sources are located in the Central-Chernozem, Volga, and North-Caucasian regions (CVN), the Ural region (URL), and the Central and Volgo-Viatsky regions (CVV).

Mercury emissions from natural sources contribute a significant proportion of the total mercury input to the atmosphere. Estimates for the value of natural emissions and re-emissions were based on a literature survey. Mercury emissions from natural sources were apportioned over the Northern Hemisphere on the basis of the nature of the underlying land/sea surface. Five surface categories were distinguished: ice covered land (glaciers, etc), seawater, soil developed from geochemical mercury belts, soils in areas of mercury deposits, and other (background) soils. It was assumed that there is zero mercury emission from ice caps/gla-



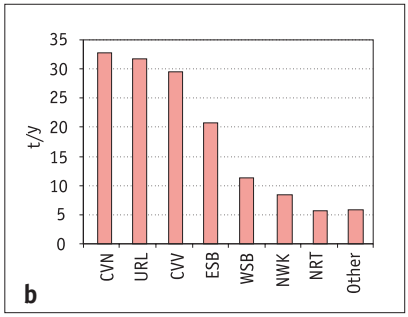


Figure 4.4.
(a) Contribution of different regions of the Northern Hemisphere to total anthropogenic mercury emissions, (b) total anthropogenic mercury emissions from different regions of the Russian Federation.

ciers. Natural emissions from seawater were distributed proportionally to the ocean's primary production of carbon. Emissions from soil are most significant from soils occurring over mercury deposits and lowest for background soils. In addition, the temperature dependence of emission fluxes was also calculated, based on data obtained through measurements.

PCBs

Modeling long-range transport of individual PCB congeners to the Russian North was made using a global emission inventory concerning 22 individual PCB congeners covering the period 1930-2000 (Breivik *et al.*, 2002b). This inventory is based on estimates of the global production and consumption of these PCBs in 114 countries (Breivik *et al.*, 2002a). The emissions were distributed to the (2.5° x 2.5° lat./long.) model grid using (as a proxy for emission distribution) a 1990 population distribution data set obtained from the CGEIC website (http://www.ortech.ca/cgeic).

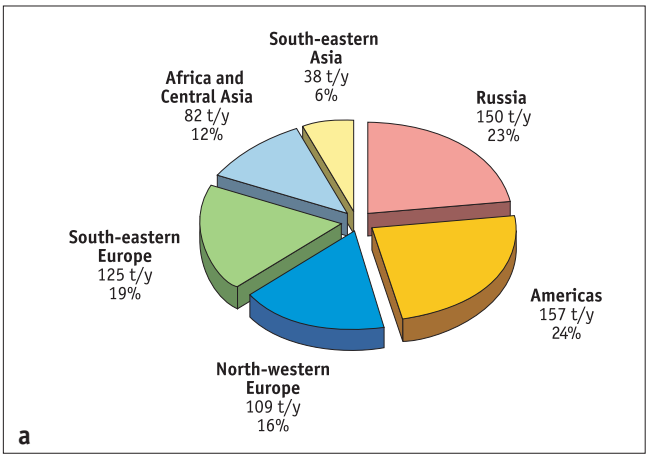
The total global production of PCBs from 1930-1993 amounted to approximately 1.3 million tonnes. Almost 97% of intentionally produced PCBs were used in the Northern Hemisphere. Emission data for individual congeners for 1996 were used in all model calculations and, according to the high emission scenario discussed by Breivik *et al.* (2002b), total emissions of the 22 PCB congeners in the Northern Hemisphere in 1996 amounted to about 662 tonnes. Total emissions of PCB-28, -118, -153, and -180 from the Northern Hemisphere in 1996 were about 80, 23, 16, and 4.5 tonnes, respectively. Congener composition of PCB emissions varies between source regions.

In order to study the contributions of different source regions in the Northern Hemisphere to the contamination of the receptor-regions in the Russian Arctic, six main regional sources were identified, based on the emission distribution: Russia, Northwest Europe, Southeast Europe, the Americas, Southeast Asia, and Central Asia and Africa.

The major emission sources of PCBs in the Northern Hemisphere in 1996 were the Americas (24%), Russia (23%), Southeast Europe (19%), and Northwest Europe (16%) (Figure 4.5(a)). The main Russian emission sources are located in Central-Chernozem, Volga and North-Caucasus regions (CVN) as well as in Central and Volgo-Viatsky regions (CVV) (Figure 4.5(b)).

γ-HCH

The scenario for γ-HCH emissions in the Northern Hemisphere was based on official data submitted to the UN ECE Secretariat in 2002 (Vestreng and Klein, 2000) and available expert estimates (Pacyna *et al.*, 1999). In addition, γ-HCH emissions for 1990-1996 from the Russian Federation, and some other countries in the Northern Hemisphere were estimated from information in a range of literature sources (Revich *et al.*, 1999, Year-books, 1992, 1993 1999,



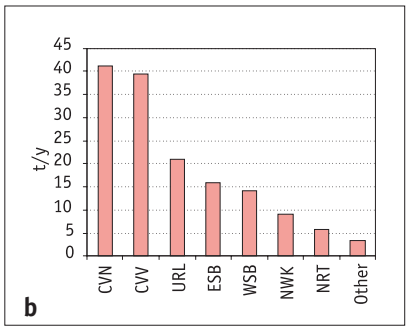


Figure 4.5.
(a) Contribution of different regions to PCB emissions (22 congeners) in the Northern Hemisphere for 1996, (b) PCB emissions (22 congeners) from different regions of the Russian Federation in 1996.

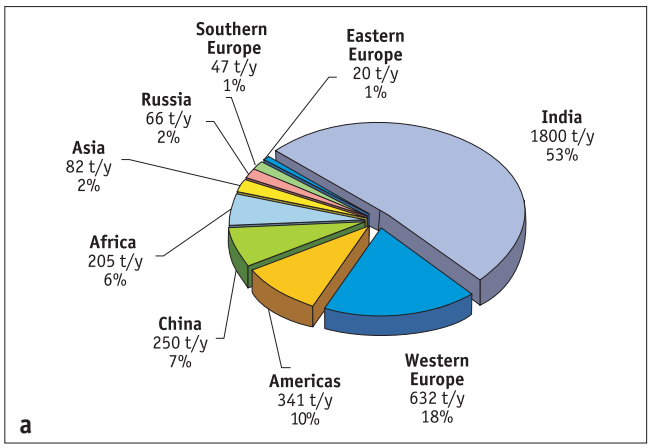


Figure 4.6.
(a) Contribution of different regions to γ-HCH emission in the Northern Hemisphere for 1996, (b) γ-HCH emissions from different regions of the Russian Federation in 1996.

Ananieva *et al.*, 1990, Li *et al.*, 1996, 1998,1999, and Macdonald *et al.*, 2000) regarding the use of this insecticide. To estimate emissions from data on insecticide use, the emission factor for lindane in agricultural use (0.5) (Guidebook, 1999) was applied. The resulting estimate for total γ-HCH emissions from the Northern Hemisphere in 1996 was about 3445 tonnes. The spatial distribution of these γ-HCH emissions in the Northern Hemisphere, for modeling purposes, was made using crop area as a surrogate parameter (Pacyna *et al.*, 1999).

To model long-range atmospheric transport of γ-HCH to the Russian North, nine source regions were identified in the Northern Hemisphere: Russia, Western Europe, Eastern Europe, Southern Europe, the Americas, China, India, the rest of Asia, and Africa. China and India were considered as individual source regions due to their high use of this insecticide compared to the rest of Asia. Estimates of the contribution of main source regions to total γ-HCH emissions in the Northern Hemisphere in 1996, based on the selected emission scenario, is shown in Figure 4.6(a). γ-HCH emissions from Russian regions in 1996 are shown in Figure 4.6(b).

The main contribution to γ-HCH emissions in the Northern Hemisphere, was made by India (53%) and Western Europe (18%). The contribution from Russia is only 2%. Major Russian γ-HCH emissions in 1996 originated from the European part of the Russian Federation. The highest Russian γ-HCH contributions were made by sources located in the Central-Chernozem, Volga and North-Caucasian regions (CVN).

4.2.3. Contamination levels in the Arctic resulting from long-range atmospheric transport

To evaluate levels of contamination of the Arctic region by global pollutants (mercury, PCBs, and γ-HCH) resulting from long-range atmospheric transport, a hemispheric modeling approach was employed. For this purpose, the EMEP Meteorological Synthesizing Centre-East (MSC-E) have developed hemispheric multi-compartment transport models 'MSCE-Hg-Hem' and 'MSCE-POP'.

Mercury, PCB and γ-HCH concentrations in air and their deposition loads as evaluated for the Northern Hemisphere and the Arctic for 1996, are discussed below in the relevant subsections. Particular attention has been given to atmospheric long-range transport to, and deposition of these pollutants in the Russian Arctic. For mercury, the effect of Mercury Depletion Event (MDE) chemistry on Arctic deposition was considered. In addition, for the assessment of environmental pollution by PCBs and γ-HCH, the role of transport via sea currents and ice cover dynamics were taken into account. The marine environment is particularly important in relation to the transport and fate of γ-HCH. Characteristic values of mean annual air concentrations and deposition fluxes of mercury, PCBs and γ-HCH over the Arctic area are summarized in Table 4.2. The consistency of the modeling results was verified by comparison with available measurements.

Pollutant	Air concentrations, ng/m³			Deposition flux, g/km²/y			Total deposition, t/y
	Min	Max	Average	Min	Max	Average	
Hg	1.11	1.76	1.47	1.6	29.9	7.2	240
PCB-28	0.0003	0.0186	0.0014	0.002	0.320	0.021	2.7
PCB-118	0.0002	0.0057	0.0006	0.003	0.377	0.026	1.1
PCB-153	0.0002	0.0041	0.0008	0.007	0.367	0.043	1.15
PCB-180	0.0001	0.0012	0.0003	0.004	0.204	0.025	0.5
γ-HCH	0.009	0.113	0.023	0.159	3.140	0.671	78

Table 4.2. Characteristic values of mean annual air concentrations and annual deposition fluxes for mercury, selected PCBs, and μ-HCH over the Arctic in 1996.

Mercury

Figure 4.7 shows the annual deposition flux of mercury in the Northern Hemisphere. Highest deposition levels are in those regions with considerable emissions: i.e. Southeast Asia, Europe, and the eastern part of North America. For other areas, the deposition pattern, to some extent, corresponds to annual precipitation values, since wet deposition plays a dominant role in removing mercury from the atmosphere. From the model results, total deposition over the Arctic region in 1996 amounted to 240 tonnes. The influence of MDEs on deposition fluxes within the Arctic region has been the subject of considerable research in recent years. The postulated MDE mechanism (Lindberg *et al.*, 2002) includes complicated

chemistry, involving the formation of halogen related radicals. The development of a detailed model component for MDE chemistry is the subject of a separate study. For the purposes of this study, an attempt was made to qualitatively estimate the effect of MDE on Arctic Hg contamination by using a simplified set of parameters.

As illustrated in the enlarged panel in Figure 4.7, even short-term phenomena such as MDEs, which occur during only a few weeks of the year, can considerably increase the annual deposition of mercury in some regions of the Arctic, in particular coastal areas. The influence of MDEs on total annual mercury deposition is illustrated in Figure 4.8(a). Additional contributions of mercury as a result of MDEs can amount to more than 50 percent of total deposition values in areas adjacent to Arctic coasts (i.e. within about 300 km of the coast inland and offshore). These areas include the Queen Elizabeth Islands, Hudson Bay, the White Sea, the Gulf of the Ob river, and the Laptev Sea coast, among others. Negative values (for percentage increase in deposition due to MDEs) show that increased deposition fluxes due to MDEs in some regions, lead to decreased fluxes in other areas. A part of the mercury transported by the air therefore does not enter the High Arctic during springtime, due to it being scavenged during MDEs over coastal and contiguous regions.

Figure 4.8(b) shows the seasonal variation in total mercury deposition in the Arctic. The model predicts that the most pronounced MDE effect is in May and June (taking into account a temporal shift due to the model parameters used), when monthly deposition in the Arctic increased two-fold or greater. The calculations predict that MDE are responsible for deposition of about 50 tonnes of mercury per year in the Arctic – about 20% of the total annual deposition.

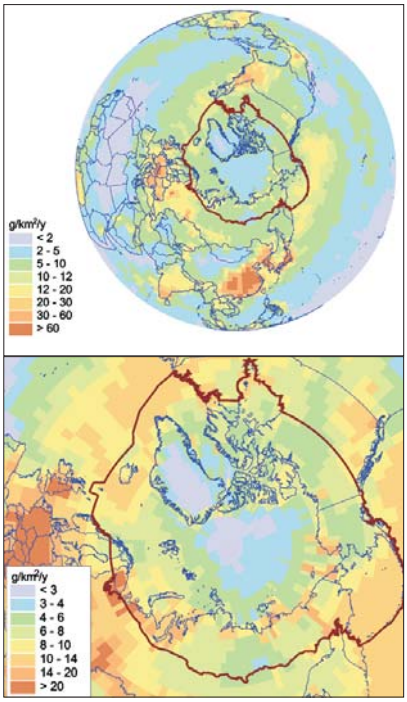
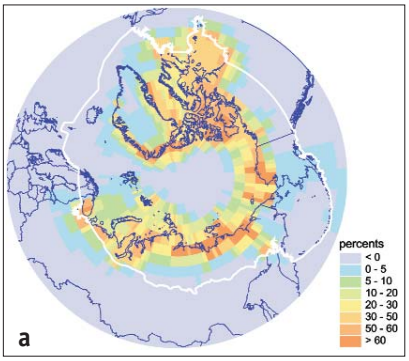


Figure 4.7. Annual deposition of total mercury in the Northern Hemisphere. The enlarged panel shows elevated mercury deposition over the Arctic coast due to MDEs.

Due to the high transport potential of mercury in the atmosphere, many anthropogenic and natural sources from different regions of the Northern Hemisphere contribute to Arctic pollution. The contribution from



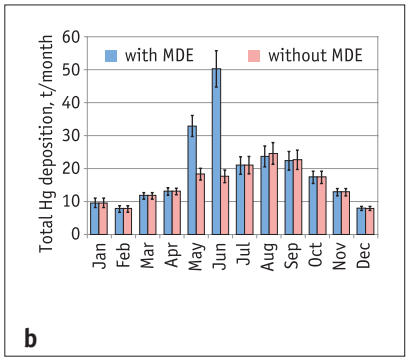
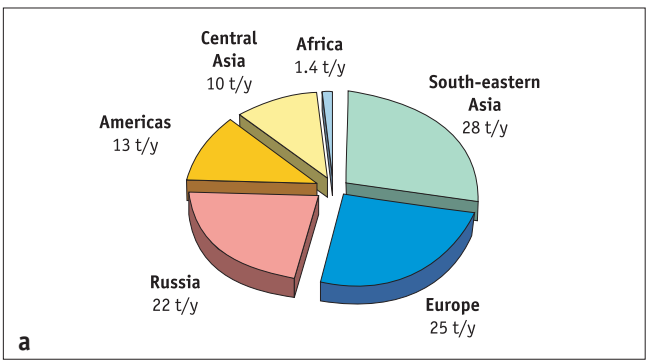


Figure 4.8. (a) Influence of MDEs on total annual mercury deposition in the Arctic (area defined by the white (AMAP area) boundary), and (b) seasonal variation in total mercury deposition to the Arctic with and without MDEs. The figures present the difference between two model computational runs – one with and one without MDEs included.



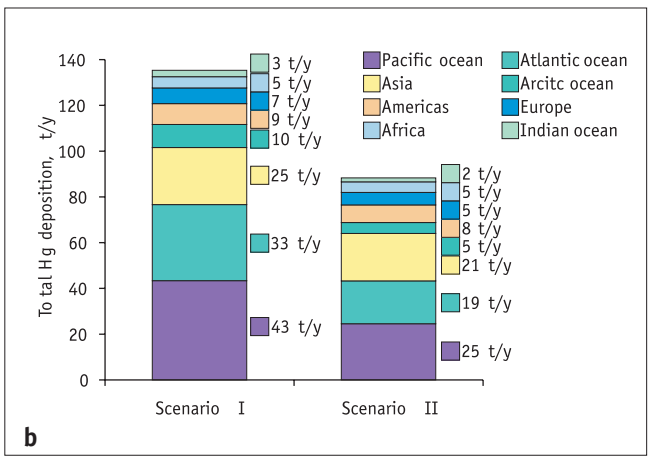


Figure 4.9. Contribution of different source regions to the annual deposition of mercury in the Arctic arising from (a) anthropogenic sources and (b) natural sources and re-emissions.

the various regions of the Northern Hemisphere to total annual mercury deposition in the Arctic from anthropogenic and from natural sources is shown in Figures 4.9(a) and 4.9(b), respectively for the upper (Scenario I) and lower (Scenario II) limits of emission estimates.

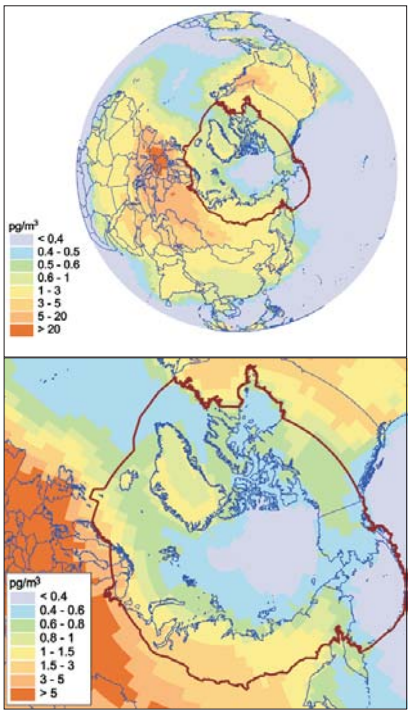


Figure 4.10.
Mean annual air concentrations of PCB-153 over the Northern Hemisphere. The enlarged panel shows the air concentration pattern over the Arctic region.

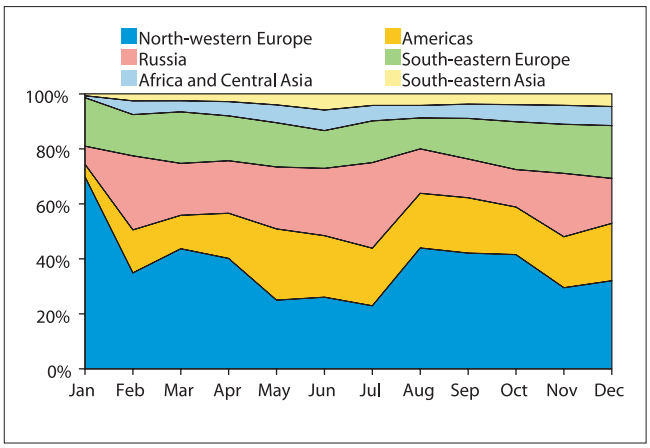


Figure 4.11.
Seasonal variation in the relative contributions of different source regions to PCB-153 deposition in the Arctic.

The most significant contribution to anthropogenic mercury deposition in the Arctic come from sources located in Southeast Asia, Europe and Russia. The most significant contributions to the natural component of annual deposition in the Arctic are from the Pacific and Atlantic Oceans, and from Asia. Bearing in mind that there is still considerable uncertainty regarding the input parameters used for the modeling of natural emission and re-emission processes, and that natural emissions cannot be controlled by political decisions, attention should be focused on deposition from anthropogenic sources.

PCBs

Levels of PCB contamination are exemplified by PCB-153. Figure 4.10 shows that areas with the highest air concentrations of PCB-153 are located close to European and North American source regions. Air concentrations range from 5 to 20 pg/m³ in contaminated areas of North America, and can exceed 20 pg/m³ in Europe. European sources make the largest contribution to the contamination of the Arctic region. The mean annual air concentration of PCB-153 over the Arctic ranges from 0.2 to 4 pg/m³.

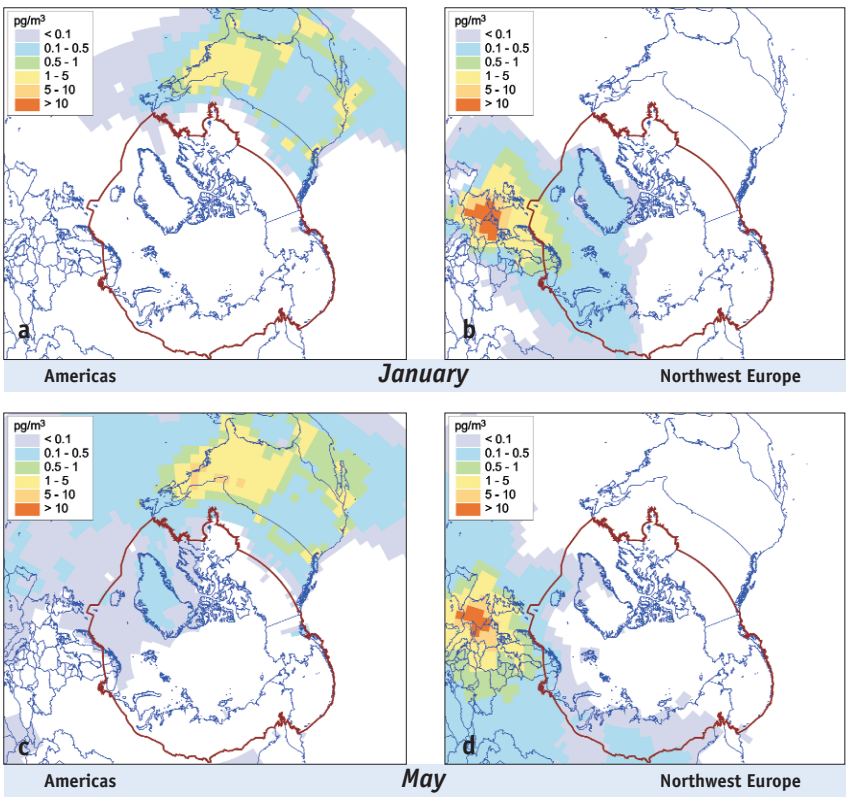


Figure 4.12.
Air concentrations of PCB-153 emitted in January and May from sources in the Americas and Northwest Europe. respectively, from modelling results for 1996.

The relative contributions made by different source regions to PCB-153 deposition in the Arctic are subject to seasonal variations, as shown in Figure 4.11. The contribution from sources in Northwest Europe is the most variable, varying from about 70% in January, to about 25% in May. The amount contributed by the Americas is only about 5% in January, but in May it amounts to 26%, and is comparable with the contribution from sources in Northwest Europe.

These noticeable variations are explained by the peculiarities of atmospheric circulation in the Arctic during various seasons, and also by seasonal variations in temperature, precipitation, and degradation rates. Seasonal variation of emissions are not taken into account in this assessment. To illustrate pathways of atmospheric transport, simulation results of PCB-153 transport from two source regions (the Americas and Northwest Europe) for 1996 were examined. Figures. 4.12 show air concentrations of PCB-153 emitted in the Americas and Northwestern Europe in January. The air concentrations of PCB-153 originating from the same sources in May are given in Figures. 4.12.
Figure 4.13 shows the contribution of different source regions to PCB-153 deposition in the Arctic. The major contribution is from sources in Northwest Europe (about 40%). Other significant contributors are Russia (19%), the Americas (17%) and Southeast Europe (16%). For PCB-28 and PCB-118, Northwest Europe and Russia are the main contributors. However, for PCB-180, main contributors are Northwest Europe and the Americas.

The total amount of PCB-153 deposited in the Arctic region from emissions in 1996 was estimated at 527 kg. The contribution from re-emission of PCB-153 accumulated in the environment in the period preceding 1996 equals 629 kg. Therefore, the estimated total PCB-153 deposition to the Arctic in 1996 was 1.15 tonnes.

On the basis of the transport simulations for the four congeners (PCB-28, -118, -153, and -180), and taking into account the fractions of these congeners in the typical PCB mixture in air, a rough estimate of total PCB deposition in the Arctic in 1996 of approximately 40 tonnes was made.

γHCH

Figure 4.14 represents the spatial distribution of γ-HCH concentrations in the air over the Northern Hemisphere and the Arctic. High concentrations (up to 5 ng/m³ or more) are mainly characteristic of regions with high emissions. However, in spite of the fact that there are no significant sources in the Arctic region, relatively high concentrations (from 0.01 to 0.11 ng/m³) are also observed there. These concentrations result from long-range transport of γ-HCH from remote sources, mainly in Western Europe, India, and the Americas.

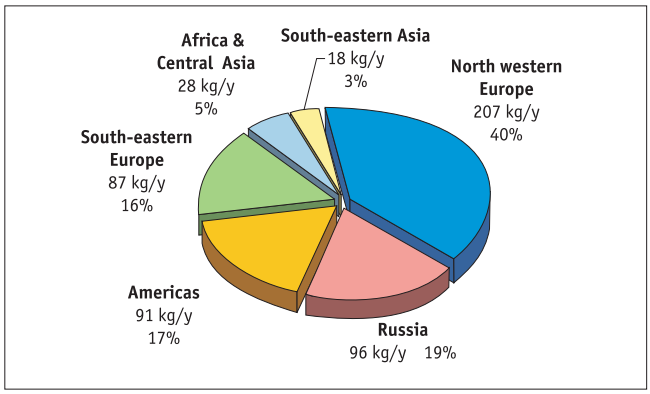
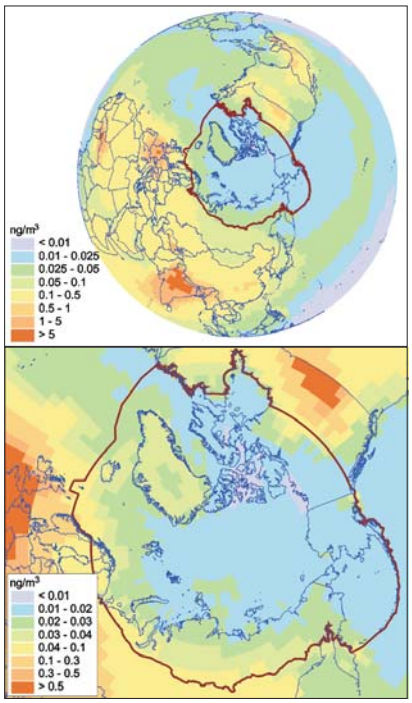


Figure 4.13. Contributions of different source regions to PCB-153 deposition in the Arctic region in 1996.

Figure 4.14.
γ-HCH concentrations in air of the lower atmosphere over the Northern Hemisphere and the Arctic.



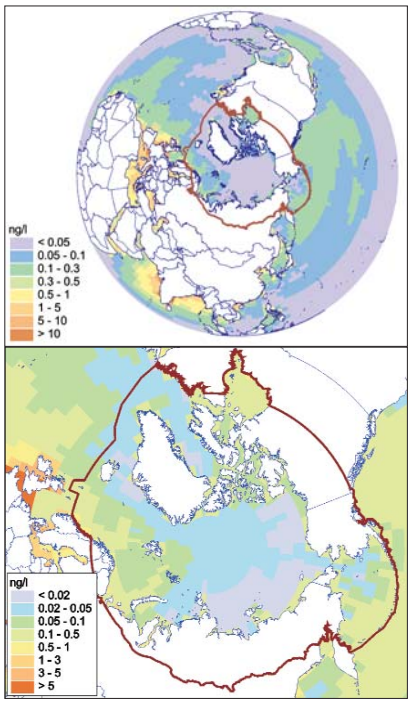


Figure 4.15.
Mean annual concentrations of γ-HCH in seawater in the Northern Hemisphere. The enlarged panel shows the seawater concentrations pattern over the Arctic Ocean.

Since γ-HCH tends to accumulate in seawater (which accounts for about 80% of the overall environmental pool of this substance), the spatial distribution of γ-HCH in seawater is of interest. The distribution of γ-HCH in seawater (Figure 4.15) reveals that maximum concentrations are found in the Indian Ocean, the Mediterranean Sea, and the East Atlantic. Considerable amounts of γ-HCH flow into the Arctic Ocean from the North Atlantic, as reflected in the higher seawater concentrations in the Barents Sea in the region between northern Norway and Svalbard. Seawater concentrations in the seas along the coast of northern Russian are in the range 0.01–2 ng/L.

The total amount of γ-HCH deposited in the Arctic region in 1996 from the atmosphere was estimated to be 78 tonnes. Due to high deposition rates over the sea (the models assume this rate to be twice as high over sea as on land), and taking into account the large proportion of the Arctic area that is covered by ocean (about 60%, according to figures provided by AMAP, 1998), this equates to an estimate for γ-HCH deposited to the Arctic Ocean in 1996 of 58 tonnes.

Modeling results have been used to indicate contributions of different emission sources to the contamination of the Arctic region by γ-HCH (Figure 4.16). Western Europe is the largest contributor to this region (about 40%), followed by India (19%), the Americas (17%), China (10%), and Russia (6%), with other source regions responsible for the remaining 8%.

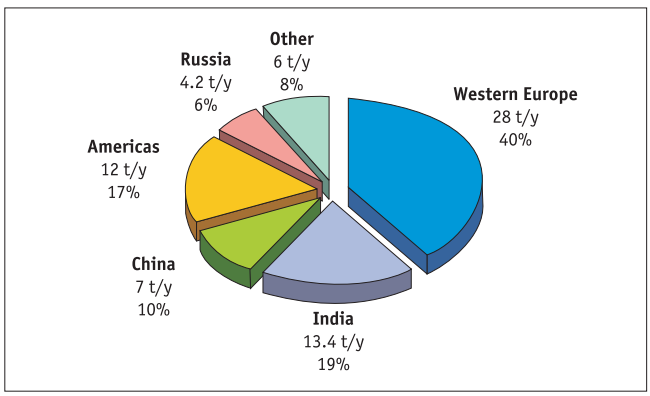


Figure 4.16. Contributions of different source regions to γ-HCH deposition in the Arctic in 1996.

4.2.4. Contamination levels and deposition loads resulting from long-range atmospheric transport to the Russian North

Mercury

Figure 4.17 shows the modeled spatial distribution of mean annual concentrations of total gaseous mercury (TGM) in the air in northern Russia, which are fairly constant across the territory (from 1.4 to 1.8 ng/m³) (see also Table 4.3). Concentration levels over Murmansk Oblast and in the central Republic of Sakha (Yakutia) are slightly elevated, mainly due to local emission sources. There is also a weak decreasing gradient in mercury concentrations to the north over

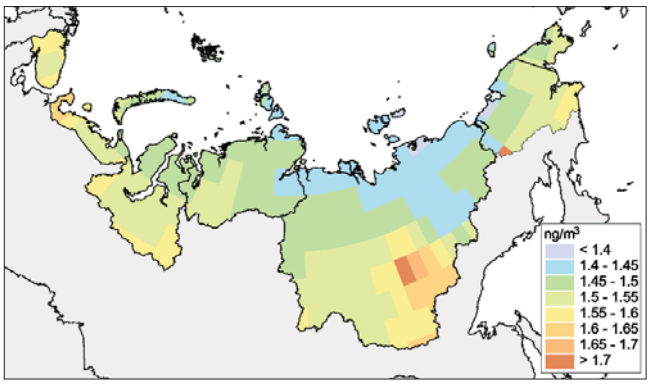


Figure 4.17. Spatial distribution of mean annual air concentrations of total gaseous mercury in the Russian North.

regions including the Yamalo-Nenets AO, the Republic of Sakha (Yakutia), and the Chukchi AO. A possible reason for this, in addition to distance from main emissions areas, is the decrease in elemental mercury concentration over the Arctic coast during springtime, as a result of MDEs.

Table 4.3. Characteristic values of mercury air concentrations in the Russian North, ng/m³.

Region	min	max	average
MUR	1.52	1.62	1.56
NEN	1.44	1.66	1.52
YNT	1.43	1.58	1.5
YAK	1.38	1.75	1.5
CHU	1.38	1.71	1.5

The spatial distribution of annual deposition loads of total mercury in the Russian North is shown in Figure 4.18. The highest depositions, exceeding 20 g/km²/y, are observed over the coast of the Arctic Ocean, due to MDEs (Table 4.4). The lowest depositions (less than 5 g/km²/y), are in Central Yakutia, an area of low annual precipitation. Values of total mercury deposition for regions of the Russian North and the Arctic as a whole are given in Table 4.5.

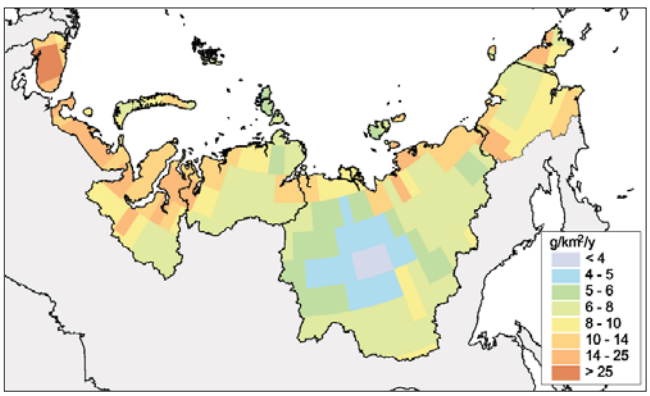


Figure 4.18. Annual deposition of total mercury in the Russian North.

Table 4.4. Characteristic values of total annual mercury deposition loads in the Russian North, g/km²/y.

Region	min	max	average
MUR	8	30	21
NEN	6	26	14
YNT	5	15	10
YAK	3	17	7
CHU	6	18	10

Region	MUR	NEN	YNT	YAK	CHU	Arctic
Mercury deposition	3	4	15	21	7	240

Table 4.5. Total deposition of mercury in 1996 in different regions of the Russian North, and the Arctic as a whole, t/y.

PCBs

Figures 4.19 and 4.20 show the spatial distributions of mean annual air concentrations and annual deposition loads of PCB-153 over selected regions of the Russian North for 1996. There is a clear decrease in PCB-153 air concentrations from western to eastern areas of the Russian North, with increasing distance from source areas in Europe. Relatively high air concentrations (up to 4 pg/m^3) occur in Murmansk Oblast, the Nenets AO, and the southern part of the Yamalo-Nenets and Taymir AOs (Table 4.6). Moderate values (1–2 pg/m^3) are characteristic of the northern part of the Yamalo-Nenets AO, the Taymir AO, and the Republic of Sakha (Yakutia). The Chukchi AO is characterized by low values (<1 pg/m^3).

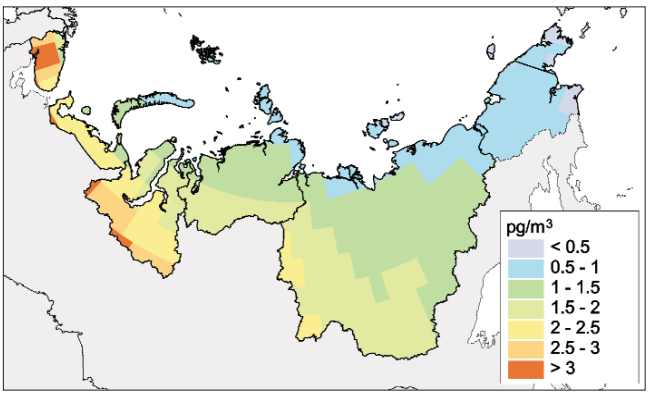


Figure 4.19. Spatial distribution of mean annual air concentrations of PCB-153 in the Russian North, calculated for 1996.

Table 4.6.
Characteristic values of PCB-153 air concentrations in the Russian North, pg/m^3.

Region	min	max	average
MUR	1.3	4.1	2.6
NEN	0.5	3.8	1.7
YNT	0.5	3.3	1.8
YAK	0.4	2.3	1.4
CHU	0.4	1	0.7

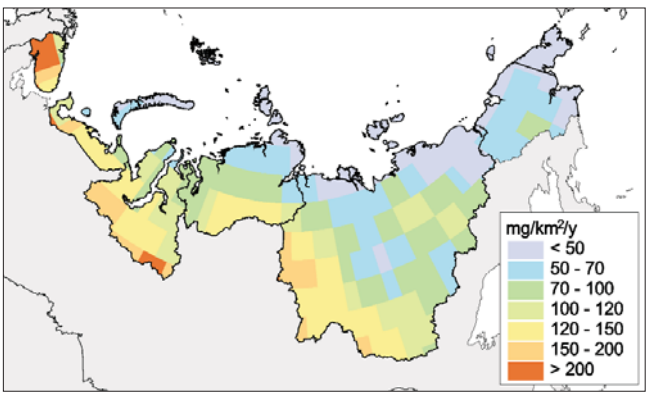


Figure 4.20. Annual deposition of PCB-153 in the Russian North, calculated for 1996.

A similar pattern is seen for deposition loads. Substantial values (>150 mg/km^2/y) are estimated for Murmansk Oblast, the Nenets AO and the southern part of the Yamalo-Nenets and Taymir AOs as well as for the western part of the Sakha Republic. Moderate values (70-150 mg/km^2/y) are obtained for the northern part of the Yamalo-Nenets and Taymir AOs, the Republic of Sakha (Yakutia), and the western part of Chukchi AO. The northern parts of the Russian North are characterized by lower values for deposition loads (<70 mg/km^2/y) (Table 4.7).

Region	min	max	average
MUR	70	333	208
NEN	27	373	97
YNT	27	216	106
YAK	16	224	89
CHU	16	74	51

Table 4.7.
Characteristic values of PCB-153 annual deposition loads in the Russian North, mg/km^2/y.

Depositions of PCB-153 and of total PCBs to the Russian North and the Arctic are given in Table 4.8. To calculate these depositions, emissions of the 22 PCB congeners considered, from all source regions, were divided into four groups: di- plus tri-chlorinated PCBs, tetra- plus penta-chlorinated PCBs, hexachlorinated PCBs, and hepta- plus octa-chlorinated PCBs. It was assumed that these groups are transported in a similar way to PCB-28, -118, -153 and -180, respectively. Together, these 22 congeners represent about one half of total PCB emissions, a fact that was taken into account in the calculation.

Region	MUR	NEN	YNT	YAK	CHU	Arctic
PCB-153	0.020	0.031	0.095	0.038	0.012	1.15
Σ PCB	1.6	1.7	4.8	4	0.46	40

Table 4.8. Total deposition of PCB-153 and total PCB in 1996 in different regions of the Russian North, and the Arctic as a whole, t/y.

By undertaking simulations of long-range transport and the accumulation of four PCB congeners (PCB-28, -118, -153 and -180), it was possible to compare the congener compositions in the air of different regions of the Russian North (Figure 4.21).

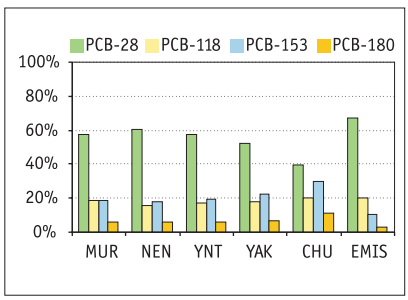


Figure 4.21.
PCB congener composition in air of different regions of the Russian North.

For all receptor regions, the fraction of PCB-28 is the highest and PCB-180 the lowest, with other congeners falling between, however, the congener patterns vary noticeably between the regions.

γ-HCH

Mean annual air concentrations of γ-HCH in the receptor regions of the Russian North, for 1996, are illustrated in Figure 4.22. Higher air concentration levels (from 0.02 to 0.07 ng/m³) are characteristic for Murmansk Oblast, the Nenets AO, the south of the Yamalo-Nenets AO, and the Republic of Sakha (Yakutia). Lower levels (from 0.01 to 0.3 ng/m³) are characteristic for the Taymir AO, the Chukchi AO, and the north of the Republic of Sakha (Yakutia) (Table 4.9).

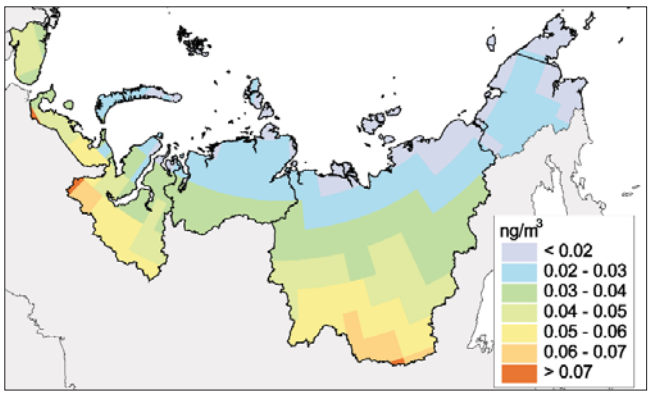


Figure 4.22. Spatial distribution of mean annual air concentrations of γ-HCH in the Russian North, calculated for 1996.

Table 4.9. Characteristic values of γ-HCH air concentrations in the Russian North, ng/m³.

Region	min	max	average
MUR	0.029	0.066	0.043
NEN	0.016	0.082	0.038
YNT	0.018	0.071	0.036
YAK	0.014	0.072	0.038
CHU	0.013	0.027	0.02

The spatial distribution of γ-HCH annual deposition loads is shown in Figure 4.23. Deposition loads are larger for Murmansk Oblast, the Nenets AO, and the Yamalo-Nenets AO (from 2 to 7 g/km²/y or more) and lower for the Taymir AO, the Republic of Sakha (Yakutia), and the Chukchi AO (0.1–3 g/km²/y). Annual deposition loads vary from region to region (Table 4.10). This is mainly due to different precipitation levels in these regions.

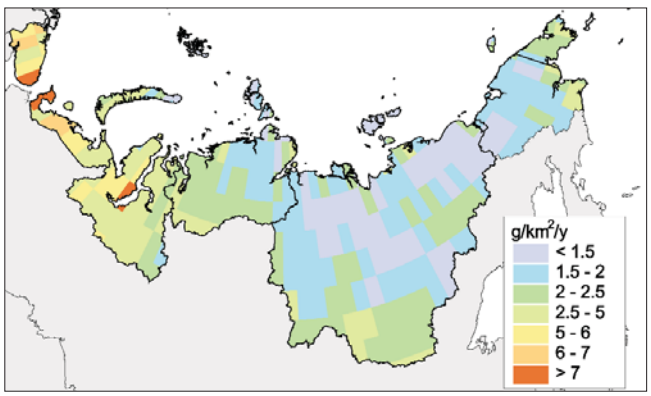


Figure 4.23. Annual deposition of γ-HCH in the Russian North, calculated for 1996.

Table 4.10. Characteristic values of γ-HCH annual deposition loads in the Russian North, g/km²/y.

Region	min	max	average
MUR	3.5	14	6
NEN	0.9	9.7	4.3
YNT	0.8	8	2.7
YAK	0.5	4.3	1.8
CHU	0.7	4.6	1.9

Estimated values for total deposition of γ-HCH in the regions of the Russian North and the Arctic as a whole are given in Table 4.11.

Regions	MUR	NEN	YNT	YAK	CHU	Arctic
Total depositions	0.8	1.1	4	5.4	1.3	78

Table 4.11. Total deposition of γ-HCH in 1996 in different regions of the Russian North, and the Arctic as a whole, t/y.

4.2.5. Source-receptor relationships for the selected pilot study regions.

4.2.5.1. Murmansk Oblast

Mercury

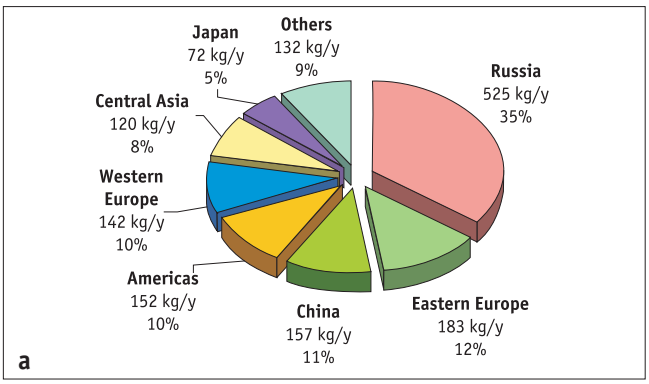
Murmansk Oblast is the most westerly region of Russia and is located on the Kola Peninsula. This explains the greater influence of European sources of mercury on this region (including sources both inside and outside the territories of Russia). Figures 4.24(a) and 4.24(b) illustrate the contributions of major Northern Hemispheric and Russian anthropogenic mercury source regions to annual mercury deposition in Murmansk Oblast. The largest contribution is made by Russian sources (35%). Among these, about 13% is from Murmansk Oblast itself (MUR) and 18% from other Russian European regions (NRT, NWK, CVV, CVN and URL). The most important sources outside of Russia are those in Eastern Europe (12%), China (11%), the Americas (10%), and Western Europe (10%). The 'other' category (defined in this and other sections addressing mercury source-receptor relationships) includes Northern and Southern Europe, Southeast Asia (excluding China and Japan), and Africa, due to their relatively small contributions to depositions in the receptor area.

PCB

The largest contributions to PCB-153 deposition in Murmansk Oblast are from emission sources in Russia (44%), Northwest Europe (35%) and Southeast Europe (14%) (Figure 4.25(a)). Contributions from sources located in the Americas, Africa, and Central Asia are less significant due to their considerable distance from the Oblast. Amongst Russian sources (Figure 4.25(b)), the major contribution is made by emissions from Murmansk Oblast itself (22%).

γ-HCH

γ-HCH sources in Western Europe make the largest contribution to deposition in Murmansk Oblast (more than 50%). Other significant contributors are Russia (17 %) and India (9%) (Figure 4.26(a)).



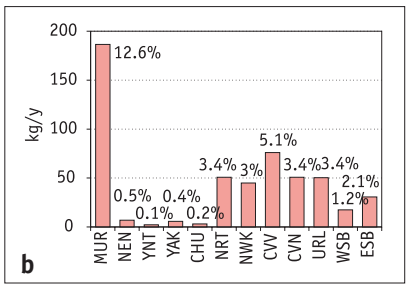
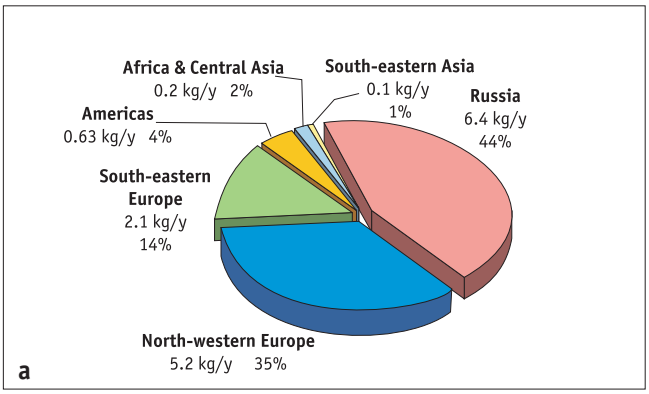


Figure 4.24. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in Murmansk Oblast.



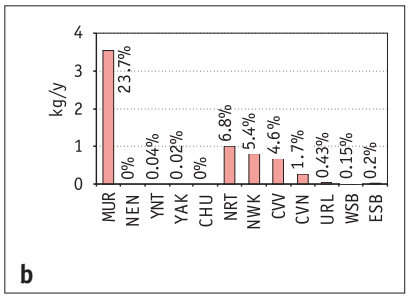
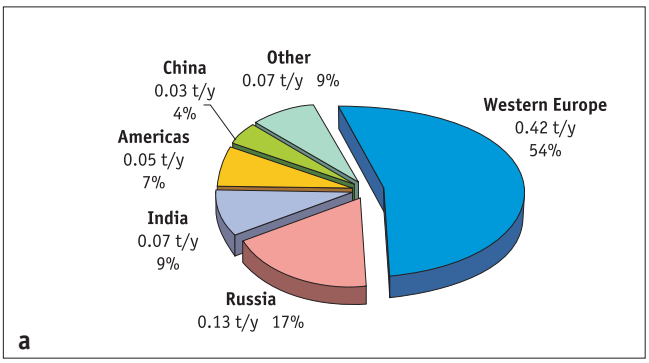


Figure 4.25. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in Murmansk Oblast.



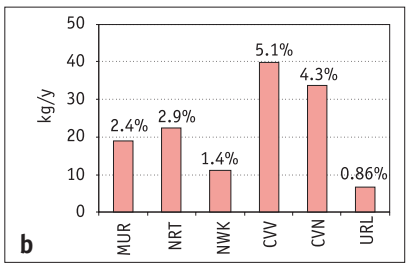


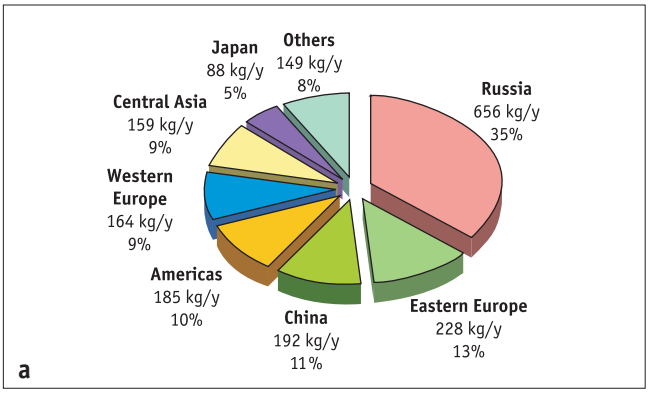
Figure 4.26. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, and (b) regions of Russia to annual γ-HCH deposition in Murmansk Oblast.

Russian contributions to γ-HCH depositions in Murmansk Oblast are mostly made by the Central and Volgo-Viatsky regions (CVV) and the Central-Chernozem, Volga, and North-Caucasian regions (CVN), 5% and 4%, respectively. The inputs from other regions are comparatively small (Figure 4.26(b)). For the purposes of this report, contributions from Russian emission sources to γ-HCH depositions in receptor areas are shown only for those regions with significant emissions of γ-HCH.

4.2.5.2. The Nenets Autonomous Okrug

Mercury

The Nenets AO is located in the northern part of European Russia. Therefore the main source areas of long-range atmospherically transported pollution affecting the region are similar to those affecting Murmansk Oblast. Differences in deposition are associated mainly with the greater significance of Russian emission source regions. Figures 4.27(a) and 4.27(b)



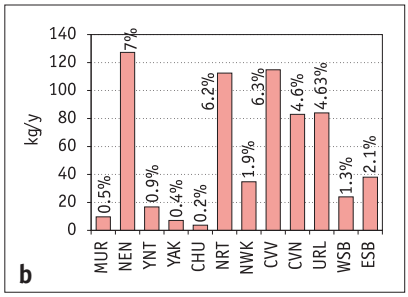


Figure 4.27. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in the Nenets AO.

show the relative contribution of the different regions to the total annual deposition of mercury in the Nenets AO from anthropogenic sources. The largest contribution is from Russian sources (35%). However, sources within the Nenets AO itself only contribute 7%, whereas the combined contribution of regions in European Russia make up 24% of the deposition. The most important of these are the Northern region (NRT) and the Central and Volgo-Viatsky regions (CVV). The most significant external contributors are Eastern Europe (13%), China (11%), the Americas (10%), Western Europe (9%), and Central Asia (9%).

PCB

The largest contributions to PCB-153 depositions are made by Russia (41%), Northwest Europe (31%) and Southeast Europe (18%) (Figure 4.28(a)). The main contributions among Russian sources (Figure 4.28(b)) are made by the Central and Volgo-Viatsky regions (CVV) and the Northern region (NRT), with values of 15% and 10%, respectively.

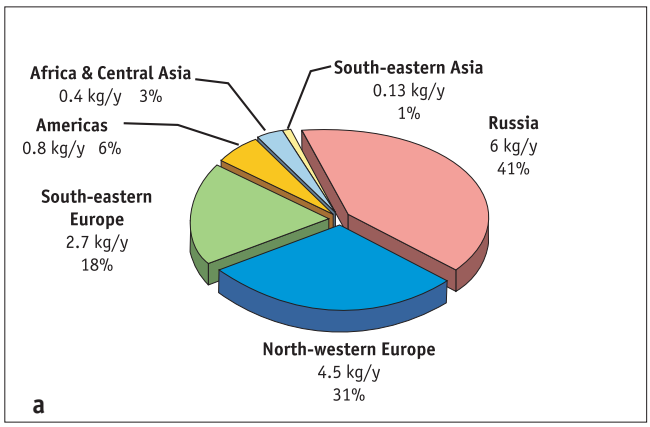
γHCH

The major contributions to the contamination of the Nenets AO by γ-HCH are from emission sources in Western Europe (49%), Russia (23%), and India (9%) (Figure 4.29(a)). The main sources within the Russian Federation are the Central and Volgo-Viatsky regions (CVV) and the Central-Chernozem, Volga, and North-Caucasian regions (CNV), contributing 8% each (Figure. 4.29(b)).

4.2.5.3. The Yamalo-Nenets and Taymir Autonomous Okrugs

Mercury

The location of the Yamalo-Nenets AO and the Taymir AO in the northern part of western Siberia, accounts for the fact that Asian sources play a noticeable role in their contamination. European sources, however, still continue to exert a considerable influence. Up to 30% of all mercury annually deposited in these two regions is from Russian sources (Figure 4.30(a)). The contribution from sources within the Yamalo-Nenets and



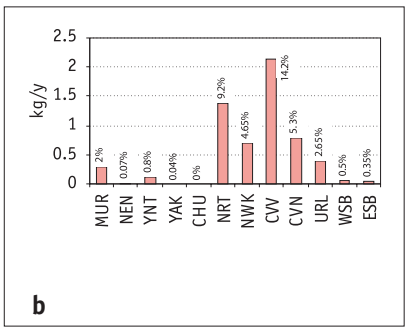
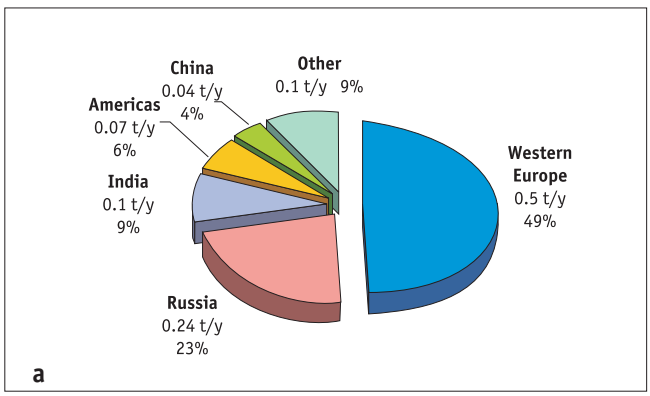


Figure 4.28. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in the Nenets AO.



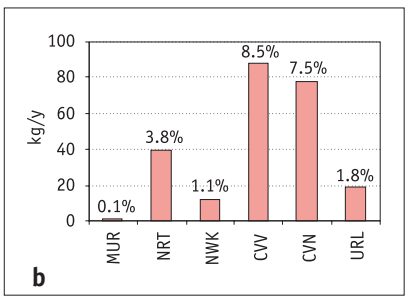
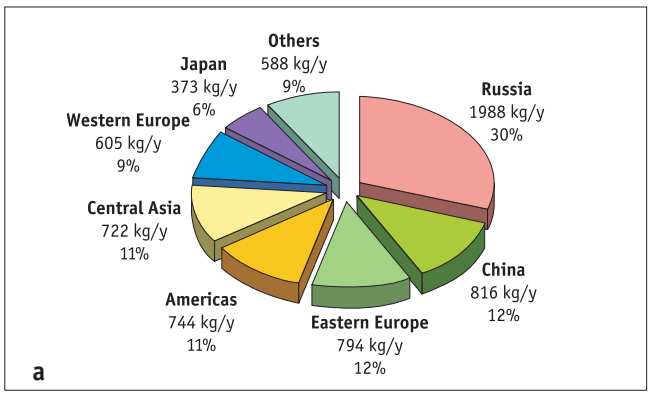


Figure 4.29. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual γ-HCH deposition in the Nenets AO.



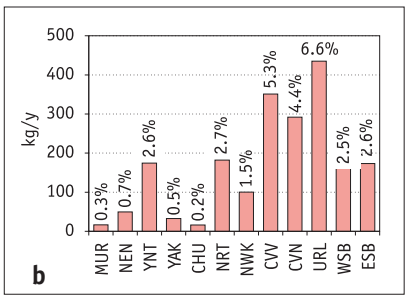
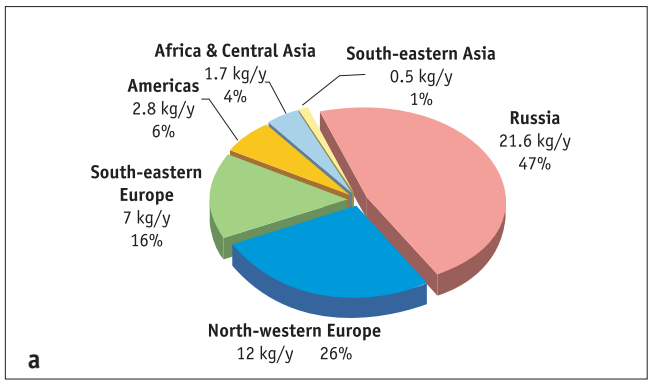


Figure 4.30. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in the Yamalo-Nenets AO and the Taymir AO.



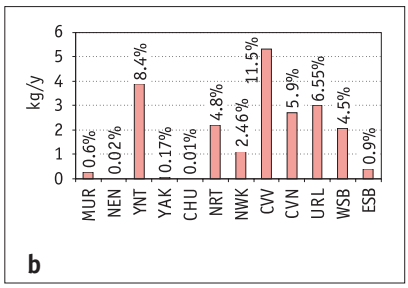
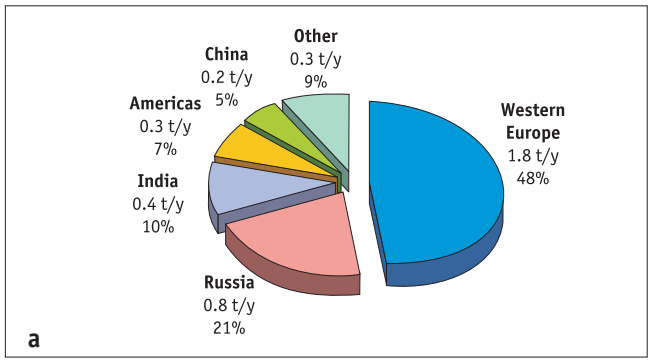


Figure 4.31. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in the Yamalo-Nenets AO and the Taymir AO.



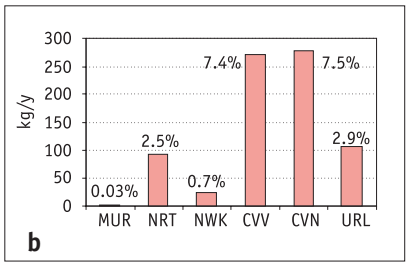
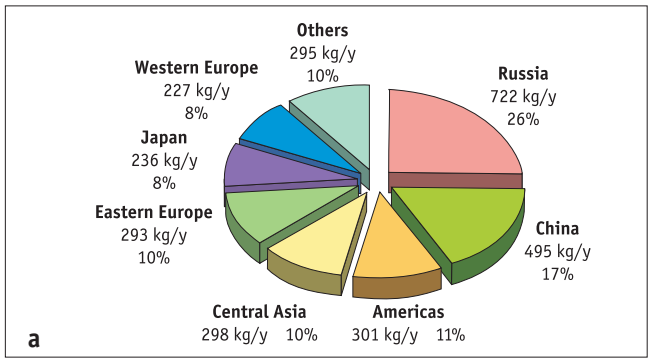


Figure 4.32. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual γ-HCH deposition in the Yamalo-Nenets AO and the Taymir AO.



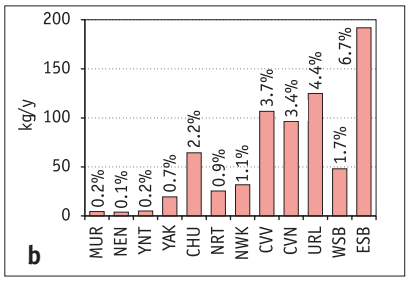


Figure 4.33. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in the Chukchi AO.

Taymir AOs themselves is comparatively low (only about 3%), whereas three major Russian contributors (CVV, CVN, and URL) make up 16% of total deposition (Figure 4.30(b)). The two major external contributors are China (12%) and Eastern Europe (12%). Some impact is also made by the Americas (11%), Central Asia (11%) and Western Europe (9%).

PCB

Major contributions to PCB deposition in the Yamalo-Nenets and Taymir AOs are made by sources in Russia (47%), Northwest Europe (26%) and Southeast Europe (16%) (Figure 4.31(a)). Among Russian sources (Figure 4.31(b)), the largest contribution (12%) to depositions are made by the Central and Volgo-Viatsky regions CVV). The contribution of emission sources located within the Yamalo-Nenets and Taymir AOs is 9%.

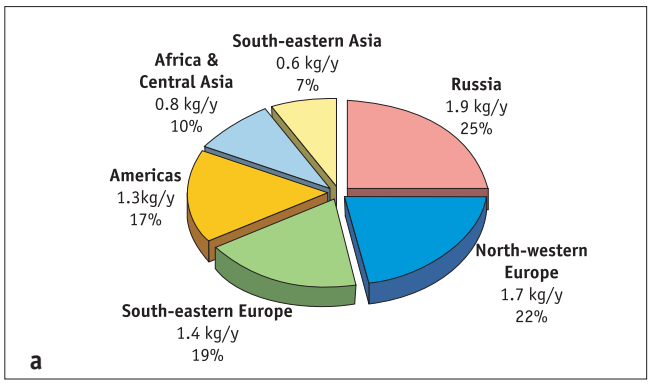
γ-HCH

Main contributors to depositions of γ-HCH in the Yamalo-Nenets and Taymir AOs are similar to those for the Nenets AO. Sources in Western Europe make the largest contribution to ongoing deposition in these territories (48%). Russia is responsible for 21% and India, for 10% (Figure 4.32(a)). Russian contributions to depositions in the Yamalo-Nenets and Taymir AOs are mainly from the Central and Volga-Viatsky regions (CVV) and the Central-Chernozem, Volga, and North-Caucasian regions (CVN), 7% and 8% respectively (Figure 4.32(b)).

4.2.5.4. Chukchi Autonomous Okrug

Mercury

The Chukchi AO is the most eastern and remote region of the Russian North. Its location, far from major industrial regions, accounts for the fact that the global background pool of atmospheric mercury is the main source of mercury contamination in this region. Figure 4.33(a) demonstrates the relative contributions of different source regions to annual mercury deposition in the Chukchi AO. The main contributor is Russia (26%), however, contributions from China are also considerable (17%). Among other sources, the Americas (11%), Central Asia (10%), and Eastern Europe (10%) are of note. The contribution from the Chukotka AO itself is insignificant compared to emission sources located in Eastern Siberia and the Far East (Figure 4.33(b)). However, the influence of major emission regions in European Russia (CVV, CVN, URL) are also apparent.



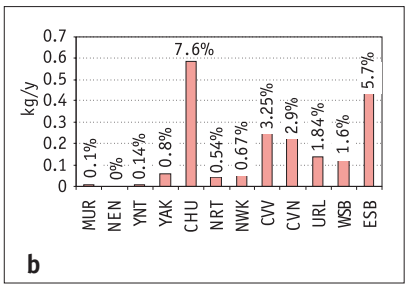
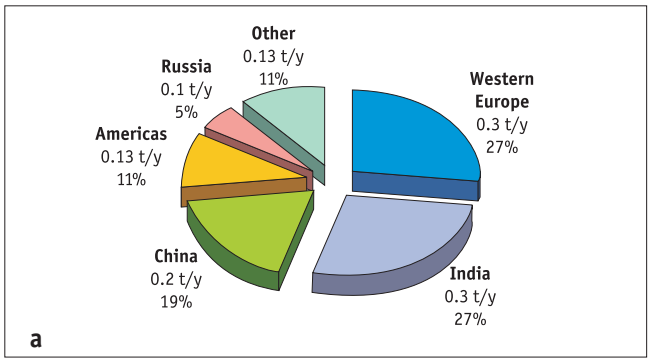


Figure 4.34. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in the Chukchi AO.



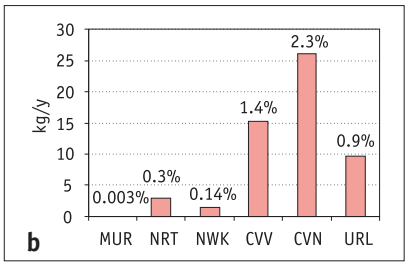


Figure 4.35. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual γ-HCH deposition in the Chukchi AO.

PCB

The most important contributions to PCB-153 deposition in the Chukchi AO are made by sources located in Russia (25%), Northwest Europe (22%), and Southeast Europe (19%), followed by American sources (17%). (Figure 4.34(a)). The main contribution from the Russian source regions (Figure 4.34(b)) is made by emissions from the Chukchi AO itself (8%).

γ-HCH

For the Chukchi AO, the main contributions to γ-HCH contamination are made by India (27%), Western Europe (27%), China (19%), and the Americas (11%) (Figure 4.35(a)). The contribution from all Russian sources accounts for only 5% (Figure 4.35(b)).

4.2.6. Conclusions

Murmansk Oblast

The largest contribution to anthropogenic mercury deposition in the Oblast is made by Russian sources (35%) of which 13% is from sources within Murmansk Oblast itself. The most important external sources are Eastern Europe (12%), China (11%), the Americas (10%), and Western Europe (10%). Total annual deposition of mercury is around 3 t, including 1.5 t from anthropogenic sources.

A major contribution to PCB deposition is made by Russian sources (44%) including 22% from sources within Murmansk Oblast itself. Among other emission sources, significant contributions originate in Northwest Europe (35%), and Southeast Europe (14%). Total annual deposition of PCB-153 in Murmansk Oblast amounts to 20 kg, and of total PCBs, 0.7 t.

Main contributions to γ-HCH deposition are made by sources within Western Europe (54%), Russia (17%), and India (9%). Russian contributions to deposition are mainly from sources located in the Central and Volgo-Viatsky regions (5%), and Central-Chernozem, Volga, and North-Caucasian regions (4%). Total annual deposition of γ-HCH amounts to 0.8 t.

The Nenets Autonomous Okrug

The most important contribution to anthropogenic mercury depositions in the Nenets AO is made by Russian emission sources (35%). As well as deposition from sources within the Nenets AO itself (7%), emissions from regions in the European part of Russia contribute considerably to the pollution of this region (24%). The most important external contributors are Eastern Europe (13%), China (11%), and the Americas (10%). Total annual deposition of mercury in the Nenets AO amounts to 4 t, of which 1.8 t is from anthropogenic sources.

Main contributions to PCB deposition in the Nenets AO are from sources in Russia (41%), Northwest Europe (31%), and Southeast Europe (18%). Major contributions from sources within the Russian Federation are made by the Central and Volgo-Viatsky regions (15%), and the Northern region (10%). The contribution of local sources to deposition in the Nenets AO is negligible. Total annual deposition of PCB-153 in this Okrug amounts to 31 kg, and of total PCBs, 1 t.

γ-HCH pollution of the Nenets AO is due to emission sources in Western Europe (49%), Russia (23%), and India (9%). The main sources within the Russian Federation are the Central and Volgo-Viatsky regions

(8%), and the Central-Chernozem, Volga, and North-Caucasian regions (8%). Total annual deposition of γ-HCH to this Okrug is 1.1 t.

The Yamalo-Nenets and Taymir Autonomous Okrugs

The major contribution to anthropogenic mercury deposition in these regions is from emissions sources in Russia (30%). Among Russian sources, the main contributors are sources in the Ural, Central and Volgo-Viatsky regions, and the Central-Chernozem, Volga, and North-Caucasian regions (16% in total). Main external contributors are China (12%), Eastern Europe (12%), the Americas (11%), and Central Asia (11%). Total annual deposition of mercury is estimated at 15 t, of which 6.6 t is from anthropogenic sources.

Major contributions to PCB depositions are made by sources located in Russia (47%), Northwest Europe (26%) and Southeast Europe (16%). Among Russian sources, the largest contribution to deposition is made by the Central and Volgo-Viatsky regions (12%). Total annual deposition of PCB-153 is 95 kg, and 3.2 t for total PCBs.

Main contributions to γ-HCH depositions are made by Western Europe (48%), Russia (21%), and India (10%). Main sources within the Russian Federation are the Central and Volgo-Viatsky regions (7%) and the Central-Chernozem, Volga, and North-Caucasian regions (8%). Total annual deposition of γ-HCH amounts to 4 t.

The Chukchi Autonomous Okrug

The main contributions to anthropogenic mercury deposition in this Okrug originate from Russian sources (26%). Emission sources from Eastern Siberia and the Far East are the dominant influences on mercury contamination of the Chukchi AO. The main external contributor to the region's pollution is China (17%), with a contribution comparable to that of Russian sources, although this varies slightly during the year. Among others, the Americas contribute 11% and Central Asia 10% to the deposition. Total annual deposition of mercury is estimated at 7 t, of which 2.9 t is from anthropogenic sources.

The main contributors to PCB deposition are the following: Russia (25%), Northwest Europe (22%), and Southeast Europe (19%), followed by American sources (17%). The Chukchi AO itself contributes 8%. The total annual deposition of PCB-153 amounts to 11.8 kg, and of total PCBs, 0.4 t.

Main contributions to γ-HCH deposition are made by India (27%), Western Europe (27%), China (19%), and the Americas (11%). The contribution from Russian sources accounts for 5%. Total annual deposition of γ-HCH in the Chukchi AO is estimated at 1.4 t.

In addition, the following general conclusions can be made, based on the studies undertaken:

- Europe, North America, and Southeast Asia are the most significant emission source regions for mercury, PCBs and γ-HCH. The main Russian emission sources are located in the European part of the Russian Federation. Due to their geographical location, and to meteorological conditions, European sources make the greatest contribution to the contamination of the western regions of the Russian North. Asian and North American sources play a more significant role in the pollution of the eastern territories of the Russian Arctic, although the contribution of European sources is still considerable.

- The results obtained make it possible to make some predictions for the near future regarding contamination levels in the Russian Arctic. An analysis of emission data shows that mercury emissions are decreasing in Europe and North America, whereas emissions from Southeast Asia are increasing. Asian sources may eventually become the more significant, thus contamination levels of this pollutant in some regions of the Russian North, in particular the Chukchi AO, may increase in the future. Regarding γ-HCH, use of technical-HCH (a mixture of HCH isomers, including γ-HCH) is now banned in most western countries, and in Russia since the late-1980s; China, a major user, also switched to lindane (pure γ-HCH) in 1984. Although restricted in most countries, lindane is still widely used in North America, Europe and Asia, for seed treatment and other applications (AMAP, 2002). Thus the relative influence of Asian countries on pollution of the Russian Arctic by γ-HCH is likely to increase. PCB contamination levels are expected to decrease with emission reductions resulting from bans and controls on use of PCBs. However PCB contamination is likely to continue for many years as a result of re-emissions from PCBs accumulated in the general environment over the last 50-years.

4.3. Preliminary assessment of riverine fluxes as PTS sources

4.3.1. Introduction

Flows of large Arctic rivers are considered one of the most significant pathways by which contaminants reach the Arctic. Riverine transport is particularly relevant for PTS, as potentially PTS contamination within the entire catchment areas of these rivers can be transported to the Arctic through watershed runoff, and these catchments include heavily industrialized areas and agricultural regions (Figure 4.36).

Riverine PTS transport is particularly important for two of the study areas selected for project implementation: the lower Pechora basin, and the eastern part of the Taymir Peninsula, in the area of the Yenisey river.