UN environment programme

Assessing Regional and National Capacities for Monitoring and Research of Persistent Organic Pollutants in Air and Water

ISBN: xxx

Job number: xx

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Suggested citation: United Nations Environment Programme (2024). *Assessing Regional and National Capacities for Monitoring and Research of Persistent Organic Pollutants in Air and Water.* Geneva.

URL:

ACKNOWLEDGEMENTS

This report was coordinated by the Chemicals and Health Branch of the United Nations Environment Programme (UNEP) in the framework of the Global Environment Facility-funded POPs Global Monitoring Plan projects in the Africa, Asia, Pacific and Latin America and the Caribbean regions (Project GEF ID 4881, 4886, 4894, 6978).

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Ramon Guardans (Ministry of Agriculture, Food and the Environment of Spain), Jana Klánová (RECETOX center, Masaryk University), Rainer Lohmann (University of Rhode Island) and Branislav Vrana (RECETOX center, Masaryk University) are acknowledged for their insightful review and contribution to the development of this assessment report.

The report has been produced with the financial assistance of the Global Environment Facility.

Layout and graphic design: Murat Özoğlu and Lowil Fred Espada

ABBREVIATIONS

a-HCH	Alpha hexachlorocyclohexane
AMAP	Arctic Monitoring and Assessment Programme
AnMAP	Antarctic Assessment and Monitoring Programme
APOPSBAL	Assessment of the selected POPs in the atmosphere and water ecosystems from the waste generated by warfare in the area of former Yugoslavia
b-HCH	Beta hexachlorocyclohexane
CEE	Central and Eastern Europe
CMSS	Convention on Migratory Species Secretariat
COP	Conference of Parties
COVID	CoronaVirus Disease of 2019
CSIC	Consejo Superior de Investigaciones Científicas (Spanish Research Council)
CWS	Convention on Wetlands Secretariat
DCs	Depurations compounds
DDT	Dichlorodiphenyltrichloroethane; DDD and DDE are transformation products of DDT
dl-PCB	Dioxin-like PCB
Drins	aldrin, dieldrin, and endrin as a sum
DWH	GMP Data Warehouse
ECCC	Environment and Climate Change Canada
EE	Effectiveness Evaluation
EMEP	European Monitoring and Evaluation Programme
EU	European Union
FTOH	Fluorotelomer alcohol
GAPS	Global Atmospheric Passive Sampling (Network)
GC	Gas chromatography
GCG	Global Coordination Group for the Global Monitoring Plan
GEF	Global Environment Facility
GEN	Geneva Environment Network
GEO	Group on Earth Observations
GFF	Glass fiber filter
GIN	Global Integrated Networks
GLB	Great Lakes Basin Monitoring and Surveillance Program
GMP	Global Monitoring Plan
GRULAC	Group of Latin America and the Caribbean
HBCD	Hexabromocyclododecane
HCBD	Hexachlorobutadiene
HCH(s)	Hexachlorocyclohexane(s)
HERA	Health Environment Research Agenda for Europe
HRMS	High resolution mass spectrometer
HV-AAS	High-volume active air sampler

IADN	Integrated Atmospheric Deposition Network
IISD	International Institute for Sustainable Development
IPCP	International Panel on Chemical Pollution
IPW	International Pellet Watch
JMoE	Japan Ministry of Environment
LAPAN	Latin Passive Air Monitoring Network
LC-PFCAs	Long-chain perfluorocarboxylic acids
LRAT	Long-range atmospheric transport
LV-AAS	Low-volume active air sampler
MEAs	Multilateral environmental agreements
MeFOSE	N-Methylperfluorooctanesulfonamidoethanol
MONARPOP	Monitoring Network in the Alpine Region for Persistent and other Organic Pollutants
MONET	Monitoring Network for Persistent Organic Pollutants
MS	Mass spectrometer / Mass spectrometry
NAPS	National Air Pollution Surveillance (Program)
NCP	Northern Contaminants Programme
NILU	Norwegian Institute for Air Research
NIP	National Implementation Plan
NO2	Nitrogen dioxide
NTS	Non-targeted screening
OCPs	Organochlorine pesticides
OEWG	Open Ended Working Group
PA	PurpleAir
PACs	Polycyclic aromatic compounds
PARC	Partnership for the Assessment of Risks from Chemicals
PBDE	Polybrominated diphenylether(s)
PCB	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PDMS	Polydimethylsiloxane
PE	Polyethylene
PeCBz	Pentachlorobenzene
PFAA	Perfluoroalkyl acids
PFAS	Per- and polyfluoroalkyl substances
PFHxS	Perfluorohexane sulfonic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PM	Particulate Matter
POPRC	Persistent Organic Pollutants Review Committee
POPs	Persistent Organic Pollutants

POPsEA	POPs Monitoring Project in East Asian countries
PUF	Polyurethane foam
PUF-PAS	Polyurethane foam-passive air sampler
QA	Quality assurance
QA/QC	Quality assurance and quality control
QFF	Quartz fiber filter
RECETOX	Research Centre for Environmental Chemistry and Ecotoxicology
REGs	Regional expert groups
ROGs	Regional Organization Groups for the Global Monitoring Plan
SAICM	Strategic Approach to International Chemicals Management
SCCPs	Short-chain chlorinated paraffins
SCRC	Stockholm Convention Regional Centre
SIP-PAS	Sorbent-impregnated polyurethane foam-passive air sampler
SMP	Spanish Monitoring Program
SOPOPP	Southern Ocean Persistent Organic Pollutants Program
SPMD	Semi-permeable membrane devices
SVOCs	Semi-volatile chemicals
TF HTAP	Task Force on Hemispheric Transport of Air Pollution
TOMPs	Toxic Organic Micro Pollutants
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNEA	United Nations Environmental Assembly
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
VU	Vrije Universiteit, Amsterdam, The Netherlands
WEOG	Western European and Others Group
XAD	Styrene/divinylbenzene-co-polymer resin

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KEY MESSAGES

There is a widening demand for POPs monitoring information in particular for new POPs.

Persistent Organic Pollutants (POPs) are hazardous chemicals that remain intact for a long time, widely distributed throughout the environment, accumulate and magnify in living organisms through the food chain, and are toxic to both humans and wildlife. The Stockholm Convention on POPs as a multilateral environmental agreement entered into force in 2004 to safeguard human health and the environment from the adverse effects of POPs. On top of the initial list of 12 POPs, new POPs are continuously created, used and then listed under the Convention. As of 2023, 34 POPs have been listed under the Convention for elimination or restricted production and use, with four more POPs under review. Scientifically sound evidence on the environmental existence and human exposure to these POPs is critical for risk prevention and to advice effective policy making and control actions. However, challenges exist to ensure global data coverage given the high cost and complexity associated with laboratory analysis of these organic compounds in particular for the newly listed POPs (*e.g.* chlorinated paraffins, dechlorane-plus, UV-328). Furthermore, interpretation of monitoring results remains a barrier in particular for spatial-temporal trend analysis in a broader context of long-range transport that include vectors such as microplastics, waste streams and bio-vectors.

Significant data gaps still exist in POPs monitoring.

Significant data gaps exist—mainly in the global south with limited capacities for POPs monitoring—to measure the extent of environmental existence and human exposure to POPs. These gaps include spatial and temporal coverage of data and missing information for specific POPs such as dioxins, chlorinated paraffins, brominated flame retardants, among others (see Chapter 2, table 1). As shown in the Stockholm Convention Data Warehouse, only 126 countries have environmental monitoring data; more than forty of those generated data through international collaboration. Meanwhile, most low- and middle-income countries do not have national POPs monitoring activities. Furthermore, the transformation products of POPs in the environment are often poorly understood and not typically measured, despite their potential hazards. The lack of monitoring results limits the effectiveness evaluation of the Stockholm Convention from providing concrete instructions for effective actions at the regional and national level. Consideration also needs to be given to the collection and analysis of gender-disaggregated data.

Strengthening coordination and integration among monitoring programmes.

Literature review from 2005 – 2022 identified 337 papers published on POPs measurements in air and 129 in water based on studies conducted in developing countries. This indicated existing analytical capacities in countries and regions with potential to fill in data gaps and to provide critical information for the effectiveness evaluation of the Stockholm Convention and actions on the management of POPs. Strengthening communication and collaboration between diverse national and regional science initiatives and expertise, as well as exploring opportunities like citizen science, is crucial for improving science-policy interface and enhancing the global capacity for POPs monitoring. Emphasis should be placed on having broader engagement, knowledge exchange, and a comprehensive understanding of environmental and health impacts. This will lead to more effective policy development and address intersecting issues related to POPs such as health, climate change, biodiversity, and waste management and pollution control.

EXECUTIVE SUMMARY

The Stockholm Convention on Persistent Organic Pollutants (POPs) is a legally binding international agreement that aims to protect human health and the environment from the harmful effects of POPs (Stockholm Secretariat 2019a). Article 16 of the Convention requires that effectiveness of the measures adopted by the Convention is evaluated in regular intervals, including a global monitoring plan (GMP) to identify changes in POPs concentrations over time and to elucidate their regional and global environmental transport. Global monitoring data for the listed POPs in core media (i.e., air, human milk and blood, and water) is compiled and reported every 6 years in support of the effectiveness evaluation of the Convention, which informs the Conference of the Parties (COP) on the state of progress and relevant issues with respect to the listed POPs. Due to the accrued body of scientific evidence on chemicals, new POPs have been listed in the Convention at each of the past 7 COPs, widening the need for monitoring data. Since entry into force in 2004, the overall number of POPs listed under the Stockholm Convention on POPs (Stockholm Convention) has more than doubled from an original 12 POPs to 34 POPs, as of May 2023, and will continue to increase. Other candidate POPs are due to be decided upon at COP 12 in 2025.

POPs are ubiquitous pollutants which contribute adversely to air and water quality and related ecosystem and human health impacts. Adverse impacts of chemical pollution include developmental neurotoxicity, reproductive toxicity, immunotoxicity and other effects which are currently inadequately understood (Fuller *et al.* 2022). Such impacts of POPs often disproportionately affect marginalized and vulnerable communities, including men, women and children. Gender-disaggregated data collection and analysis should be integral to monitoring and mitigation strategies (United Nations Environment Programme [UNEP] and Stockholm Secretariat 2017; Secretariat of the Basel, Rotterdam and Stockholm Conventions n.d.). Besides POPs and other emerging chemicals of concern, many of the transformation products of these chemicals in the environment are largely unknown and not typically measured. They are also of concern as they have equally, and sometimes more hazardous properties compared to the original chemical (Liu *et al.* 2021).

Determining the concentrations of POPs in water is important for understanding the sources, global distribution and ultimately exposure of aquatic organisms and their food webs. Therefore, water is a widely used matrix for monitoring environmental contaminants such as perfluorinated alkyl substances (PFAS). Meanwhile, air pollution is recognized as a leading cause of premature mortality, especially in developing country regions (Fuller *et al.* 2022). The dramatic increase in chemical production and its diversity has resulted in growing and more challenging demands for science and monitoring. These demands stem from the need to better understand the occurrence and implications of POPs and POP-like chemicals, as part of the air pollution problem (Diamond *et al.* 2015).

As the list of POPs expands, addressing the growing demand for data and information is crucial to comprehending human exposure and the environmental presence of these chemicals. To enhance data availability, it may be beneficial to strengthen coordination and integration among broader monitoring programmes and experts. This could also complement the existing global data collection mechanism of the Stockholm Convention GMP, which until now has relied mainly on the work of relatively small teams, namely the Regional Coordination Group. This expanded effort would make best use of available resources and data to better keep pace with the growing demands for data on POPs.

By involving a wider range of national and regional experts, the monitoring of POPs will fortify the groundwork for developing enhanced national and regional communication between science and informed policy making. This, in turn, will aid in fostering a more comprehensive understanding of the impacts on ecosystems and human health, encompassing not only POPs but also a broader range of crosscutting issues such as emerging chemicals, transformation products, waste streams, plastic pollution, as well as the effects on biodiversity loss and climate change. Engaging with local research groups and expert communities on POPs monitoring will also contribute to identifying intersecting issues.

The data generated would consequently provide a valuable source of information that can support further exploration into complex issues such as gender and age-differentiated windows of exposure and the relationship between POPs and vulnerable groups. Other opportunities for engagement, such as with indigenous and traditional knowledge and citizen science, may also be beneficial and lead to cost-effective approaches to POPs monitoring with the added benefit of improving outreach across the public-science and public-policy interfaces.

This report provides insights to the existing challenges and approaches for improving national and regional capacity for sustainable monitoring of POPs in air and water elaborates on the strategies outlined above. The assessment on air is presented in Chapters **2**, **3** and **4** of the report and the assessment on water is presented in Chapters **5**, **6** and **7**. The main findings are summarized below.

In **Chapter 2** a broad review of the literature was conducted to better understand the available and untapped information and expertise on POPs measurements in air, over the period 2005 to January 2022. The literature review identified 337 papers published on POPs measurements in air, with most studies in either Asia-Pacific or WEOG regions. Publication rates have increased gradually over this period with a notable drop-off following 2019, likely associated with the global COVID pandemic. The proportion of publications using passive air samplers (primarily PUF-PAS samplers) continues to increase and now outnumbers studies using active air sampling. A large list of national/regional and international experts on POPs in air as well as institutions are actively publishing in this area and are capable of performing POPs analysis. This is well catalogued in a database included in the Annex to this report.

Despite many air monitoring programmes involved in reporting to the GMP, there continue to be significant data gaps. These gaps include spatial omissions in both regional/sub-regional air monitoring for POPs as well as missing information for specific POPs, in some cases almost entirely. These challenges are expected to continue, especially in developing regions, as more POPs are listed. To close the data gaps, re-evaluating the requirements and approach for data inclusion and quality control could be considered to enable contributions from a broader group of researchers.

Chapter 3 considers current and future modalities for capacity enhancement for POPs measurements in air, including international data quality exercises such as, *inter alia*, the interlaboratory assessments conducted under the UNEP/GEF POPs GMP projects.

As shown in this report, there are modalities available for generating comparable POPs monitoring data in air. Mature sampling approaches such as PUF-PAS air samplers have been used by the international research community over the past 20 years for measuring POPs in air. They have proven to still be effective by recent studies capturing both gas-phase and particle associated chemicals which is particularly relevant for newer POPs.

Improved scientific communication and knowledge integration to support policy making can be achieved through a more inclusive framework that better recognizes POPs monitoring efforts and expertise in the field. This can foster new teams and partnerships for enhancing POPs measurements and support model development and testing to better understand regional and global transport of POPs in air and water. Increased data quality, comparability and coordination efficiency are also factors to be considered. Other co-benefits include synergies with national and international priorities such as health, climate change, waste, and biodiversity.

Chapter 4 considers approaches to enhance partnerships among countries and regions and to strengthen communication to boost capacity for monitoring POPs in air.

Improving communication between science and informed policy and decision making is an important first step for long term national/regional POPs monitoring in air. This foundation-building requires more attention to inclusiveness and engagement with diverse national and regional science experts. The current limitations of communication between science and policy have been recognized and are a source of frustration for many researchers. This limitation can be addressed through greater collaboration with and among these experts to develop national and regional strategies and priorities for POPs monitoring in air and fulfilling obligations such as GMP reporting. This science-policy enhancement will also lead to improvements at the policy-policy interface, as these experts represent a diverse and networked community able to recognize intersecting issues and synergies with other priority issues connected to POPs. Other opportunities for engagement, such as citizen science, may also be beneficial and lead to cost-effective approaches to POPs monitoring with the added benefit of improving outreach across the public-science and public-policy interfaces.

The framework introduced in chapter 4 proposes a more sustainable and cost-effective POPs monitoring system. It includes greater engagement with POPs experts at national, regional and global scales. In this sense, a key step to enhancing the current situation is taking stock of existing talent and considering opportunities that already exist for partnerships and collaboration. Reporting to the GMP is cast as a coupled "bottom-up" and "top-down" information flow (see text box). This makes best use of available resources and data to keep up with the growing demands of the GMP. It also provides a strong basis for informing the Effectiveness Evaluation of the Stockholm Convention in a more sustainable and inclusive manner.

In the context of this report "bottom-up" reporting under the GMP refers to the approach under the current framework where regional organizational groups (ROGs) assemble data on POPs in air from existing and officially recognized programmes or through newly implemented and GMP-targeted programmes, to develop baselines and trend information for POPs in air; the bottom-up approach ultimately helps to identify gaps in information and the need for new efforts to address these gaps; whereas, the "top-down" approach uses broader and diverse sources of existing information/programmes and expertise, currently outside of the ROGs, to address data gaps and interpret monitoring data (see 4.2.1). In addition to incorporating diverse data, "Top-down" approaches could also include "inverse modelling" where these data are used in models to estimate the location and magnitude of emissions

Chapter 5 identified 129 articles on POPs in surface waters from 30 countries within Africa, Asia-Pacific, Latin America and the Caribbean (GRULAC), as well as selected countries in the Central and Eastern Europe (CEE) region, bordering Asia-Pacific. Studies on POPs in surface waters of neighboring seas/oceans in these same regions were included and a total of 103 institutions/agencies were identified. The relatively large number of publications and institutions involved demonstrates that there is significant capacity within developing countries in all four UNEP regions to undertake POPs analysis in water. However, most studies were on a limited number of POPs, predominantly dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH). Analysis of a broader range of POPs in water would be advantageous in terms of understanding potential sources, geo-spatial trends, and "hot spots" which are currently not identified with air and human milk analyses under the GMP. However, it must be recognized that many analytes are present at picogram per liter (pg/L) concentrations that are often below the detection limits for analysis of POPs in 1L samples, the most common volume used. Passive sampling, using silicone sheets to absorb dissolved POPs from water, was used in 14 of the 129 studies, and generally provided lower detection limits than 1L "grab" samples. However, the analyses of passives were mainly conducted by experienced, well equipped, laboratories in Europe, the USA and China. The combined data for POPs from the 129 articles created a dataset with 242 freshwater sampling sites and 433 marine sites totaling approximately 7400 individual results for concentrations of POPs in surface waters. This data could be useful for assessment of geospatial and temporal trends of POPs in water.

Chapter 6 is forward looking, comparing results of interlaboratory studies of POPs in which water was used as a matrix. Interlaboratory studies are widely used to assess laboratory performance and provide training of laboratory staff. UNEP has included water in 3 interlaboratory assessments over the past 10 years, but with a focus only on PFAS. Nevertheless, the successful involvement of laboratories in Asia-Pacific, CEE, GRULAC, and WEOG for analysis of PFAS in water is an indication of the feasibility of an interlaboratory comparison for hydrophobic, non-polar POPs (Polychlorinated biphenyls (PCBs), DDT, HCH etc) in water samples. The QUASIMEME (Quality Assurance of Information on Marine Environmental Monitoring in Europe) proficiency test for non-polar POPs and pentachlorophenol in water presents an opportunity to involve laboratories in these regions who prefer to use conventional 1L samples and extractions with solvents or solid phase cartridges. QUASIMEME has also organized interlaboratory comparisons using passive samplers. Participation of labs in Asia-Pacific, CEE, GRULAC, and Africa in the passive sampler proficiency testing could be encouraged by funding the cost of participation. Future intercomparisons could also reach out to the laboratories analysing water samples that have been identified in this report.

Finally, **Chapter 7** present as case study two recent programmes as possible models for monitoring of POPs in water in developing countries: The UNEP/GEF POPs GMP II projects and its PFAS monitoring in water, which included 22 countries of Africa, Asia-Pacific, GRULAC in 2017–2019; and the AQUAGAPS-MONET project involving passive sampling of water for non-polar POPs including 22 sites in developing countries. In both programmes a single expert lab analysed all samples. When conditions exist, a future framework for water sampling and analysis at the national and subregional level would ideally be permitting the analysis to be done by the local labs.

Enhancing the capacity to conduct analyses of POPs in water at the national and subregional level would connect POPs monitoring to other studies such as measurements in air, sediments and biota. Review of publications showed that many laboratories involved with water sampling and analysis were also involved with collection and analysis of sediment and air for POPs.

There is also the potential for a "citizen science" component to the water sampling program whereby local volunteers could be identified, possibly via environmental non-government organizations (NGOs), to deploy and retrieve passive samplers or conduct "active" sampling. There are many examples of successful citizen science projects for water quality monitoring, including UNEP's citizen science program "Citizen Data for SDG Indicator 6.3.2". However, they are mainly focused on standard water chemistry parameters. Thus, application to studies on POPs at nanogram and picogram per litre levels in water would need careful planning and volunteer training.

INTRODUCTION AND CONTEXT

1 CHAPTER

Enhanced monitoring capacity for POPs is important for several reasons including: i.) at the national scale, having a network of scientists and concerned stakeholders, that contribute to a strong sectoral approach in the development of informed chemicals policies that considers POPs with interconnected issues such as health, climate, biodiversity, and waste, and ii.) at the international scale, to support international chemicals management and reporting to support Effectiveness Evaluation (EE, Article 16) under the Stockholm Convention on POPs, including reporting under the Global Monitoring Plan (GMP) and support of important activities under Articles 8-12 of the Convention. The Global Monitoring Plan for POPs under Article 16 of the Convention, is a key component of the effectiveness evaluation and provides a harmonized framework to identify changes in concentrations of POPs over time, as well as information on their regional and global environmental transport. It is a central component of EE and therefore linked to how other elements of the Convention are working. These include, for instance, measures to decrease sources (Articles 3-6), national implementation plans (NIP, Article 7), listing of new substances (Article 8), information exchange (Article 9), public information (Article 10), research and development (Article 11), technical assistance (Article 12) and reporting (Article 15) (Stockholm Secretariat 2019b).

The United Nations Environment Programme (UNEP), in collaboration with the Secretariat of the Basel, Rotterdam and Stockholm (BRS) Conventions, and with support provided by the Global Environment Facility (GEF), implemented regional capacity building projects in developing countries and countries with economies in transition to support the Global Monitoring Plan for POPs.

Under the framework of the UNEP/GEF Global Monitoring Plan projects, the aim of this report is to provide insight to existing challenges and approaches for improving national and regional capacity for sustainable monitoring of persistent organic pollutants (POPs) in air and water. The main results of the report are presented in chapters **2**, **3** and **4** for air and in chapters **5**, **6** and **7** for water, which are summarized below.

Chapter 2, and 5 – are in-depth assessment for regional initiatives and national capacities to identify opportunities for the establishment of strategic regional or subregional frameworks for long-term sustainable monitoring of POPs in air and water respectively.

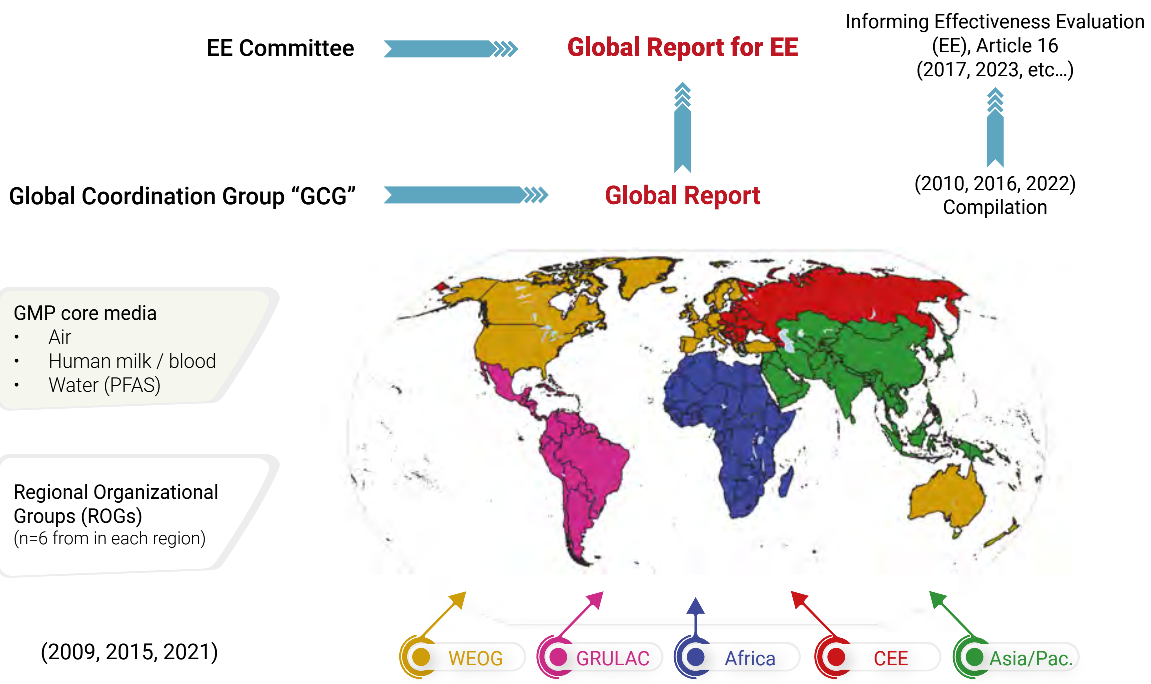
Chapter 3, and 6 – are assessments for global analytical service and modalities to quality control/quality assurance for the generation of comparable data on POPs in air and water respectively.

Chapter 4, and 7 – present guidance for the establishment of coordination mechanisms in developing countries for the monitoring of POPs in air and water respectively.

The aim of these chapters is to provide an objective, accurate, and concise summary of the current state of knowledge relating to existing POPs monitoring and surveillance activities in air and water and perspectives for enhancing future capacity to address future needs and the increasing number of POPs. The content of the report is consistent with and builds upon recent reports such the third GMP report as well as several recent assessments of the performance of the GMP, made by various experts/groups. The report also benefits from a recent and in-depth review of the peer reviewed literature on measurements of POPs in air and water. Therefore, the report broadly reflects the views of experts in the field, including those involved in Stockholm Convention implementation and reporting under the Global Monitoring Plan (GMP).

The GMP is a key element of Effectiveness Evaluation, Article 16, of the Stockholm Convention. The GMP reports on changes in levels of POPs in core media – air, human tissues and water (currently only for PFAS). The GMP also includes a modelling section to provide context on long-range transport, sources, and for informed interpretation of levels and trends in air. The GMP global report is a summary of the regional reports from the 5 United Nations (UN) regional groups, as shown in Figure 1, which are compiled on a 6-year cycle. The five regional reports form the basis for the global report and in turn the global report is one of the key resources for Effectiveness Evaluation of the Convention.

Figure 1: Regional reporting scheme under the Global Monitoring Plan of the Stockholm Convention.



Reporting of POPs under the GMP is focused on two core media - air and human tissues (human milk or blood). Temporal trend information of POPs in core media informs on the effectiveness of control measures on POPs that have been implemented by Parties prior to or as a result of listing of chemicals under the Convention. Water is included as a core media for the purpose of reporting only for per- and polyfluoroalkyl substances (PFAS) that partition strongly to water, namely PFOS, PFOA and PFHxS that are already listed, and LC-PFCAs proposed for listing under the convention. In this regard, the 3rd GMP report included an assessment of spatial and temporal trends of PFAS in water based on a review of the global scientific literature as well as national monitoring data (United Nations Environment Programme [UNEP and Stockholm Secretariat 2023). However, no equivalent assessment has been conducted for other POPs in water for the GMP. The GMP report also considers other media (*inter alia*, biota, sediment) and incorporates information from completed assessments on POPs by established, long-term programmes and initiatives.

Reporting under the third phase of the GMP has revealed that although levels of many older and even some newer POPs are generally declining in core media, substantial data gaps in monitoring information are becoming evident. For some of the listed POPs there is no monitoring data reported in the GMP by which to assess temporal trends in air and other core media. These data gaps include spatial/geographic gaps, where data are limited or entirely absent for some sub-regions. In other cases, it is data on certain POPs that are lacking. This missing information on POPs in core media, as reported under the GMP, is an impetus for assessing other sources of reliable and peer reviewed data not currently considered under the GMP that could be used to provide a more complete assessment. Additionally, the insights gained and lessons learned from the UNEP/GEF POPs monitoring activities can contribute to exploring the feasibility of this approach.

PART 1: AIR

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REGIONAL INITIATIVES AND NATIONAL CAPACITIES FOR MONITORING POPS IN AIR

2

CHAPTER

In this chapter, the data gaps identified in the third GMP report, with respect to monitoring of POPs in air, are summarized. Additional and related challenges associated with sustainability of the GMP and intersecting issues on biodiversity, climate change, and chemical pollution are also identified as potential linkages since they also require research and adaptive monitoring of POPs in air and other environmental media. Finally, the availability of additional POPs monitoring data, currently not included in the third GMP report, is assessed from the peer-reviewed literature over the period 2005-2022. In addition to uncovering data sets for POPs in air that could contribute to GMP reporting, the literature review also identifies experts and institutions that are active in the field. This information could be useful for future reporting and beyond and for developing coordinated and sustainable strategies for enhancing POPs monitoring at national, regional and global scales as considered further in Chapters 3 and 4. The results of the peer-review exercise are catalogued in Annex 1.

2.1. POPs measurements in air under the third phase of GMP

POPs monitoring under the GMP includes contributions from long-term monitoring programmes that pre-dated the Stockholm Convention (*inter alia*, Arctic Monitoring and Assessment Programme (AMAP), European Monitoring and Evaluation Programme (EMEP), and Integrated Atmospheric Deposition Network (IADN)/ Great Lakes Basin (GLB)) which relied mainly on high volume active air sampling. These programmes have provided valuable data with good temporal resolution. Furthermore, these data were among the first information reported in the GMP that demonstrated the effectiveness of control measures for POPs, some of which predated the Convention and have since been incorporated into it. While temporal resolution and trend information from these active air sampling programmes has been invaluable, the spatial resolution has been limited. This is in part due to the relatively high costs associated with infrastructure, maintenance, and the equipment for active sampling. Over the past few decades, passive air samplers have become popularized as a cost-effective approach to supplement data from active sampling programmes and to address national and regional gaps in monitoring. Because they do not require electricity to operate and are compact, passive air samplers can be deployed easily and almost anywhere. (UNEP 2021, GMP Guidance Document)

At the time of the first GMP report, passive air monitoring programmes such as GAPS (Environment and Climatic Change Canada) and MONET (RECETOX, Masaryk University) were already generating global and regional baseline data for many POPs and these data were incorporated into the report. In addition, since the first phase of GMP, the active air sampling programmes listed above have started to incorporate passive air sampling pilot campaigns in their methods. As part of the ongoing implementation of the GMP, GAPS and MONET have worked with regional experts to extend monitoring to support reporting in other UN regions where significant data gaps existed for POPs (MONET-Africa and the GAPS-GRULAC special study). In addition, new passive air sampling under the UNEP/GEF capacity building projects has also helped to introduce and implement passive air sampling in developing countries and regions with significant geographic gaps in monitoring (*e.g.*, Africa, GRULAC, and the Asia-Pacific Region). The current situation for air monitoring under the third phase of GMP is summarized in Figure 2.

Figure 2: Sampling sites currently operating under existing passive (top panel) and active (bottom panel) air monitoring programmes for POPs that are contributing to the GMP.

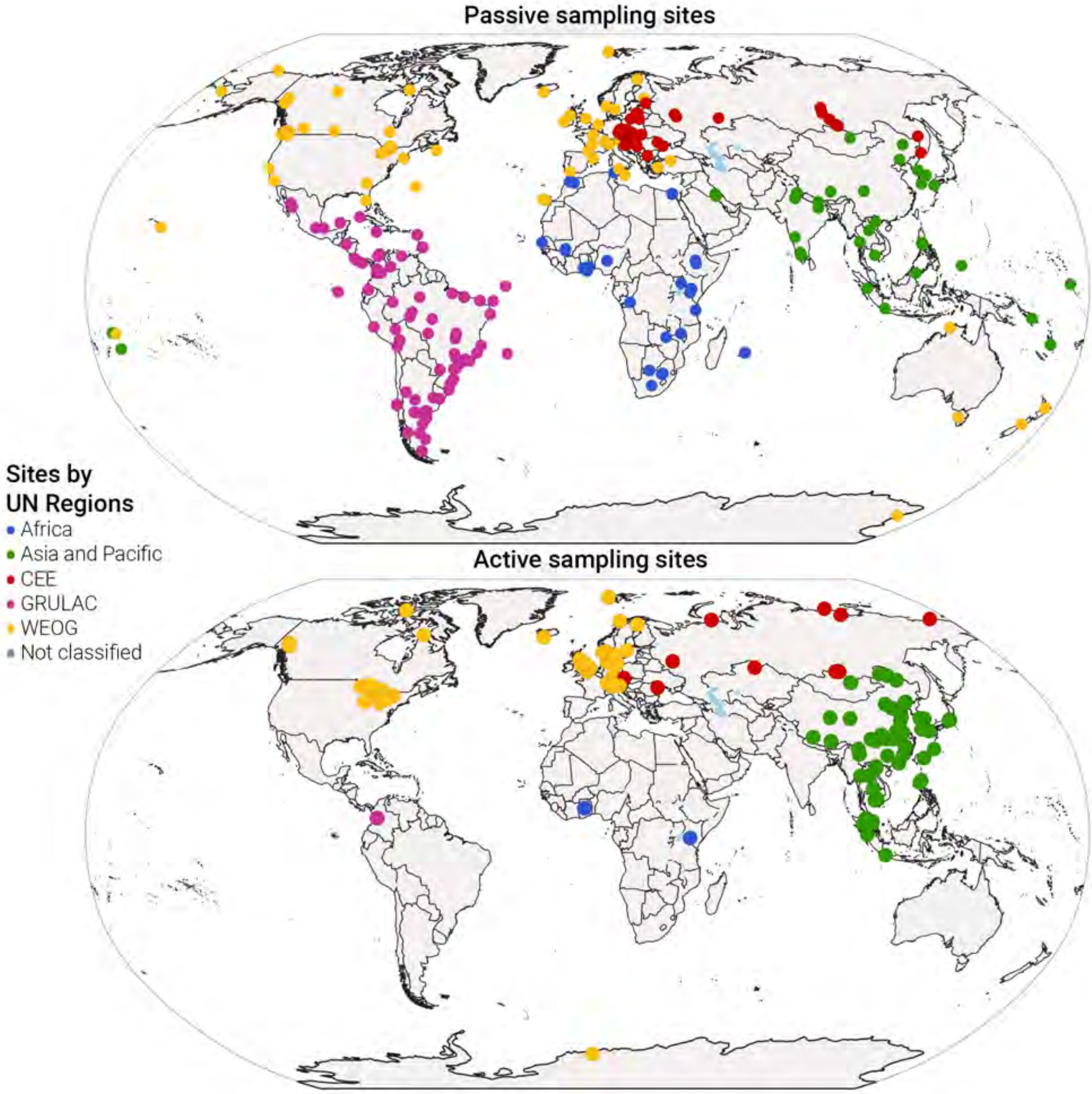


Figure 2 highlights the important role of passive air samplers (top panel) in extending regional and global coverage for generating air monitoring data for POPs. However, despite this progress in coverage, some limitations in POPs reporting in air under the GMP are becoming apparent. For instance, many of the sites shown in Figure 2 have generated data for past GMP reports but are not currently operating. Therefore, these sites are unlikely to generate data for future GMP reports. Secondly, for many of the listed POPs, there is currently very limited or no long-term data at all included in the third GMP report for assessing temporal trends in air. In fact, only a subset of the listed POPs has "adequate" information on temporal trends and only for two of the five UN regions (see Table 1).

These data gaps in POPs reporting (Table 1), are partly attributable to the complexity of analysis for some POPs and the growing demands and complexity associated with some of the newer POPs. Unfortunately, these challenges and information gaps are likely to continue and even increase in future reporting as air monitoring programmes reporting to the GMP are unable to keep pace with the continual addition of new POPs to the Convention (Wang *et al.* 2021; Persson *et al.* 2022; Sheriff, Debela and Mans-Davies 2022; Wang *et al.* 2022).

Table 1: Summary of available temporal trend information on POPs in air by region arranged by date of listing of new POPs.

Original 12 POPs (2005)					
Chemical	Africa	Asia-Pacific	CEE	GRULAC	WEOG
Aldrin					
Chlordane					
DDT					
Dieldrin					
Endrin					
Heptachlor					
Hexachlorobenzene					
Mirex					
Toxaphene					
PCBs					
PCDDs					
PCDFs					
"New" POPs Listed in 2009					
a-HCH					
b-HCH					
Chlordecone					
Hexabromobiphenyl					
Hexa-/Hepta-BDE					
Lindane					
Pentachlorobenzene					
PFOS					
Tetra-/Penta-BDE					
"New" POPs Listed in 2011					
Endosulfan					
"New" POPs Listed in 2013					
Hexabromocyclododecane					
"New" POPs Listed in 2015					
Hexachlorobutadiene					
Pentachlorophenol					
Polychlorinated Naphthalenes					
"New" POPs Listed in 2017					
Deca-BDE					
SCCPs					
"New" POPs Listed in 2019					
Dicofol					
PFOA					

	Adequate information on trends		Limited information on trends		No information on trends

This ongoing and potentially increasing gap in reporting of POPs in air through the GMP could undermine the ability of the GMP to compile representative information to support Effectiveness Evaluation of the Convention. The time has come to reflect on strategies to improve the situation by tapping into other sources of information and participation and support through additional teams of experts.

A review of the peer-reviewed literatures is an important first step to identifying additional sources of information and experts that could potentially contribute to sustainable monitoring of POPs and future work of the UNEP/GEF GMP capacity building projects. The outcomes of a review covering the period 2005-2022 are summarized in chapter 2.3 and address the following list of objectives:

- To identify and categorize sources of information and available data on POPs in air, which could potentially complement/supplement reporting under the GMP to address growing gaps in information, especially in the regions of Africa, Asia-Pacific and GRULAC (see Table 1).
- To identify and recognize a broader group of experts/institutions who/which may assist GMP Regional Organizational Group (ROG) members and national focal points to access dispersed and relevant information.
- To deliver information that can lead to synergies and formation of expert teams to support the ROG and the GMP and the related national activities and obligations covered by the Convention's articles. Inputs from broader sources will help to generate informed, representative and coordinated future strategy for capacity building towards sustainable monitoring of POPs.
- To discuss the future relevance and sustainability of capacity building projects and national/ regional monitoring networks for POPs monitoring.

2.2. Intersecting issues on air monitoring

2.2.1. The sustainability and future relevance of the GMP

The sustainability of the GMP is a growing issue which has been recognized by working group experts and assessments related to GMP activities. For instance, a section on sustainability was included in the latest version of the GMP Guidance document in order to raise awareness of this issue and considerations for future cooperation. A roadmap is also developed under the UNEP/GEF GMP projects to enhance sustainability of POPs monitoring in developing countries and regions. Conclusions and recommendations regarding how the GMP should adapt, in an efficient way, to address current and future challenges, have been presented in reports and assessments related to GMP activities.

The following bullets are a high-level compilation of proposed approaches and needs related to enhancing capacity for reporting of POPs in air, taken from the stakeholder consultation meeting of the UNEP/GEF GMP project, GMP Guidance Document, and the third report of the GMP (UNEP 2019a; UNEP 2021; UNEP and Stockholm Secretariat 2023).

Challenges:

- High cost and complexity associated with analysis of growing list of POPs, which include complex mixtures.
- New priorities for considering "chemical mixtures", transformation products of parent POPs, and related health effects associated with exposure to human populations (urban and indoor air).
- Interpretation of POPs trends in a broader context of long range transport (including vectors such as microplastics, waste streams and bio vectors).

Opportunities:

- Building upon existing capacity and utilizing partnerships with existing programmes.
- Strengthening communication, collaboration, and coordination among national, regional and global experts and programmes.
- Exploring sample banking and non-target analysis as strategies for improving information under the GMP and future reporting
- Presenting and integrating the POPs issue in a broader context that intersects with biodiversity and climate change as well as highlighting linkages to national interests, indigenous groups, gender mainstreaming and other social sectors on sound chemicals management.

Considerations:

- Taking steps to fill in data gaps and to ensure the GMP is capable and informed to address future challenges.
- Tapping into existing expertise to improve science-policy integration and to help ensure future relevance of the GMP for supporting the needs of the effectiveness evaluation of the Stockholm Convention.

2.2.2. Challenges at the national level

To identify the challenges and obstacles that Parties face in developing their National Implementation Plans (NIPs) for the Stockholm Convention, an assessment has been made of the available information on the development of NIPs including developing and maintaining the required capacities (UNEP 2018). Although these challenges cover a much broader scope than the topic of this report on POPs measurements in air, the challenges are overlapping and relevant, as shown in the excerpts below taken from the NIP report:

(i) lack of coordination between the line ministries and the national research programmes on policy-related priorities and needs; (ii) lack of connection between scientific or technical experts and policy- or decision-makers; (iii) lack of or insufficient capacity to understand and assess the national implications of scientific and technical information to support policymaking regarding the Conventions; (iv) lack of technical and financial capacity to conduct targeted research relevant to the Stockholm Convention; and (v) lack of cooperation and networking with the regional and global POPs research community.

The report also calls for the need to raise greater public awareness about how POPs are linked to other important issues such human health, loss of biodiversity, and climate change. These intersecting issues have been the topic of recent UNEP reports, discussed next.

2.2.3. Intersection of biodiversity, climate, and chemical pollution

Chemical pollution is recognized as one of main threats to ecosystems integrity, biodiversity, and public health. From a planetary boundary perspective, the increase in production and use is accelerating at a pace which is beyond our current ability to monitor and manage these chemicals (Diamond *et al*. 2015; Persson *et al*. 2022). The production of plastics is expected to double by 2050. While some reductions of older POPs levels have been observed in air, chemicals such as PCBs continue to be found in biota and exert effects. For instance, decline in whale populations is linked to the strong persistence and biomagnification potential of PCBs coupled with the associated toxicity. The report on interlinkages between the chemicals and waste multilateral environmental agreements and biodiversity (Secretariat of the Basel, Rotterdam and Stockholm Conventions and Secretariat of the Minamata Convention [Minamata Secretariat] 2022) calls for improved monitoring of POPs in all regions of the world so that effects on humans and the environment can be understood. Climate change is also recognized as key factor that can potentially amplify the effects and remobilize POPs to be redistributed in the environment. A comprehensive assessment of the impact of climate on POPs has been recently conducted under AMAP (de Wit, Vorkamp and Muir 2022; Hung *et al*. 2022), which raises awareness to future research and monitoring in order to address knowledge gaps and emerging issues. The impact of climate change on POPs has direct implications to reporting of temporal trends under the GMP and the ability to distinguish observed changes in trends to climate-effects vs chemical regulation effectiveness.

A common theme in the activities and assessments discussed above is the recognition of an apparent disconnect between science and policy which has given rise to many related challenges, which in turn has impeded progress at the national level and also at the international/GMP level as shown earlier. This report attempts to propose more effective assessment strategies by improving the science-policy interface.

The call to enhance the science-policy interface and consideration of the whole life cycle of chemicals and waste in developing science, monitoring and policy strategies (UNEP 2019b; Wang *et al.* 2021; Wang *et al.* 2022) has increased greatly over the past decade. An International Panel on Chemical Pollution (IPCP) (International Panel on Chemical Pollution [IPCP] 2021) was formed in 2008 with the aim to improve access to scientific knowledge and expertise in order to support global management of chemicals. Support has been growing further for a global science-policy body on chemicals and waste, which could play a complimentary and advisory role to assist Parties in meeting their obligations under the Convention. The recent UN Environmental Assembly meeting (UNEA 5.2, Feb. 28-March 2, 2022) adopted resolution 5/8 (United Nations Environment Assembly [UNEA] 2022) to establish such a science-policy panel to contribute further to the sound management of chemicals and waste and to prevent pollution. An ad-hoc Open Ended Working Group (OEWG1.2) (UNEP 2023a) has begun its work to prepare proposals for establishing the panel, with the ambition to complete its work by 2024.

Ultimately, through better and bi-directional communication, coordination and mutual respect, across the science-policy interface, it will be possible to attain a progressive and adaptable “science-driven policy” environment. This will lead to improvements in the state of knowledge with respect to POPs in air, as well as integration of new resources that are required to address the challenges for measuring POPs in air in a rapidly changing world with many intersecting issues.

2.3. Literature review on national and regional capacities for measuring pops in air

The Scopus search database was used to conduct the literature review. Only publications since 2005 (inclusive) have been considered here. To be included in the search results, papers must have contained either "persistent organic pollutant" or "Stockholm Convention" in the publications' title, abstract, or keywords. Further, these papers were narrowed down by their inclusion of either "air" or "atmosphere" in the title, abstract, or keywords in order to focus on results pertaining to air quality studies and monitoring. Results were screened out of the review if the subject area was related to medicine or pharmacology. Documents were further limited to articles, reviews, or conference proceedings. The complete search query can be seen as follows:

(TITLE-ABS-KEY ("persistent organic pollutant" OR "stockholm convention") AND TITLE-ABS-KEY (air OR atmosphere)) AND PUBYEAR > 2004 AND NOT (SUBJAREA (medi) OR SUBJAREA (phar)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "cp"))

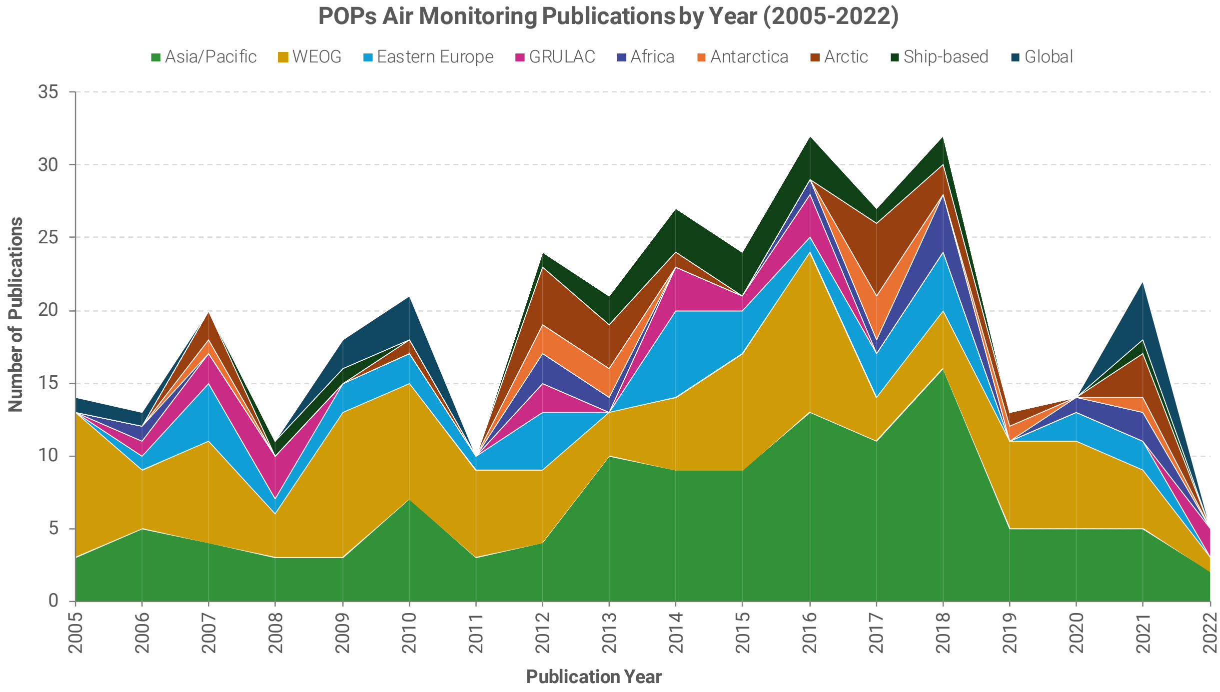
As of January 20, 2022, this search returned 1,101 results which were manually inspected for persistent organic pollutant air sampling, or other methodologies that could be relevant to analytical capacity building. In total, this process identified 337 publications relevant to the sampling and analysis of POPs in air. The actual number of papers is likely much higher than the number captured here, due to alternate and broader terminology used by some authors (*e.g.*, "emerging chemicals", "semi-volatile chemicals- SVOCs" and others). In addition, the increasing use of passive air samplers in indoor studies (exposomics) to link chemical exposure to human health is very relevant but beyond the scope of this review, which focuses on ambient air.

A supplementary file has been provided, containing information on the relevant publications. This *"Catalogue of POPs Measurements in Air"* contains publication information such as primary author, institutional affiliation, the country and region of air sampling, the country and institution of sample analysis, POPs investigated, sampling methods, and approximate study periods. We note that there is potential for undercounting in this review due to (1) not all publications specifying location of sample analysis, or (2) not all publications indicating author(s) responsible for analysis. Where neither were available, we assumed the institution of analysis be that of the primary author.

In reviewing the available literature relating to atmospheric POPs monitoring, there is clear evidence that disparities exist among countries in their capacity to report on sampling and analysis of POPs in air.

Seen in both Figure 3 and Figure 4, the majority of air monitoring studies for POPs have been in Asia/Pacific or WEOG countries. These regional groups represent 33% and 25% of publications respectively. Conversely, Eastern Europe, GRULAC, and Africa account for less than 20% of publications (10%, 5%, and 4% respectively) with the remainder being broad global studies or ship-based sampling.

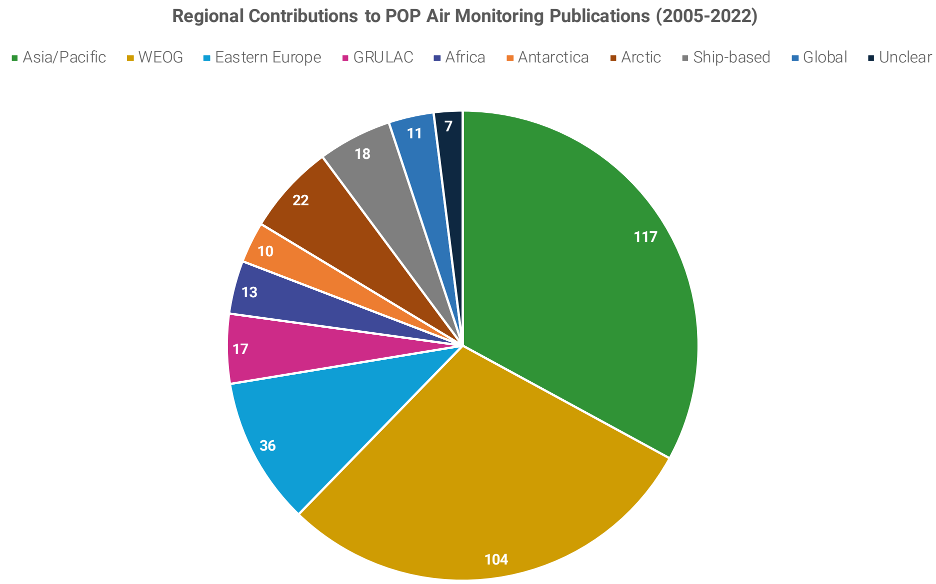
Figure 3: Summary of publications concerning monitoring of persistent organic pollutants in air since 2005 (up to January 2022) by UN Regions.



Note: Data is stacked to indicate the sum of publications by region and the overall number for each year. Arctic studies were determined based on how they were presented in the articles, and as such 'Arctic' publications may include sampling relevant to other regions (*i.e.*, Svalbard, Norway may be presented as an Arctic study location, but could alternatively counted as a WEOG publication). Similar categorization was used for 'Ship-based' and 'Global' studies.

Since 2005, relevant publications have been steadily increasing. However, the rate of publication appears to have been negatively impacted by the COVID-19 pandemic (2020-2021 in Figure 3). This recent decline is likely the combined impact of (i) sampling difficulties, (ii) laboratory restrictions, and (iii) a lack of data for analysis.

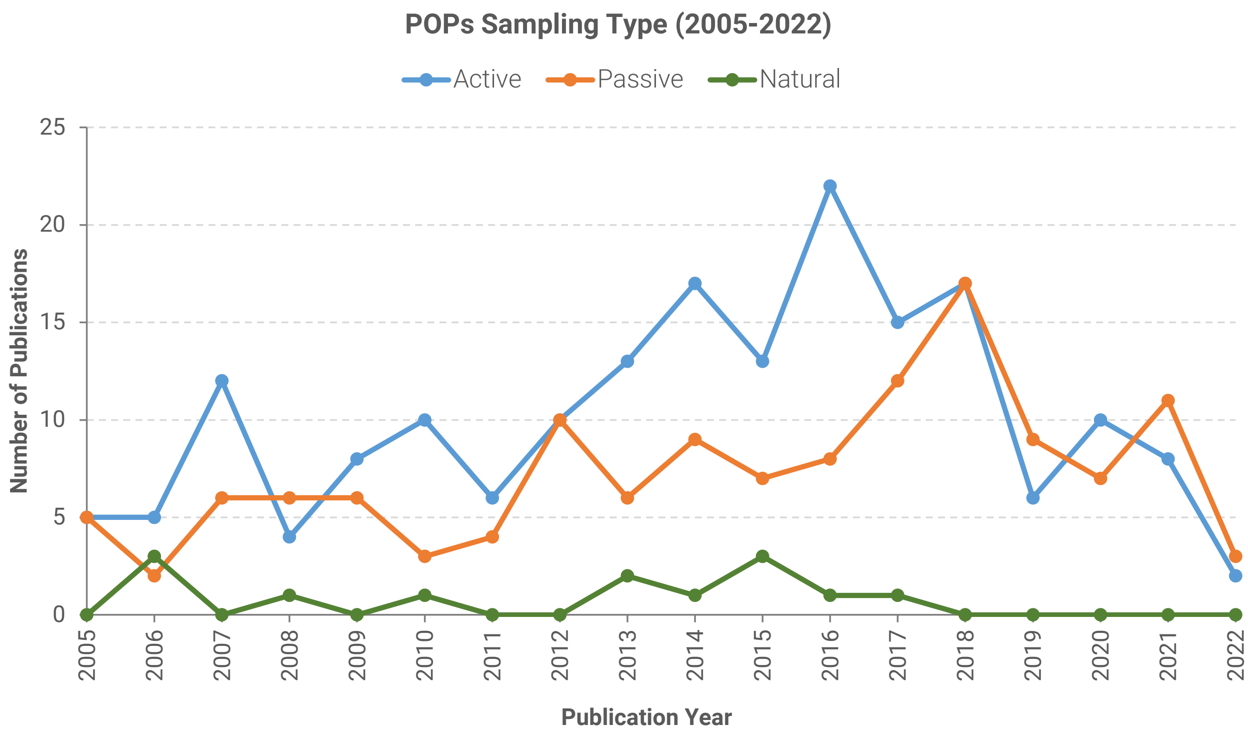
Figure 4: Air monitoring/sampling by region (where sampling was conducted) in persistent organic pollutant air monitoring publications.



Note: Arctic studies were determined based on how they were presented in the articles, and as such 'Arctic' publications may include sampling relevant to other regions (*i.e.*, Svalbard, Norway may be presented as an Arctic study location, but could alternatively counted as a WEOG publication. Similar categorization was used for 'Ship-based' and 'Global' studies. 'Unclear' indicates the publication provided enough evidence to suggest it was air quality monitoring, but the study location was unable to be determined (*i.e.*, Published in non-English language, publisher paywall with minimal details in abstract).

Air sampling since 2005 has been composed of mainly active and passive air sampling (Figure 5). However, a handful of publications have utilized passive methods involving natural materials, such as lichen and moss, to monitor for airborne POPs. Such studies have not occurred since 2017, with active and passive sampling making up the entirety of sampling since. The last 4-5 years have also seen greater parity between active and passive sampling. Prior to 2018, active sampling was consistently the higher utilized sampling method. Since 2018 however, the two sampling types have been roughly equivalent.

Figure 5: Type of air sampling conducted by year. Natural sampling includes a variety of mediums such as lichen, bark, leaves, and pine needles.



A brief overview of sampling capacities since 2005 is indicated in Figure 6a-e. Here, there are several immediately visible findings.

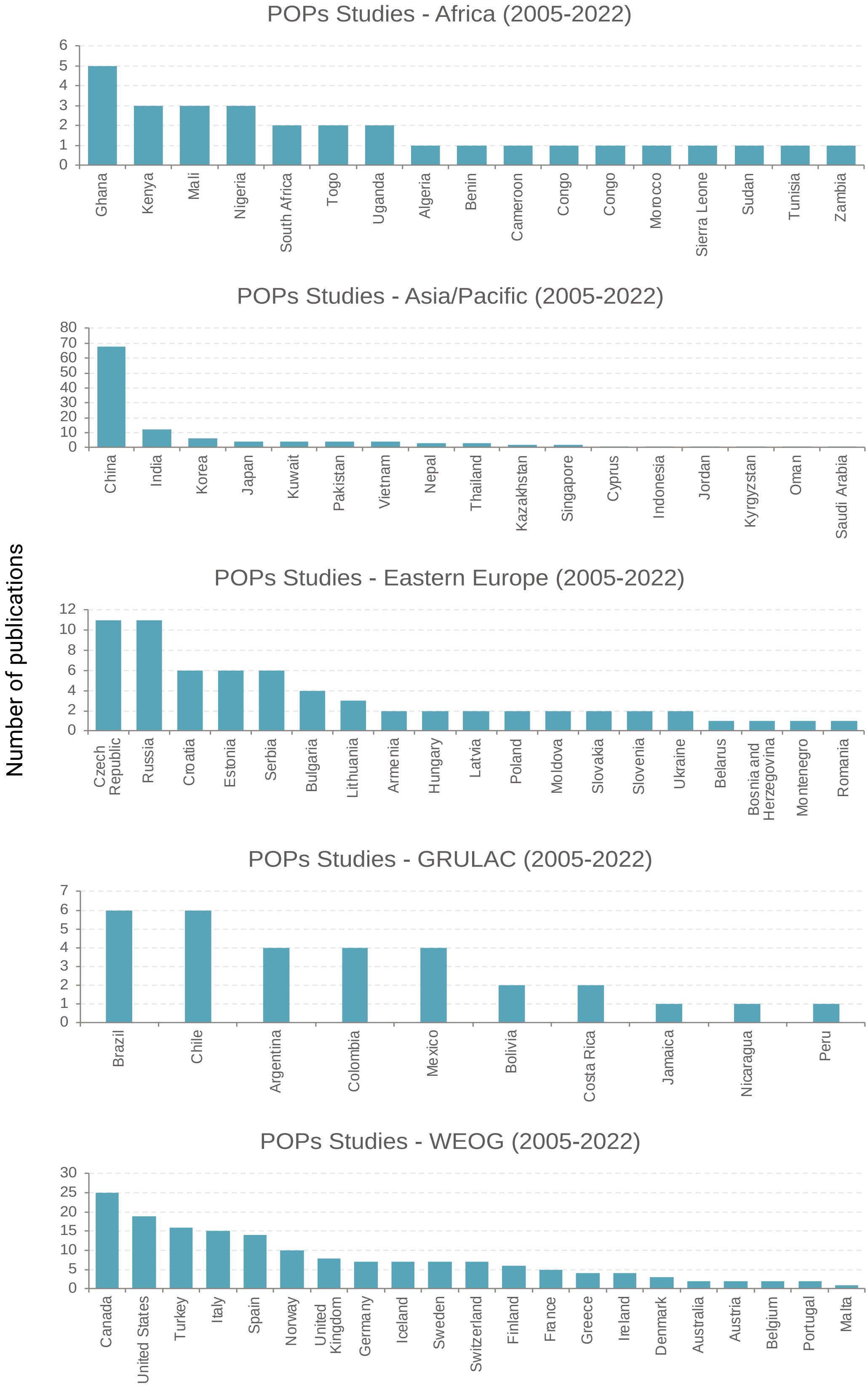
First, sampling conducted in China far exceeds that in any other country. For comparison, there is roughly two (2) times the sampling conducted in China compared to that of the second most sampled country, Canada. Sampling in China is also far greater than any other country in the Asia/Pacific region, outpacing the next highest country (India) by nearly seven (7) times.

Second, beyond the UN regions of Asia/Pacific (primarily China), WEOG, and Eastern Europe (primarily Czech Republic and Russia) regions, there has been minimal reporting of POPs in air in the peer reviewed literature in other regions. In Africa, this review revealed that data for Ghana is the most frequently reported, while published data is sparse for other countries. Similar findings exist for the GRULAC region.

The results of the review exercise were also used to evaluate countries and institutions involved in sample processing and analysis of the POPs in air samples (see Annex). Figure 7 shows countries associated with 2 or more instances of airborne POPs analysis. In line with findings regarding sampling, analysis capacity/capabilities are largely found within the Asia/Pacific and WEOG regions. Likewise, GRULAC and Africa appear to be under-represented. These regions present a need and opportunity for increased analytical capacity.

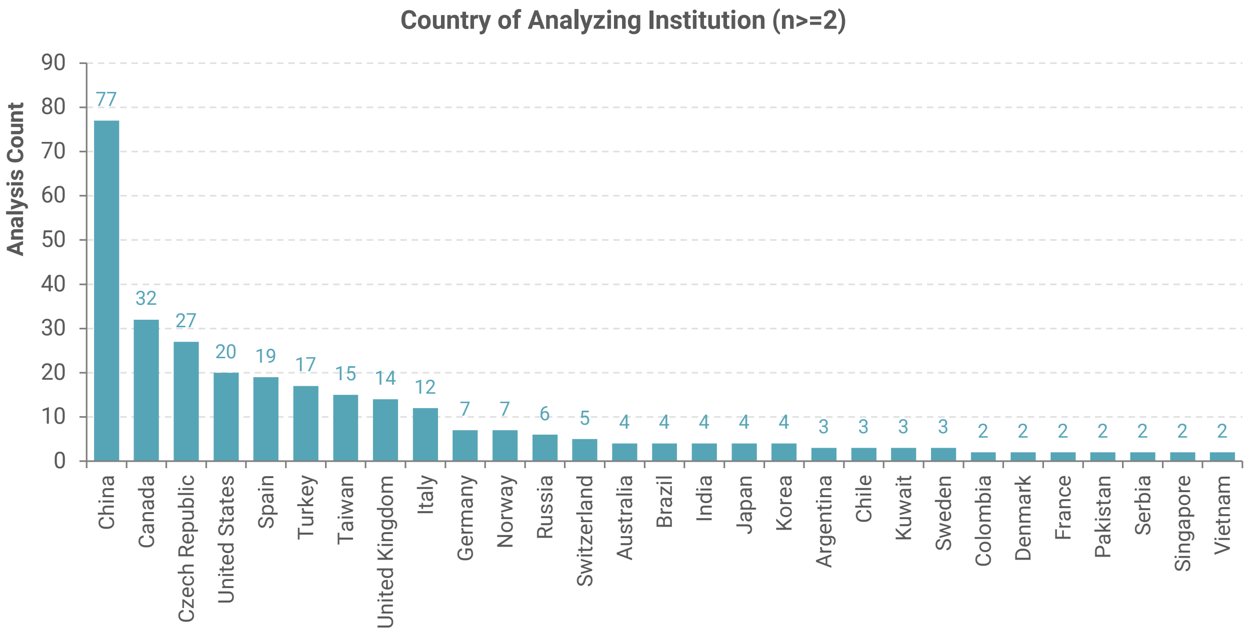
A full list of institutions found to have analyzed airborne POPs since 2005 can be found in Table A1 (Annex), with private laboratories highlighted in bold font.

Figure 6: Sampling conducted in UN regions (a) Africa, (b) Asia/Pacific, (c) Eastern Europe, (d) GRULAC, and (e) WEOG.



Note: Each separate publication detailing sampling within a country is considered one sampling occurrence and may encompass several sites. Note that due to how some publications reported information, these values may be undercounts as some instances of sampling locations were unclear (i.e., non-English publications). Y-axis scales made uniform for ease of comparison.

Figure 7: Count of POPs analyses by country of analyzing institution.



Note: Some results may be unintentionally omitted, as not all publications explicitly stated where analysis was conducted. Where not stated, analyzing institution is assumed to be that of the primary author, or author with analysis credit.

The outcomes of the literature review have revealed that:

1. Since 2005, a few hundred papers on POPs measurements in air have been published with the majority of studies in either Asia-Pacific or WEOG region.
2. The publication rate has increased gradually over this period with a notable drop-off following 2019, likely associated with the global COVID pandemic.
3. The proportion of publications using passive air samplers (primarily PUF-PAS samplers) continues to increase and has recently exceeded studies using active sampling.
4. The review has identified a large list of national/regional and international experts on POPs in air as well as institutions actively publishing in this area and capable of performing POPs analysis; this information has been catalogued in a database file which includes information on each publication including a list of POPs that were measured and the geographic region of the study (see Annex1, Excel file).

INTERLABORATORY ASSESSMENT AND QUALITY CONTROL/QUALITY ASSURANCE SCHEME FOR POPS IN AIR

3

CHAPTER

Whereas Chapter 2 presented the status quo in terms of data gaps in GMP reporting and other measurements of POPs in air that could be included, this chapter considers existing modalities and mechanisms which can be further developed to enhance POPs monitoring in air. This enhancement could be through the formation of partnerships with established long-term programmes as well as continuation and possibly expansion of existing coordinated activities already part of the GMP. Ultimately, the aim is to develop a more inclusive approach and to consider resources, programmes, and integrated strategies to stimulate and generate comparable air monitoring data for POPs for supporting national and international chemicals policy.

Chapter 3.1 summarizes the existing modalities under the GMP, with a focus on air monitoring of POPs and specifically programmes that have employed passive air samplers to improve spatial information on POPs in air. These programmes include passive air sampling networks such as GAPS, MONET, SMP (Spain), LAPAN, Australian passive sampling network, and the UNEP/GEF GMP projects, as well as long term active air sampling programmes such as EMEP that have been incorporating passive air sampling methods. Other international air monitoring activities where passive air samplers could be adopted will also be considered. This chapter also reviews and summarizes existing coordinated international activities that assess and help to ensure the quality assurance and quality control (QA/QC) of POPs measurements in air, again, with a special emphasis on passive air sampling using PUF-PAS and the characterization of the samplers. Finally, the last section of this chapter, will summarize additional modalities and resources identified through a review of the literature (*e.g.*, in Chapter 2), which could help to enhance POPs monitoring in air, including "top-down" big-picture approaches which are both cost-effective and time-efficient in generating results.

3.1. Current global analytical service and modalities under the GMP

Table 2 summarizes the monitoring programmes that have contributed POPs monitoring data for air to the third phase of GMP. As shown previously in chapter 2 (Figure 1), despite the large number of sites included in these programmes, reporting to the GMP is not keeping pace with the growing number of listed POPs. This growing gap in information is amplified further, if we consider recent awareness and guidance for the need for measuring and assessing transformation products, precursors and analogs to the listed POPs. In addition, the importance of POPs in urban air has also been recognized, as many new classes of POPs exist in commercial products (*e.g.*, plastics, electronics) and therefore exhibit elevated concentrations in urban air (Saini *et al.* 2020).

Table 2: Monitoring programmes contributing data to the GMP with details on sampling approach (passive vs active) and number of sites currently operating.

Air Program	Comments	Published*
	Africa	Yes/No
Global Atmospheric Passive Sampling (GAPS) Network	Passive using PUF disk deployed quarterly at 11 sites (9 GAPS, 2 GAPS-MC), operating since 2004 and 2018 (GAPS and GAPS-MC; 5 remain active). (Saini *et al.* 2020 [GAPS-MC]; Schuster *et al.* 2021; Rauert *et al.* 2018a)	Y
MONET-Africa	Passive using PUF disk deployed quarterly at 9 sites (White *et al.* 2021) operating since 2008.	Y
UNEP/GEF GMP I and GMP II projects	Passive using PUF disk deployed quarterly during 2 sampling years at 11 sites during 2008/12 and at 15 sites during 2017/18 (González *et al.* 2021; Abad, Abalos and Fiedler 2022).	Y
	Asia-Pacific	
POPs Monitoring Project in East Asian Countries (POPsEA)	Active using QFF/PUF/ACF deployed monthly (on average) at 8 sites, operating from 2014 to 2018. (Third Regional Monitoring Report, Asia-Pacific Region; some data available for download at: Environmental Monitoring of Persistent Organic Pollutants in East Asian Countries (Japan, Ministry of Environment [JMoE] n.d.))	N
China national POPs monitoring programme	Active using PM10 inlet or QFF/PUF or PUF/XAD2 deployed in unspecified intervals at 25 sites, operating from 2014 to 2019. (Third Regional Monitoring Report Asia-Pacific Region; no peer-reviewed citation listed)	N
Japan national monitoring programme	Active using QFF/PUF/ACF deployed 1-2 times annually at 34-681 sites, operating from 2003 to 2018. (Third Regional Monitoring Report Asia-Pacific Region)	N
MONET-Fiji	Passive using unspecified medium during 2006 and 2007. Number of sites not specified. (Borůvková J. *et al.* 2015)	N
UNEP/GEF GMP I and GMP II projects	Passive using PUF/SIP disks deployed in unspecified intervals at 16 sites, duration of sampling unspecified. (Third Regional Monitoring Report Asia-Pacific Region (UNEP and Stockholm Secretariat 2021b); González *et al.* 2021; Abad, Abalos and Fiedler 2022)	Y
GAPS Network	Passive using PUF disk deployed quarterly at 30 sites (25 GAPS, 5 GAPS-MC), operating since 2004 and 2018 (GAPS and GAPS-MC; 10 remain active). (Schuster *et al.* 2021; Saini *et al.* 2020 (GAPS-MC); Rauert *et al.* 2018a)	Y
Air Program	**Comments**	**Published***
	CEE	
APOPSBAL	No information was found for period covering last 5 years. Two earlier papers from 2007.	N
AMAP	One site operating from 2002 to 2009 but details on sampling method not found. (Third Regional Monitoring Report Central and Eastern European Region)	N
GAPS Network	Passive using PUF disk deployed quarterly at 4 sites (3 GAPS, 1 GAPS-MC), operating since 2004 and 2018 (GAPS and GAPS-MC; 2 remain active). (Schuster *et al.* 2021; Saini *et al.* 2020 (GAPS-MC))	Y
European Monitoring and Evaluation Programme (EMEP)	Two sites, operating from 2009 to 2010. (Third Regional Monitoring Report Central and Eastern European Region; Sha *et al.* 2021)	Y
MONET-Europe	Passive using PUF disk deployed quarterly at 32 sites (long-term, >7years) and another 18 in the Czech Republic, operating since 2003 (earliest). (Third Regional Monitoring Report Central and Eastern European Region; White *et al.* 2021; Kalina *et al.* 2019)	Y
GRULAC		
GAPS Network	Passive using PUF disk deployed quarterly at 34 sites (29 GAPS, 5 GAPS-MC), operating since 2004 and 2018 (GAPS and GAPS-MC; 22 remain active). (Schuster *et al.* 2021; Saini *et al.* 2020 (GAPS-MC); Rauert *et al.* 2018b)	Y
Latin Passive Air Monitoring Network (LAPAN)	Passive using XAD-2 deployed annually at 56 sites, operating since 2010. (Third Regional Monitoring Report GRULAC Region)	N
UNEP/GEF GMP I and GMP II projects	Passive using PUF disk deployed quarterly at 11 sites during 2008-2012, and at 11 sites from 2016 to 2018. (Third Regional Monitoring Report GRULAC Region (UNEP and Stockholm Secretariat 2021c); González *et al.* 2021; Abad, Abalos and Fiedler 2022)	Y

Air Program	Comments	Published*
	WEOG	
AMAP	Active using GFF/PUF deployed weekly at 9 sites, operating since 1992 (starting dates vary). (Third Regional Monitoring Report WEOG Region; Hung *et al.* 2016; Wong *et al.* 2018)	Y
Australia's Casey Station	Sampling occurred from 2009 to 2014. (Third Regional Monitoring Report WEOG Region)	N
Australian Monitoring Program	Passive using XAD-2 deployed annually at 44 sites, operating since 2011. (Third Regional Monitoring Report WEOG Region – Annex 8.1).	N
EMEP	Active using filter or filter+PUF. Deployment and sampling frequency varies between 39 sites. Some sites operational for ~20 years. (Third Regional Monitoring Report WEOG Region – Annex 8.1; Sha *et al.* 2021)	Y
GAPS Network	Passive using PUF disk deployed quarterly at 53 sites (47 GAPS, 6 GAPS-MC), operating since 2004 and 2018 (GAPS and GAPS-MC; 38 remain active). (Schuster *et al.* 2021 (GAPS); Saini *et al.* 2020 (GAPS-MC); Rauert *et al.* 2018a)	Y
Great Lakes Basin Monitoring and Surveillance Program	Active using GFF/PUF or PUF/PUF deployed every 6 days, 12 days, or 36 days at 3 sites. Sampling has occurred since as early as 1990. (Third Regional Monitoring Report WEOG Region – Annex 8.1; Shunthirasingham *et al.* 2018; Guo *et al.* 2018; Li *et al.* 2021)	Y
Integrated Atmospheric Deposition Network (IADN)	Active using QFF/XAD-2 deployed for 24h every 12 days at 5 sites. Sampling has occurred since 1990. (Third Regional Monitoring Report WEOG Region – Annex 8.1; Guo *et al.* 2018)	Y
MONET-Europe	Passive using PUF deployed quarterly at 18 sites (as of 2013) to 13 sites (as of 2016). Sampling has occurred since 2012. (Third Regional Monitoring Report WEOG Region – Annex 8.1; Estellano *et al.* 2017; Kalina *et al.* 2019)	Y
MONARPOP	Active using GFF/PUF/PUF deployed quarterly at 2 sites (3 sites up until 2015). Sampling occurred from 2005 to 2017/2018. (Third Regional Monitoring Report WEOG Region – Annex 8.1); Monitoring Network in the Alpine Region for Persistent and other Organic Pollutants	N
National Air Pollution Surveillance (NAPS)	Active using GFF/PUF/PUF deployed quarterly at 2 sites (3 sites up until 2015). Sampling occurred from 2005 to 2017/2018. (Third Regional Monitoring Report WEOG Region – Annex 8.1)	N
Northern Contaminants Programme (NCP)	Active using GFF/PUF deployed weekly at 2 sites. Sampling has occurred since 1992. (Third Regional Monitoring Report WEOG Region; Yu *et al.* 2019; Tevlin *et al.* 2021; Wong *et al.* 2021)	Y
Norwegian TROLL Station	Active using filter/PUF or PUF/XAD/PUF deployed weekly at 1 site. Sampling has occurred since 2007. (Third Regional Monitoring Report WEOG Region – Annex 8.1)	N
Spanish Monitoring Program (SMP) on POPs	Passive using PUF disk deployed quarterly at 23 sites. Sampling has occurred since 2008. (Third Regional Monitoring Report WEOG Region – Annex 8.1; Muñoz-Arnanz *et al.* 2018)	Y
Swedish National Monitoring Programme	Operates 3 sites (sites also part of EMEP and/or AMAP). Further details not available in Monitoring Report. (Third Regional Monitoring Report WEOG Region)	N
TOMPs	Active using GFF/PUF deployed biweekly at 6 sites. Sampling has occurred since 1991. (Third Regional Monitoring Report WEOG Region – Annex 8.1); Toxic Organic Micro Pollutants program	N
UK-Norway SPMD Transect	Passive (SPMD and recently PUF-PAS) deployed at 13 sites. Sampling has occurred since 1994. (Third Regional Monitoring Report WEOG Region)	N

*published in peer-reviewed literature in past 5 years.

Note: Example(s) of most recent (last 5 years) peer reviewed published data for POPs are also listed.

3.2. Building partnerships and capacity for gmp

Table 2 summarizes the existing air monitoring programmes that have contributed to the third phase of GMP and includes details regarding their recent air sampling activities in the regions. Some of the programmes are multi-regional (*e.g.*, GAPS, MONET, UNEP/GEF, AMAP) and therefore could already be well positioned to support the strategy for future POPs monitoring that will help to mitigate the growing information gaps for POPs in air. In addition, these programmes are actively involved in monitoring using passive air sampling (mainly PUF disk type), which has been identified as the focus of this report as a key element in the future strategy to enhance POPs measurements in air. The potential roles of these programmes, as well as other programmes (*e.g.*, multi-national programmes such as POPsEA and LAPAN) are considered further in Chapter 3.3. The next chapter will also summarize key messages resulting from a stakeholder consultation meeting held in Brisbane, Australia in 2019, to consider elements of sustainable POPs monitoring strategy in developing countries to support future GMP (UNEP 2019a).

Several programmes reporting to the GMP, which primarily use passive air samplers or have started to incorporate passive sampling are listed below:

- GAPS (including GAPS-GRULAC, GAPS-Megacities) (PUF-PAS)
- MONET (including MONET-Europe, MONET-Africa, MONET-CEE) (PUF-PAS)
- UNEP/GEF I and II (Africa, Asia-Pacific, GRULAC) (PUF-PAS)
- EMEP (PUF-PAS)
- LAPAN (XAD and PUF-PAS)
- GLB / NCP (XAD and PUF-PAS)
- SMP (PUF-PAS)
- Australia (XAD and PUF-PAS)
- UK-Norway Transect (SPMD and PUF-PAS)

In addition to this list, there are numerous programmes, institutions and researchers employing passive samplers that have been identified through the literature review, which will be presented in Chapter 3.4. Most passive air sampling data reported in the third phase of GMP stem from programmes employing PUF-PAS samplers. Therefore, efforts to enhance measurement capacity of POPs in air using PUF-PAS samplers will build upon progress made over the past 20 years to establish data quality and comparability. The Stockholm Convention regional and subregional centres assist with implementation and training or air monitoring programmes for POPs (Table 3). The topic of data quality and comparability is considered next.

Table 3: Stockholm Convention regional and subregional centres for capacity-building and transfer of technology.

Africa

Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Algeria (SCRC Algeria)	Algiers, Algeria
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Kenya (SCRC Kenya)	Nairobi, Kenya
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Senegal (SCRC Senegal)	Dakar, Senegal
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, South Africa (SCRC South Africa)	Pretoria, South Africa

Asia and the Pacific

Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, China (SCRC China)	Beijing, China
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, India (SCRC India)	Nagpur, India
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Indonesia (SCRC Indonesia)	Jakarta, Indonesia
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Iran (SCRC Iran)	Teheran, Islamic Republic of Iran
**Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Kuwait (SCRC Kuwait)	Kuwait City, Kuwait

Central and Eastern Europe

**Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Czech Republic (SCRC Czech Republic)	Brno, Czech Republic
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Russian Federation (SCRC Russian Federation)	Novosibirsk, Russian Federation

Latin America and the Caribbean

Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Brazil (SCRC Brazil)	Sao Paulo, Brazil
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Mexico (SCRC Mexico)	Mexico City, Mexico
Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Panama (SCRC Panama)	Panama City, Panama
**Stockholm Convention Regional Centrefor Capacity-building and the Transfer of Technology, Uruguay (SCRC Uruguay)	Montevideo, Uruguay

Western Europe and others

Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology, Spain (SCRC Spain)	Barcelona, Spain

* Download the List of Regional Centres and contact details (PDF format)

** Centres actively engaged in passive air sampling for POPs and training using PUF-PAS.

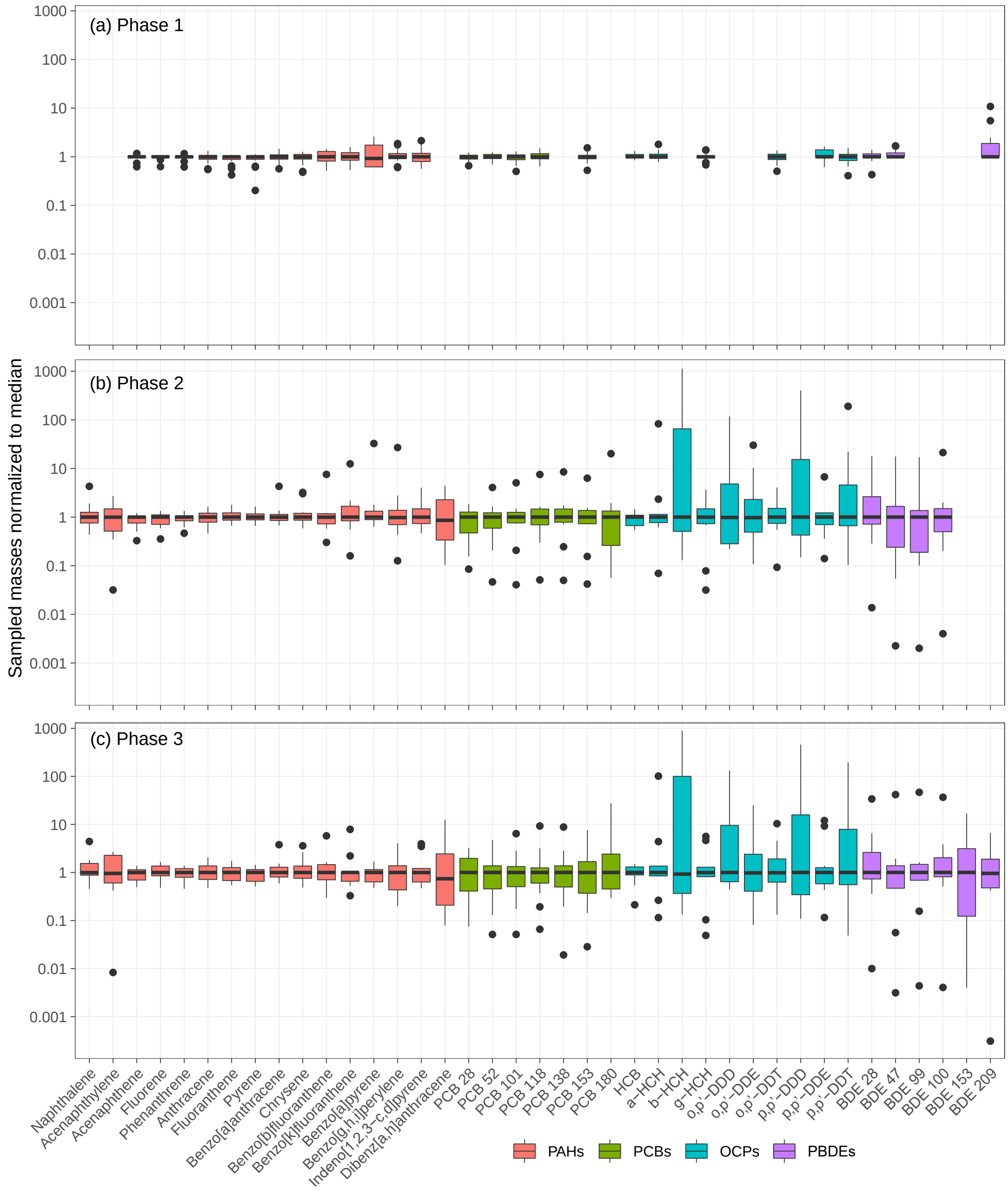
Note: Regional Centres in the Czech Republic (i.e, MONET), Kuwait, and Uruguay are actively involved in PUF-PAS sampling and coordination with developing countries.

3.3. Data comparability: QA/QC considerations and intercalibration

A focus of this chapter will be on the PUF-PAS sampler, introduced two decades ago (Shoeib and Harner 2002), which has allowed for concurrent deployment of large number of samplers across many sites to generate time-integrated data with good spatial resolution. The data derived from PUF-PAS are considered comparable when samples are analyzed by a common laboratory and/or when confirmed through interlaboratory studies (Melymuk *et al.* 2021). The PUF-PAS sampler has been a major advancement in POPs monitoring in air. The popularity of the PUF-PAS samplers can be attributed to its relatively simple and small design, low cost and electricity free operation. Although the results obtained from PUF-PAS are semi-quantitative, they provide a time weighted average which is very practical for reducing sampling/analysis costs and for assessing changes over time based on representative and mean concentrations in air (*e.g.*, versus intermittent samples which may represent high or low air concentration episodes). The ability of the PUF-PAS (and SIP-PAS) to capture both particle-associated and gas-phase POPs is also beneficial, as many of the more recently listed POPs have lower volatilities and reside in the particle-phase in ambient air. Additional technical information and characterization of the PUF-PAS sampler is provided in Annex 2.

The PUF-PAS was further evaluated by the international research community to assess the impact of different sampler configurations, analytical methods, and the benefits of using a central lab. The study which included 15 participating labs, was led by the Norwegian Institute for Air Research (NILU), in collaboration with the RECETOX Centre at Masaryk University and Environment and Climate Change Canada (ECCC) (Melymuk *et al.* 2021). As summarized in the guidance document for the GMP (UNEP 2021b), the study revealed a few discrepancies in results for POPs among research groups when participants performed their own analysis, with each group providing their own sampler housing, whereas the results were much more consistent and comparable when all the analysis was performed by a reference lab. See Figure 8. These findings highlight the advantages of using a central laboratory for regional and even global-scale programmes.

Figure 8: Results from international intercalibration study of PUF disk samplers for range of SVOCs, include PCBs, HCHs, DDT and PBDEs.



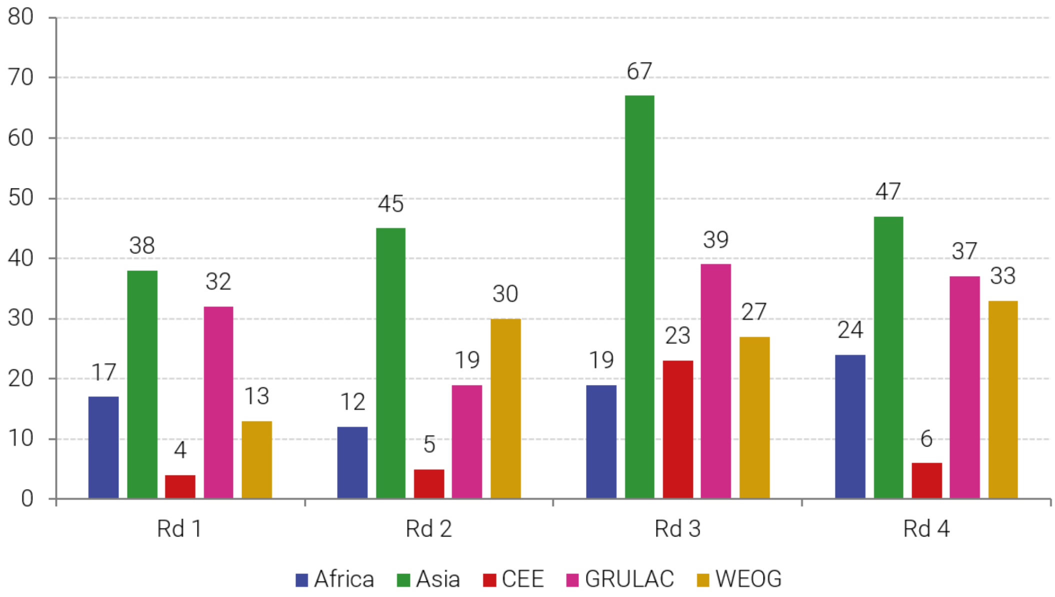
Note: The top panel (a) shows variation in POP masses collected by PUF-PAS of different geometries analyzed at a central laboratory, the middle panel (b) shows variation in POP masses from identical PAS analyzed at different laboratories, and the bottom panel (c) shows the combined variability due to sampler geometry and separate laboratories. Boxes represent the 25th to 75th percentiles, with the median (50th percentile) as a horizontal black line. Individual SVOC levels were normalized to the median. Whiskers represent ±1.5 times the interquartile range (IQR) with individual points indicating outliers. Several PUF disk sampler chamber types were used, including GAPS-type, MONET-type and CSIC-type among others. Figure reproduced from Melymuk et al. 2021.

3.3.1. UNEP interlaboratory assessments and capacity building

Laboratories are encouraged to participate in interlaboratory exercises on a regular basis to validate their data quality assurance (QA) scheme and to demonstrate that their data are comparable to other POPs monitoring labs on a global scale.

The third GMP report (UNEP and Stockholm Secretariat 2023) summarizes the UNEP-coordinated interlaboratory assessments, which have become the largest exercise on POPs analysis on a global scale and includes laboratories from all UN regions. The assessment includes a wide spectrum of test matrices, including an air sample extract. The first round of interlaboratory assessment was performed from 2010 to 2011, the second round from 2013 to 2014, the third round was completed in 2017, and the fourth round was completed in 2019 (see Figure 9). Overall, 286 laboratories registered at least once, of which 58 never submitted results. Table 4 summarizes analytical performance from the four rounds of interlaboratory assessment (UNEP 2023c).

Figure 9: Number of laboratories registered in the four rounds of UNEP Global Interlaboratory Assessment on POPs.



Although most of the participating labs performed well (satisfactory results based on Z-scores, see Table 4) the assessment raises awareness to current data quality challenges, which are expected increase further with additional listed POPs. This also points to the benefits of centralized labs as demonstrated in the PUF-PAS intercalibration exercise, described earlier.

A meeting on "Stakeholder Consultation on Securing Sustainable Conditions for the Monitoring of Persistent Organic Pollutants (POPs) under the Stockholm Convention" held in Brisbane, Australia, 10-11 December 2019 (UNEP 2019a), recognized the value of the UNEP/GEF intercalibration program, which fosters improvements in data credibility and comparability among POPs laboratories.

Table 4: Z-score assessment of laboratory performance in the four rounds of UNEP Global Interlaboratory Assessment on POPs.

z-scores	Rd1	Rd2	Rd3	Rd4	Total
#labs with results	82	89	133	116	**179 (different labs)**
#S (satisfactory)	4,410	6,708	7,737	6,337	**25,192 (61%)**
#Q (questionable)	666	1,057	1,207	1,061	**3,991 (10%)**
#U (unsatisfactory)	1,388	2,237	3,570	3,110	**10,305 (24%)**
#C (consistent)		153	128	303	**584 (1%)**
#I (inconsistent)		336	613	554	**1,503 (4%)**
Total	**6,464**	**10,491**	**13,255**	**11,365**	**41,575**

Note: S=Satisfactory, <25% from assigned value; Q=Questionable, 25%-37.5% from assigned value; U=Unsatisfactory, >37.5% from assigned value

3.3.2. Other international intercalibration studies on POPs in air

The Northern Contaminants Program and Arctic Monitoring and Assessment Programme Interlaboratory Study (NCP/AMAP) is another example of long term international intercalibration exercise that includes the performance evaluation of analytical laboratories that feed data to the NCP and AMAP. This Intercalibration exercise includes the analyses of a wide range of legacy as well as emerging organic chemicals and heavy metals. Laboratories are evaluated based on analysis/reporting of target analytes in standards as well matrices such as fish and mussel tissue, sediment, polyethylene (PE) passive sampler matrix. More recently, PUF and filter air samplers have also been added to the list of test matrices. The exercise is repeated on a yearly basis and includes more than 40 laboratories. The objective is for laboratories to assess and improve their performances to produce high quality data to support the programmes and to facilitate integration and data comparability among labs.

3.4. Global analytical service and modalities for data quality control

Figure 10 summarizes the findings of the literature review and maps countries where sampling has been most frequently carried out for measuring POPs in air (upper panel) and countries most frequently involved in the analysis of POPs (lower panel). These maps identify very active POPs monitoring activities in China and in many countries within the WEOG region. The institutions involved in these studies are listed in the Annex. A substantial proportion of these studies include passive air sampling in developing regions that are currently under-represented in GMP reporting and this can serve as an alternative source of data. Many of these passive air sampling campaigns involve collaboration among several countries in a region and analysis in a central facility to ensure data comparability. The earliest of these studies go back almost 20 years. These “top-down” approaches to regional sampling that are coordinated by a single institute in collaboration by a team of interested and qualified international researchers is complementary to the “bottom-up” approach to implementation under the GMP *e.g.*, GEF projects, involving national focal points, ROGs, agreements etc. The “top-down” approach is a relatively quick process and time- and resource-efficient, which usually supports training and the theses of graduate students and often includes a modelling collaborator/component to interpret the information.

Some examples of these “top-down” approaches to POPs monitoring in air using passive samplers are highlighted in the next chapter. It is important to note that none of the examples below have been included in GMP reporting, partly due to the criteria applied by ROGs for “accepting data”. In some cases, data are excluded if samples do not meet current criteria listed in the GMP Guidance Document. In other cases, these data are excluded because they are viewed as “research” and not “monitoring” or if the data are analyzed by an institution outside of the region. These criteria and the process for including data sets in the GMP should be reviewed and re-assessed. Ultimately the work of the ROGs in developing the GMP would need to continue in a more augmented and supportive way that would allow for greater input from experts and additional data that are already available.

Acceptance of these data and recognition of the scientists and academic institutions involved, could be a big step towards resolving the large and growing data gaps in POPs reporting in air under the GMP. It could also support building better connections across the science-policy interface. The examples presented below are based on a “top-down” approach and often link to generation of data for testing and developing long-range transport modelling capacity for POPs. This may present an alternative framework and way of thinking about how passive air samplers can be used in the GMP, and how passive sampling programmes are organized and coordinated. This will be considered further in chapter 4.

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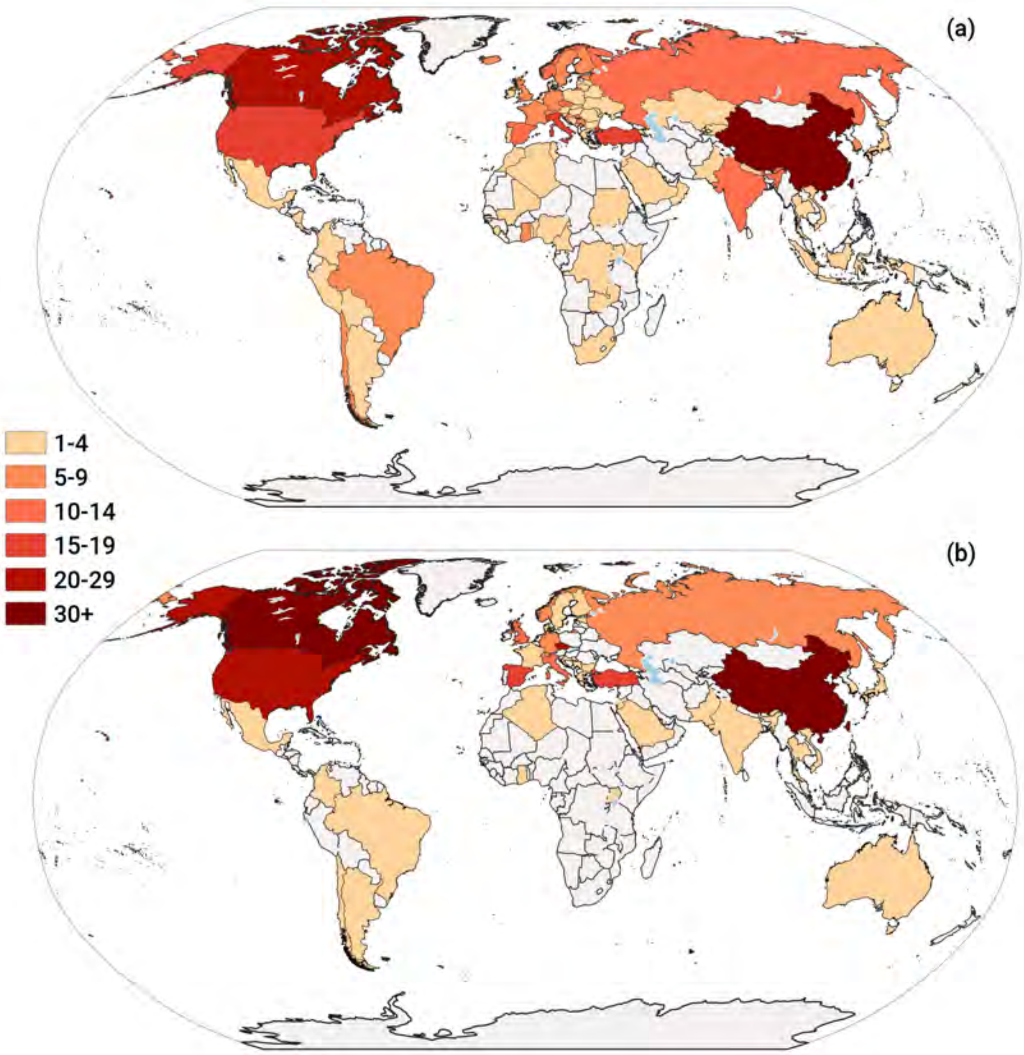
Figure 10: Number of literature instances by country in which (a) POPs outdoor air samples have been acquired and (b) POPs air samples have been extracted and/or analyzed at an institutional or private laboratory.



Note: Both panels encompass publications from January 2005 to January 2022.

3.5. Case studies on regional passive sampling studies currently not part of the GMP

The following case studies are intended to highlight some of the early and innovative work on POPs monitoring using PUF-PAS samplers, which has been peer-reviewed and published but not currently included in GMP reporting. Many of the examples below were among the first spatial studies of POPs in air. These studies involved international collaboration and coordination among air scientists from different countries. These studies are good examples of the early ingenuity, pragmatic and cost-effective approaches for research and monitoring of POPs in air using PUF-PAS samplers, in order to address data gaps and to gain information on long-range transport.

Asia-Pacific – The third GMP report revealed substantial gaps in POPs monitoring data for air in the Asia-Pacific Region (UNEP and Stockholm Secretariat 2023; see Chapter 2). As shown in the selected examples below taken from the literature (Figure 11- Figure 13), experts in the Asia-Pacific region were among the first to adopt PUF-PAS air samplers in their investigations of POPs and related chemicals in air. The literature review has revealed 25 studies of POPs in air in Asia-Pacific Region using PUF-PAS samplers. It is noteworthy that despite the large number of studies and coordinated activities in Asia-Pacific region using PUF-PAS samplers, none of these studies or researchers are currently part of the Asia-Pacific regional reporting for the GMP. There is an opportunity to better utilize this wealth of expertise and capacity in the region as part of future coordination and reporting under the GMP. Similar opportunities exist in other regions, albeit to a lesser extent.

Figure 11: Air monitoring of POPs in four countries (China, Japan, S. Korea and Singapore) in Asia-Pacific region using PUF-PAS almost 20 years ago

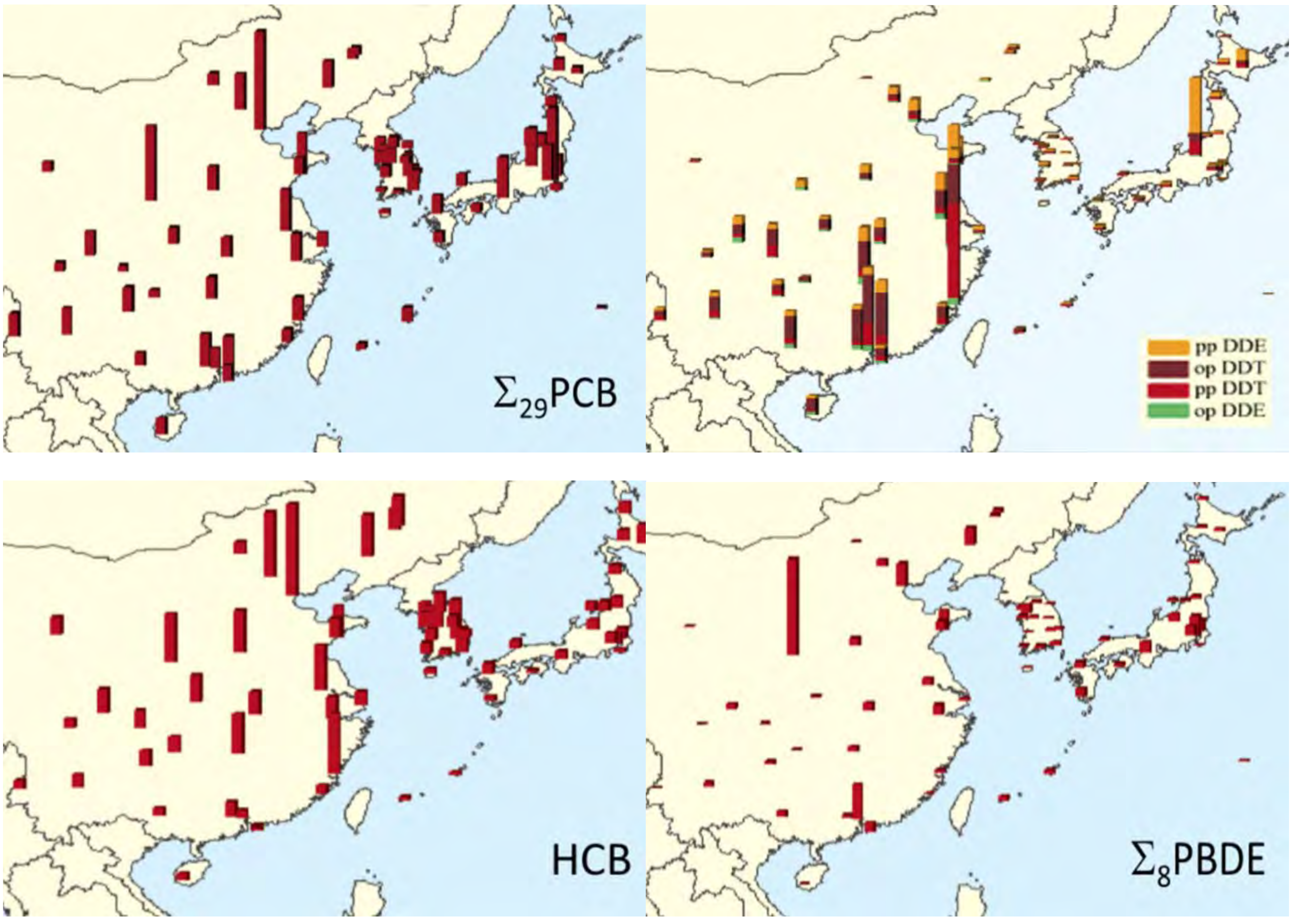
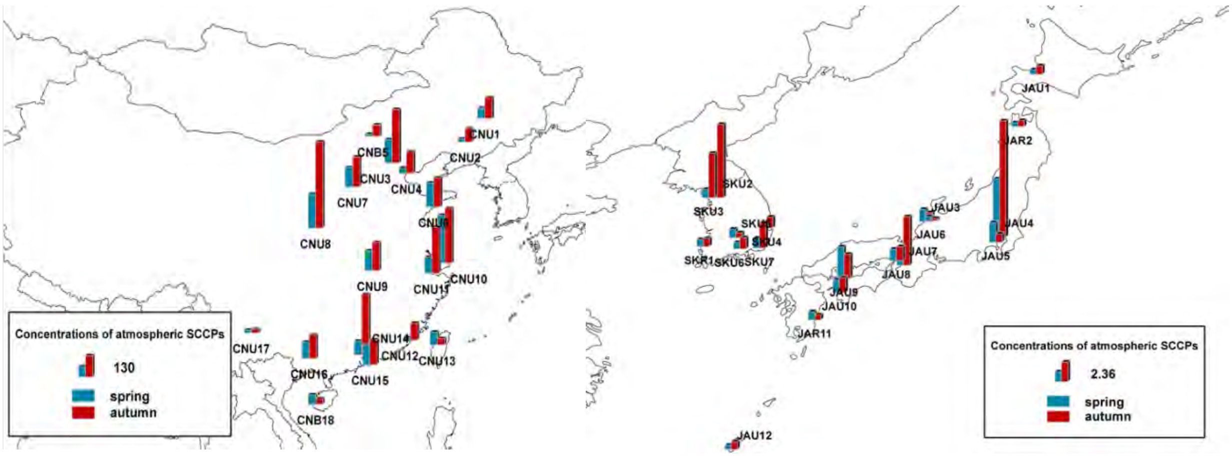
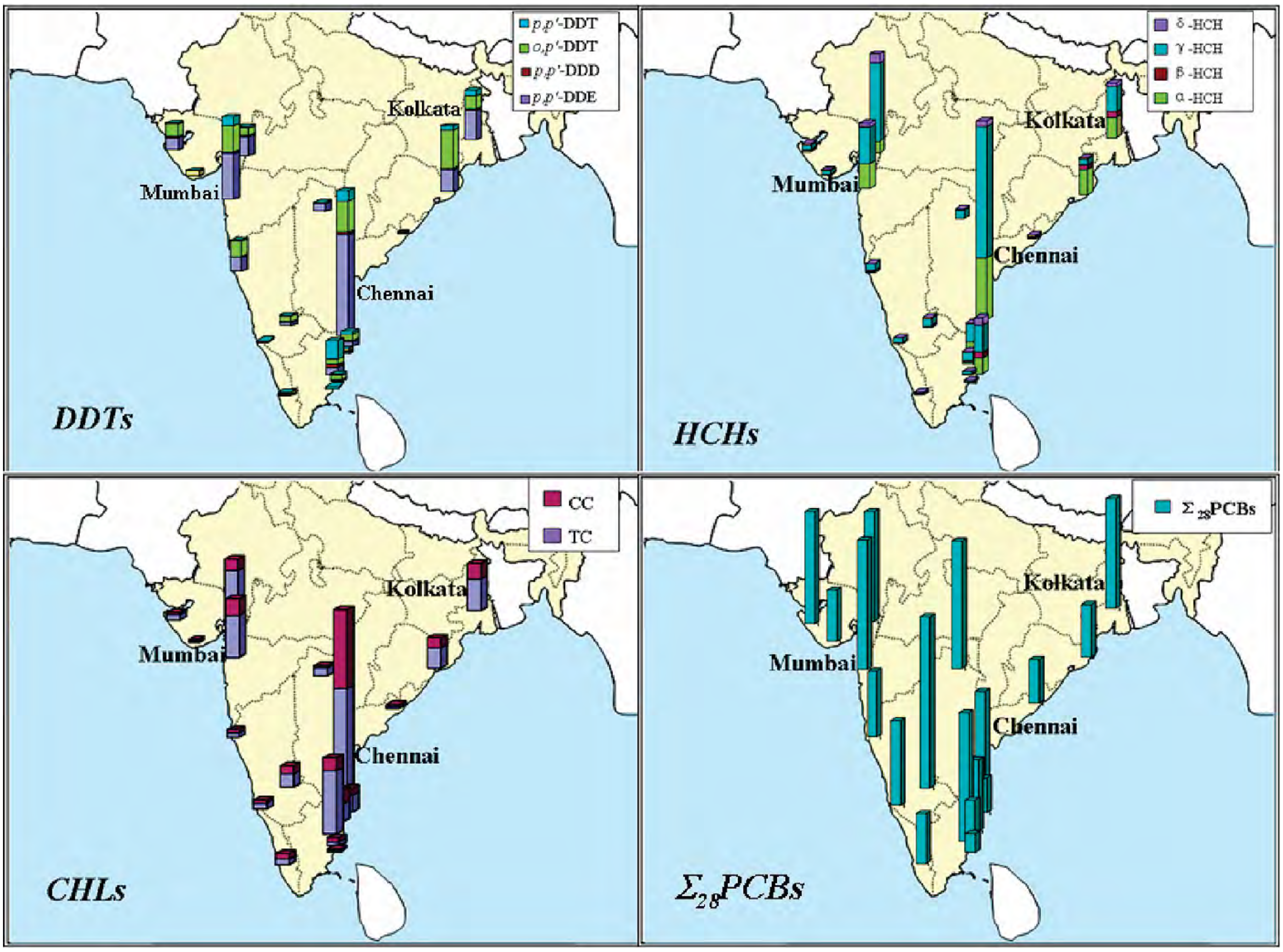


Figure 12: PUF-PAS derived spatial distributions and seasonal variations of atmospheric SCCP concentrations in China, Japan and South Korea (ng/m^3).



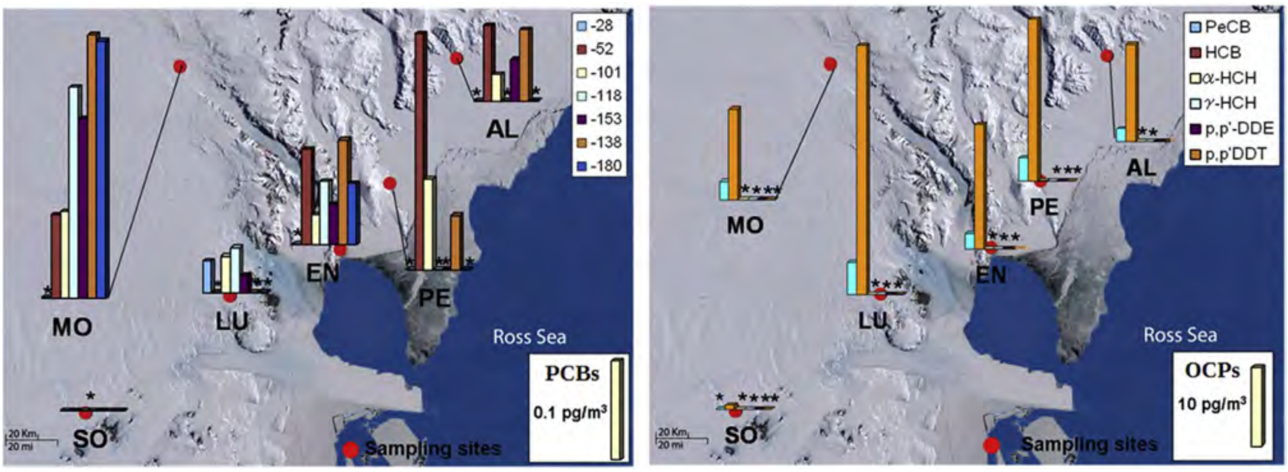
India - Through this review (chapter 2), 11 publications concerning sampling in India were uncovered. Of these 11 publications, there were four instances in which samples were analyzed within India (rather than in an external country). The work of Paromita Chakraborty here is of note, as many of these publications featured her involvement. Further, her publications have demonstrated the application of PUF-PAS throughout India (Chakraborty *et al.* 2017; Khuman and Chakraborty 2019; Prithiviraj, Taneja and Chakraborty 2021). The GAPS Network has also collaborated with Indian colleagues on special focused studies on POPs in India (Pozo *et al.* 2011; Eng *et al.* 2016). Figure 13 shows results from POPs monitoring in air at coastal sites in India, more than 15 years ago, by Zhang *et al.* (2008).

Figure 13: Air monitoring of POPs in India using PUF-PAS 15 years ago



Antarctica - The Southern Ocean Persistent Organic Pollutants Program (SOPOPP) and the Antarctic Assessment and Monitoring Programme (AnMAP), both of which operate out of Griffith University (Australia), have been actively coordinating air research on POPs in the southern polar region, which could contribute to future reporting. The work of SOPOPP also highlights an example of PUF-PAS use (Nash *et al.* 2021). Figure 14 shows summertime measurements of POPs in air from 2010-11 near the Ross Sea (from Pozo *et al.* 2017).

Figure 14: PUF-PAS derived air concentrations of individual PCBs and OCPs at Antarctic sampling sites near the coast of the Ross Sea during the Austral Summer in 2010-2011



3.6. Citizen science for enhancing POPs monitoring and awareness

Citizen science networks are increasingly used in research and monitoring for addressing data gaps, improving data resolution, and engaging and communicating the public on important health-related issues. For instance, citizen science-based networks have been implemented to assess air quality parameters such as NO_2, PM and ozone, with an emphasis on urban air and indoor environments (*e.g.*, Schaefer, Kieslinger and Fabian 2020; Perelló *et al.* 2021). The networks can be organized quickly and cost-efficiently, relying on engaged and willing volunteers from the public. In the context of enhancing national or regional POPs monitoring in air, this could involve members of the public who deploy PUF-PAS that are supplied by a central lab. In some ways, programmes such as GAPS and MONET have already been operating in this manner by partnering with willing and interested institutions and researchers to deploy samplers in a cost-effective way. The time commitment for deploying PUF-PAS on a quarterly basis is minimal and sampler shipping costs are usually covered by the lead institution. A citizen-science approach or aspect to deployment of PUF-PAS could help to engage and inform across the public and thereby improving communication across the public-science and public-policy interfaces.

3.7. Implications for long-range atmospheric transport (LRAT) assessment

As shown in Chapter 3.4 and in other sections of this chapter, only a fraction of the available and peer-reviewed monitoring data for POPs in air is currently included in reporting under the GMP. Furthermore, many of the datasets currently included in the GMP have not been published in the peer-reviewed literature.

There is a need for a more complete and accessible compilation of credible and peer-reviewed POPs monitoring data for air to support synergies with modelers, *e.g.*, Task Force on Hemispheric Transport of Air Pollution (TF HTAP) under the Convention on Long-Range Transboundary Air Pollution. These data can allow for “top-down” modelling which will, in return, advise the GMP on topics related to the regional and long-range atmospheric transport of POPs. There is an opportunity for the GMP to play a key role in compiling and making the data available.

ESTABLISHMENT OF COORDINATION MECHANISMS IN DEVELOPING COUNTRIES FOR POPS MONITORING IN AIR

4 CHAPTER

Whereas Chapter 2 focused on the status quo in terms of data gaps in GMP reporting and reviewing and presenting other measurements of POPs in air that could be useful in future reporting; and Chapter 3 summarized existing modalities and mechanisms which can be further developed under UNEP/GEF GMP activities and beyond to enhance POPs monitoring in air; chapter 4 will suggest new approaches for optimized regional and national coordination mechanisms for sustainable monitoring of POPs in air.

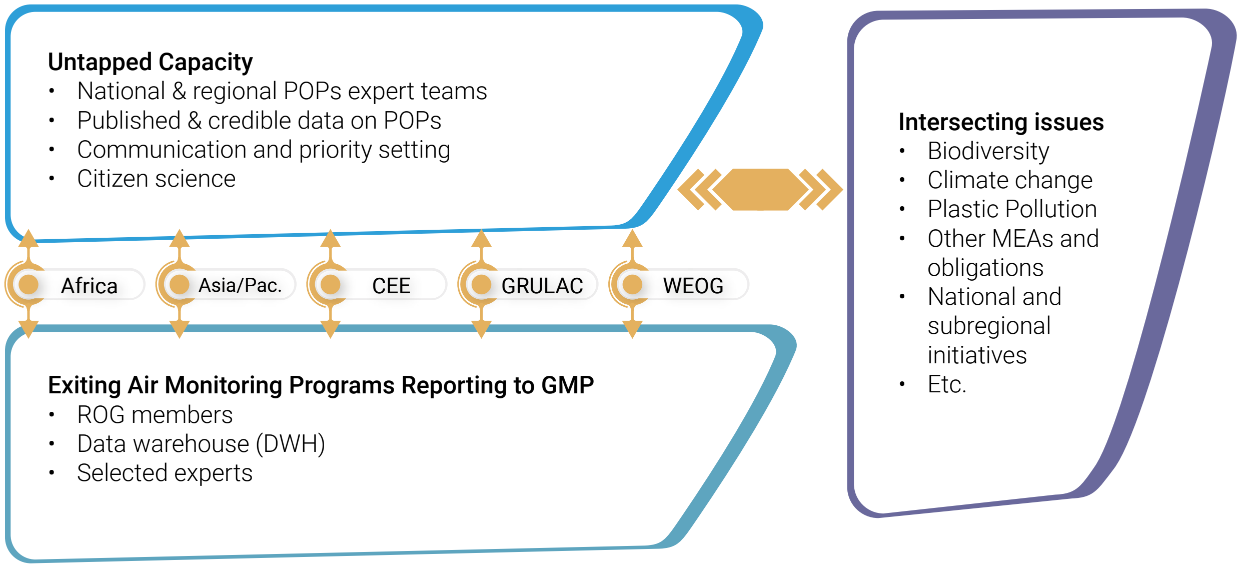
This strategy for improving POPs monitoring in air proposed herein, builds upon the information presented in previous chapters, which identify opportunities in data, expertise, tools and partnerships, which can contribute to substantial progress in future data reporting. The goal is to have a more inclusive, integrated, and communicative approach to POPs monitoring and reporting, which addresses both national and international policy needs. It is envisioned that such an approach can lead to progressive and sustainable arrangements for air monitoring in developing regions. As explained in chapter 3, the proposed path forward for enhancing POPs monitoring in developing countries in air could be implemented relatively quickly by using passive air sampling (polyurethane foam-passive air sampler or PUF-PAS) through partnership with existing programmes and include the involvement of teams of national, regional and global science experts. This approach is consistent with and builds upon strategies that have already been promulgated in the peer-reviewed literature (*e.g.*, Klánová *et al.* 2011; Klánová and Harner 2013) and under the framework of the Stockholm Convention and GMP reporting (*e.g.*, UNEP 2019; UNEP and Stockholm Convention 2023).

A more diverse and integrated participation in the flow of information across the science-policy interface (Figure 15) will allow "dots to be connected" and new connections to be made between POPs monitoring in air and existing and future national/international priorities or initiatives *i.e.*, synergies will also be realized and forged across policy making. Some examples of intersecting policy issues with relevance to POPs monitoring in air include the following, *inter alia*:

1. Chemical effects on biodiversity and the environment *e.g.*, The Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity [CBD Secretariat] 2022).
2. Climate change (*e.g.*, effect on the fate of POPs; co-benefits of mitigation measures)
3. Multilateral Environmental Agreements (UNEP n.d.) (MEAs, such as Minamata Convention on Mercury and new agreement on Plastics (IISD 2022)) - synergies and overlapping obligations (*e.g.*, air monitoring programmes) with potential linkages to the Global Earth Observation System of Systems (Group on Earth Observations [GEO] n.d.) and other MEAs related to natural and biodiversity such as the Convention on Biological Diversity (CBD) (CBD Secretariat n.d.), the Convention on Wetlands (Ramsar)(Convention on Wetlands Secretariat [CWS] 2023), and the Convention on Migratory Species (CMS)(Convention on Migratory Species Secretariat [CMSS] 2020).

4. Activities under the Global Framework on Chemicals (IISD 2023a) and the new Intergovernmental Science-Policy Panel on Chemicals, Waste, and Pollution Prevention (Geneva Environment Network [GEN] 2021)
5. POPs in the context of the planetary boundary concept and tipping points (Diamond et al. 2015; Persson et al. 2022)
6. Task Force on Hemispheric Transport of Air Pollution (HTAP) under The Convention on Long Range Transboundary Air Pollution (CLRTAP) (United Nations Environment Commission for Europe [UNECE] 2010)
7. The new treaty under UNCLOS on marine biodiversity (IISD 2023b).
8. Other international initiatives that aim to improve interlinkages and understanding of the environment, climate and health in a transparent and inclusive manner *e.g.*, HERA 2030 Agenda (Health Environment Research Agenda for Europe [HERA] 2022); Partnership for the Assessment of Risks from Chemicals (Partnership for the Assessment of Risks from Chemicals [PARC] n.d.).

Figure 15: Enhancing POPs Monitoring in Air at the Science-Policy and Policy-Policy Interfaces (GMP DWH 2020)



Chapter 4.1 of this report highlights some of the limitations, challenges and opportunities associated with enhancing POPs monitoring capacity in air in developing countries. In Chapter 4.2 a framework and strategy is proposed as well as guidance on how this can be implemented.

4.1. Rationale and elements for the establishing national coordination mechanisms.

The dynamic nature of the Stockholm Convention with its increasing POPs monitoring requirements for air is not only a major challenge for developing countries where there is limited analysis capacity; it is also an increasing challenge for existing long-term air monitoring programmes for POPs in developed countries and regions. The sustainability and adaptability of monitoring activities is considered in the most recent revision of the GMP Guidance Document, which includes a new chapter on sustainability. It is also reflected in conclusions and recommendations of the GMP reports and related assessments (*e.g.*, Brisbane meeting report, UNEP 2019a). A common theme for recommendations stemming from these assessments and echoed by the broader science community (Wang *et al.* 2021; Wang *et al.* 2022) is the need for a more inclusive, communicative and integrated approach which builds on partnerships and existing capacity. Key points and excerpts from forward thinking assessments are elaborated further below.

1. Information gaps – *Excerpt from the executive summary of the third GMP report (UNEP and* Stockholm Secretariat *2023)* - "Nevertheless, all regions have experienced limitations in available data–through limited spatial coverage, limited time trend data, or limited analytical capacity. For some regions, there are multiple limitations."

In addition, this report has identified gaps in POPs reporting under the GMP that are expected to increase as more POPs are listed under the Convention. Information on POPs in air is lacking in all 5 UN regions but most severe in developing countries/regions. The gaps include specific sub-regions where no monitoring data for POPs in air is reported at all. In addition, for certain POPs, adequate baseline and trend data are entirely missing for most regions.

2. Growing Challenges and Priorities – As presented by Wang *et al.* (2021) – "Major gaps in the science-policy interface on chemicals and waste and how it keeps the international community up-to-date on scientific findings contribute to such delayed responses. This is particularly critical for developing countries, where national regulatory and policy frameworks are generally limited owing to a lack of capacity and accessibility of scientific information."

In addition, as uncovered by Liu *et al.* (2021) through an investigation of organophosphate ester flame retardants in 18 major global cities - "…individual transformation products can be more toxic and up to an order-of-magnitude more persistent than the parent chemicals, such that the overall risks associated with the mixture of transformation products are also higher than those of the parent flame retardants. Together our results highlight the need to consider atmospheric transformations when assessing the risks of commercial chemicals." Therefore, non-targeted screening (NTS) methods will be increasingly important in future POPs research and monitoring to fully understand the levels and hazards associated with chemicals that as diverse mixtures of the currently targeted chemicals plus their products/precursors – many of which are yet unknown.

3. Partnerships – *Excerpt from the executive summary of the third GMP report (UNEP and* Stockholm Secretariat *2023)* - "Air - Continue passive air sampling and capacity building in a sustainable manner to enhance information on temporal trends and to improve spatial coverage; In some regions, a strategy for POPs monitoring using passive air sampling (and active air sampling) is needed to better address data gaps and the long-term and growing needs of the Convention. This strategy should develop through regional commitment and expertise, as well as through consultation with established programmes;"

Excerpt from Brisbane workshop, 2019 meeting report (UNEP 2019a) – "Air - Cooperation and coordination with relevant air monitoring networks must be further strengthened. The sampling sites and the substances measured by future projects should be reviewed and adjusted considering the other monitoring programmes with a focus on supporting optimum global coverage, measurement of the background concentrations."

4. Sustainability and Relevance – Some experts feel that with respect to chemicals [entities] we are now operating beyond the planetary boundary and that "…the large number of chemicals having diverse risk potentials exceeds societies' ability to conduct safety related assessments and monitoring." – *Excerpt from Persson et al. (2022).*

In order to remain relevant, air monitoring of POPs in support of the Stockholm Convention and GMP needs to be "evergreen" and adapt to changing priorities, methodologies, and concepts. Key aspects of this adaptation include integration and collaboration.

5. Integration and Collaboration – with respect to sustainability and relevance, enhancing collaboration and information flow across the science-policy, policy-policy and science-public interfaces is important for an inclusive and integrated approach to meeting existing and future challenges with POPs monitoring in air and finding opportunities for advancement. Mechanisms for improving flow of information and technology transfer between developed and developing countries is an important consideration. With respect to science-public discussions, these should be attentive to minorities, social groups, indigenous peoples and vulnerable populations. In addition, efforts should be made to improve representation of these groups in science activities and planning.

Excerpt from Wang et al. (2022) - "Ideally, a more effective and efficient avenue is to pro-actively foster science–policy coproduction by contacting relevant actors to ask them about their specific needs, discussing about possible study design (which can help increase policy salience of the studies) and providing them with research outcomes in an accessible manner. Further, scientists can pro-actively communicate their research results by participating in open calls for information initiated by the Secretariat and participation in the Convention's meetings." The regional centres could have an important role in contacting and enlisting experts.

6. POPs Expert Teams (air) – further to the suggestion by Wang *et al.* (2022) above, regional and global POPs expert teams could be integrated into strategy-development and reporting structure for the GMP. As shown in chapters 2 and 3 of this report, considerable national and regional capacity for POPs monitoring exists in developing countries which could be tapped into. In addition, building synergies with existing expert teams (*e.g.*, UNECE Task force on HTAP (POPs)) could also support POPs transport and fate modelling in developing countries.

7. Regional Centres – Stockholm Convention regional centre (see Table 3) will have a continuing and increasingly important role in facilitating collaborations and partnerships, in order to address the growing challenges for POPs monitoring in air in developing countries. For instance, regional centres could help with identifying and enlisting existing experts in air monitoring and serve as centres for discussions and planning related to regional air monitoring strategies.

8. Citizen Science – Deployment of passive air samplers is sufficiently simple that it does not necessitate technical/science expertise. In some instances, this could help to allay logistical or financial pressures of implementing new air monitoring activities for POPs by teaming-up with environmentally aware members of the public (citizen scientists). Opportunities may also exist to tap into already developed citizen-science based networks targeting air pollutions (*e.g.*, Schaefer, Kieslinger and Fabian 2020). Examples of successful and global-scale citizen science initiatives include, inter alia, Pellet Watch (International Pellet Watch [IPW] n.d.) and PurpleAir (PurpleAir [PA] 2023). Incorporating citizen involvement in air monitoring will not only facilitate and reduce costs of sample collection but will also improve communication across the science-public and policy-public interfaces, including raising awareness to Stockholm Convention and issues related to POPs.

4.2. Guidance for implementing national, regional and global coordination mechanisms.

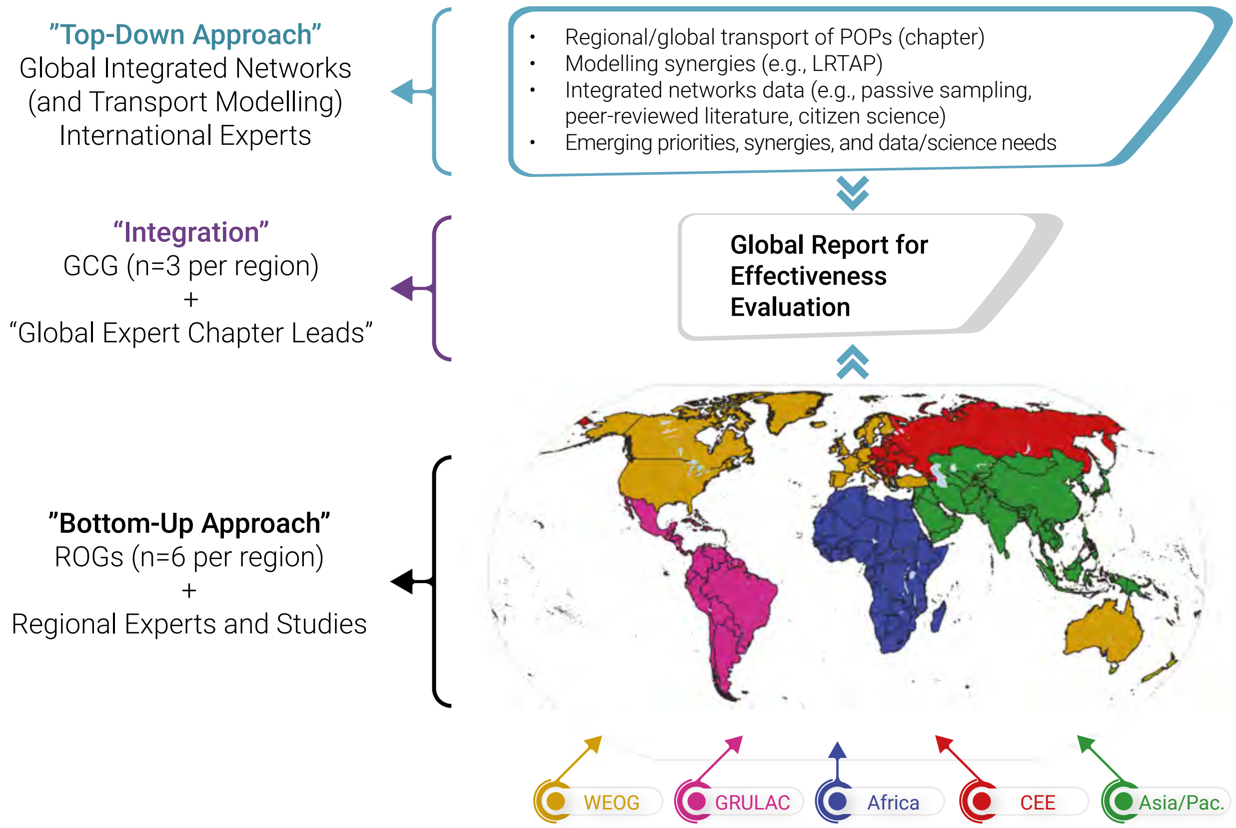
As outlined in this report, the current situation with respect to POPs monitoring in air in developing regions is not able to meet the current and growing demands of the Stockholm Convention and GMP. In fact, WEOG and CEE regions with established long term POPs monitoring programmes are also not able to meet the monitoring demands associated with the growing list of new POPs. This situation is presenting a challenge to the Effectiveness Evaluation of the Convention, which relies heavily on the GMP report.

To alleviate this situation, it is important that the GMP collaborate more inclusively across the science-policy interface and engage with POPs experts in the regions and to form partnerships within and across regions. Greater collaboration across the policy-policy interface (*e.g.*, synergies with other regional/global agreements and conventions) and public-policy interfaces (*e.g.*, citizen science, social media) will also help to support the impact, relevance, and sustainability of the GMP. Linkages and communications with expertise/labs involved in POPs measurements in other environmental media (*e.g.* soil, water, biota) and across science-science interfaces/disciplines (*e.g.*, analytical chemistry, biology, omics, toxicology, public health, and computational analysis) may also lead to new opportunities for air monitoring and advanced approaches.

4.2.1. Enhancements to future reporting under the GMP

We recommend consideration of a revised strategy in applying the framework for reporting under the GMP that would include greater engagement of available resources (experts) (Fig. 16) as well as platforms for data input (including guidelines for data criteria/format) for experts who are not able to participate more formally due to constraints *e.g.*, time constraints. The revised approach includes new, formalized expert science teams. These would include national/regional expert groups (scientists) working within the existing framework and jointly with the Regional Organization Groups (ROGs) of each region; in addition, a global expert group, which would collaborate beyond the framework of the Convention. Opportunities could also exist for coordination with broader initiatives inter alia, the new science-policy panel on chemicals, waste and pollution prevention. Membership in these groups would be voluntary and could be coordinated through regional centre and would likely not result in significant costs to the GMP.

Figure 16: Proposed revised approach in the regional structure to reporting under the GMP to meet the growing needs of the GMP.



Note: GCG – Global Coordination Group.

The proposed revised approach recognizes a "top-down" contribution of information to the GMP, which can supplement the "existing "bottom-up" flow of information that is currently coordinated through the ROGs. The top-down approach and related experts will also play a key role in identifying future priorities, additional sources of information, insights to existing data, and forming synergies across the science-policy and policy-policy interfaces. The elements of the revised approach to GMP reporting are described below:

1. Bottom-Up Approach – this retains much of the existing regional reporting framework for the GMP, which feeds information upwards towards a higher-level global compilation and report. A new addition would be the recognition of *regional experts*. The regional experts would collaborate with ROG members to conduct local monitoring of POPs towards enhancing capacity for measurements in air, as well as other core media, and to identify linkages to national/regional priorities related to POPs, *inter alia*, health, biodiversity, climate – as well as linkages to POPs measurements in other environmental media (*e.g.*, human tissues, water, sediment, biota etc.). The regional experts should be scientists who are actively involved in POPs research and monitoring (*i.e.*, experts who have led multiple publications within the past few years dealing with POPs measurements – and not policy experts). The selection of the regional experts should ideally be through an open, transparent, unbiased and voluntary process, which includes diverse perspectives.

2. Top-Down Approach – although this is identified as a new approach to supplement the existing GMP framework, some elements of the top-down flow of information have already been included in GMP reporting through long-range transport / modelling chapter of the global reports. The modeling chapter has typically relied on experts who are outside the structure of the ROGs and DWH (GMP Data Warehouse) and who are involved in the integration of "high-level" data and model outputs. Analogous to what is proposed here, modelers use the term "Top-down" to indicate initializing a model with high-level data such as air concentrations, when emissions information is lacking or limited. This is also referred to as "inverse modelling" and in some cases "model-measurement fusion". The water chapter in the recent GMP3 report is an example of how results from a "high-level" assessment conducted mostly outside of the regional reports, and incorporating peer reviewed data, can be integrated into the GMP report to present a more complete and global-scale assessment that would otherwise not be possible using only the "official data" from the regional reports.

The top-down approach relies on input from external experts. It is envisioned that the functions of these experts could be formalized and extended to a recognized *team to* provide diverse perspectives on topics such as long-range transport, modelling, emissions, sampling and analytical advances, and alternative and comparable data sets on POPs in air (to support the top-down modelling approach) as well as in other GMP monitoring media. This could include alternate data sets (*e.g.*, passive air sampling) not currently included in some regional reports (see chapter 3). The *expert group* would help to integrate broader sources of information and linkages across the science-policy and policy-policy interfaces. For instance, this could foster improved links to global modelling activities under the Task Force on Hemispheric Transport of Air Pollution, AMAP, and other institutions/networks, which could make better use of a more complete compilation of POPs levels in air. It is envisioned that some experts may also be members of *ROG as* described above. The expert group could also include diverse experts outside of the GMP process and representing other international groups having a focus on POPs. For instance, the proposed future science-policy panel on chemicals, waste and pollution prevention could play an important and impactful role.

3. Integration – under the scheme in Figure 16, the Global Coordination Group and invited experts (chapter leads) would continue function as they have been doing in previous GMP cycles. It is likely that new and qualified regional and national experts could be included as chapter co-authors to support the growing challenges and needs associated with drafting the GMP reports. In addition to supporting the GMP, the proposed structure and integration will help to address and link to Party obligations related to articles 8-12 of the Convention as discussed earlier.

4.2.2. Stepwise approach towards future monitoring of POPs

The following stepwise approach and timeline is proposed for illustrative purposes (food for thought) under the scenario of an enhanced framework for GMP reporting. Targets are included for recognition of national and regional experts for supporting reporting in the 4th phase of the GMP, as well as future reports.

Enhance Science-Policy Connections at the national/regional level

- **Step 1** (2024) – Recognize and identify national and regional experts on POPs – this would be done through an open, transparent and voluntary process to identify qualified experts. National Focal Points and the Secretariat could assist with promulgating the initiative to encourage participation. Regional Centres would also be part of this process and could assist with the review of applicants/nominees and membership of the team for the current GMP cycle. Memberships would be reviewed at the start of each cycle to make room for new and upcoming experts, based on a new Terms of Reference. Again the focus should be on an open and inclusive process and scientists/researchers who are active in the field.
- **Step 2** (2024-2025) – Discuss with regional experts and stakeholders to develop monitoring strategy and opportunities to meet the growing challenges of the GMP. These discussions should be co-chaired by ROG coordinator and a nominated representative of the regional experts. Based on previous recommendations stemming from GMP assessment, this approach and strategy could initially involve establishing partnerships with established programmes with transition to newly developed regional networks in the future.

Regional Coordination and Planning

- **Step 3** (2025+) – Workshops could be held on a regular schedule as a venue for POPs researchers from different countries within the region to present their work that contributes to the monitoring needs of the Stockholm Convention and the GMP and to coordinate with established programmes. This will help to raise awareness of activities within the region (and among ROG and GCG members) and could lead to collaborations within the region as well as partnerships across regions or globally with existing programmes and/or qualified institutions to generate new data for future GMP reporting.
- **Step 4** (2025+) – ROGs and regional experts to work together to draft the regional report to the forth report of the GMP (due in early 2027).

Global Coordination and Integration

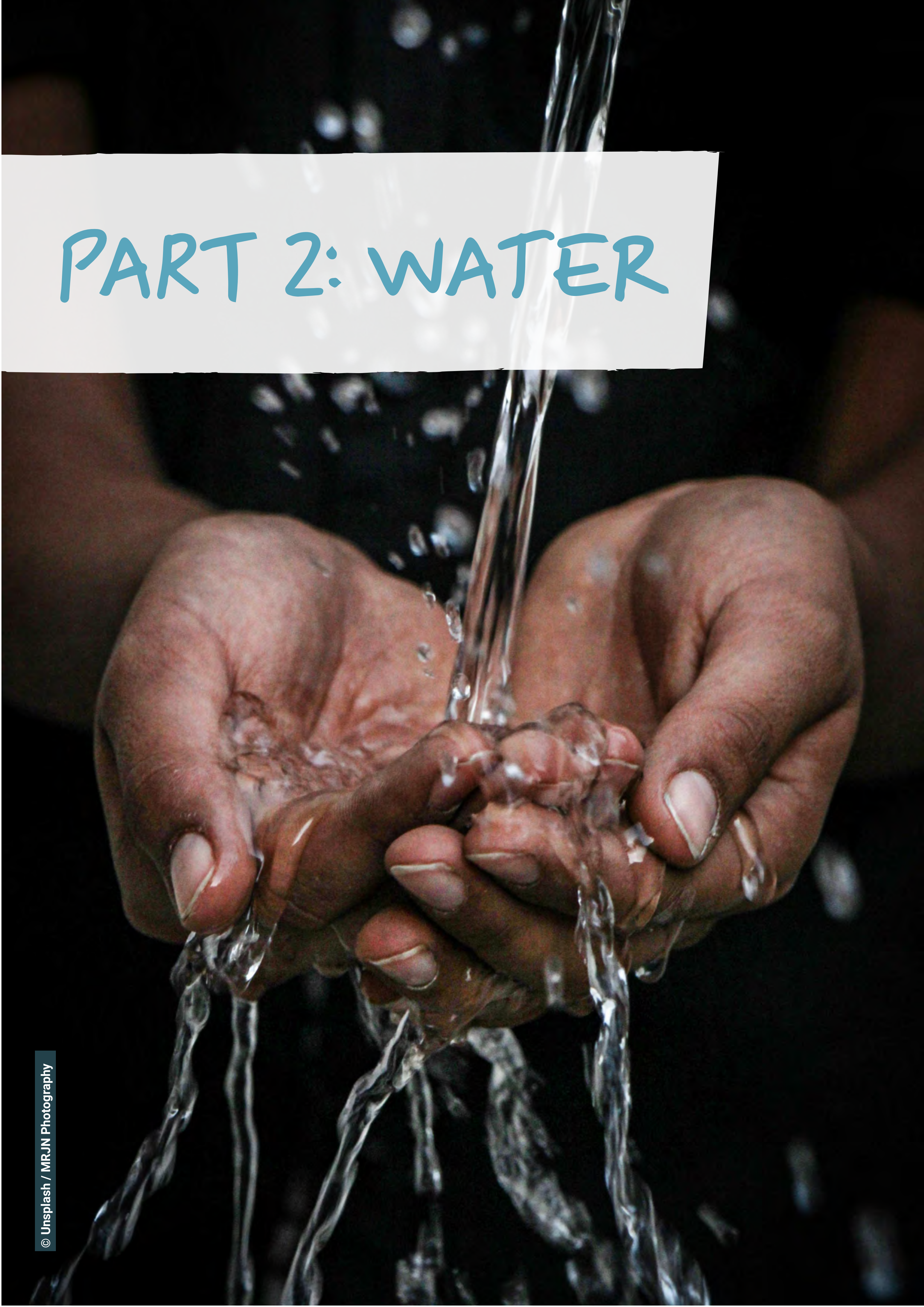
- **Step 5** (2025-2028) – Recognition and collaboration with a group of global experts including experts in relevant areas of POPs monitoring *e.g.*, science-policy panel members).
- **Step 6** (2027) – Contributing data to the preparation of the fourth report of the GMP.
- **Step 7** (2027-2028) – Integration of data from the “bottom-up” and “top-down” information flows and oversight by the Global Coordination Group (GCG). Regional could be involved, as needed, as chapter co-authors where applicable.

Financial considerations

This topic of funding is an important one but beyond the scope of the current review and will not be dealt with in detail. Sheriff, Debela and Mans-Davies (2022) provide an overview of the burdens faced by developing countries in meeting their NIP obligations under the Stockholm Convention. For instance, co-financing air monitoring of POPs is unlikely to be a high priority for these countries (apart from specific concerns related to hot spots) and it is therefore unrealistic to expect developing countries to be able to "do it themselves". Sheriff, Debela and Mans-Davies (2022) see a need for a greater role of the regional centres and for developing existing capacities (*e.g.*, specialized labs) so that they can be extended to serve the needs of many developing countries in each region.

These ideas above are consistent with the recommendations stemming from the current assessment exercise as well as past assessments – namely, encouraging greater integration of existing capacity and acting on synergies and partnerships to address common goals such as enhanced capacity for measuring POPs in air. Improved coordination and demonstration of purpose may also help in the seeking of funds, which is limited in developing countries. It is the opinion of the authors of this report that formalized financial support for research visits/training of postdoctoral researchers and other early career scientists and graduate students from developing countries, would be a worthwhile investment by funding agencies and serve as a pragmatic and effective method to build partnerships with experts and institutions. Ultimately, this approach will lead to enhanced capacity through greater collaboration and strong and integrated networks of qualified human resources / experts on POPs measurements in air.

PART 2: WATER



REGIONAL INITIATIVES AND NATIONAL CAPACITIES FOR MONITORING POPS IN WATER

5 CHAPTER

To assess the regional initiatives and national capacities, as well as global analytical services, a detailed review was conducted of scientific papers on monitoring of POPs in water published from 2011 to 2022. This time period was selected in order to try to reflect current research and monitoring capacity given that reports on POPs, particularly chlorinated pesticides, began to be published in the 1970s. The review utilized SCOPUS and Google Scholar. Keywords in the search included the common names and abbreviations of POPs, country names, along with the terms "water" and "monitoring", while excluding studies on measurements of POPs in biota, food, blood, wastewater, and several other media (See full list in Annex 3). As discussed below there was significant overlap because of many studies incorporating multiple media particularly sediments, or atmospheric measurements, with water. Thus, each article had to be screened all to check for water data. In addition, articles that included tabulations of previous measurements of POPs in water were screened for additional papers. PFAS were not included as their global distribution has been reviewed recently in the 3rd GMP report (UNEP and Stockholm Secretariat 2021a; UNEP and Stockholm Secretariat 2023) and also in a review article (Muir and Miaz 2021). Interestingly, there was no overlap of studies reporting PFAS with those reporting chlorinated and brominated POPs.

Efforts to enable women, men, youth, the elderly, vulnerable social groups, and other population sub-categories to contribute to POPs monitoring are critical for continued capacity enhancement and sustainable monitoring of POPs in countries and regions. Although the development and implementation of gender-responsive strategies and their effectiveness in eliciting gender responsive actions in national and regional POPs monitoring activities in the last ten years are not directly measurable through literature review of publication of scientific papers, follow up study is recommended to support gender integration.

Regional coverage: The review of the published literature mainly focused on studies conducted in lakes, rivers, and estuaries in the Africa, GRULAC and Asia-Pacific Regions. However, ship-based measurements from coastal seas adjacent to these regions, as well as open oceans, were also included. Studies from selected countries in the Central and Eastern Europe (CEE) region (Albania, Türkiye and Kazakhstan) along with a study of POPs in waters of the Black Sea were also included. A complete review of all studies within the CEE region was not conducted. Selected results from water monitoring programmes from the WEOG region Great Lakes (Venier *et al.* 2014) and Baltic Sea (Abraham, Theobald and Schulz-Bull 2017) were included for comparison with other regions. However, a broader review of scientific articles on POPs surface waters in WEOG countries was not conducted. Results for chlorinated POPs from the AQUAGAPS-MONET passive water sampling programme (Lohmann *et al.* 2023) for countries in Africa, Asia-Pacific, CEE and GRULAC were also included.

Screening criteria: Each article was screened and results recorded in an Excel file. The information extracted from each article is listed in Table 5. Articles without all of this information were excluded. Exclusions were mainly due to lack of latitude/longitude information or entire lack of numerical data *i.e.* if results were only presented graphically. In a limited number of cases, results were manually recorded where graphed results were clearly presented. The number of articles excluded was <5% of the approximately 135 articles screened. The combined data for POPs from these articles created a dataset with 242 freshwater sampling sites and 433 marine sites totaling approximately 7400 individual results for concentrations of POPs in surface waters.

Table 5: Information recorded for each scientific article included in the POPs in water dataset

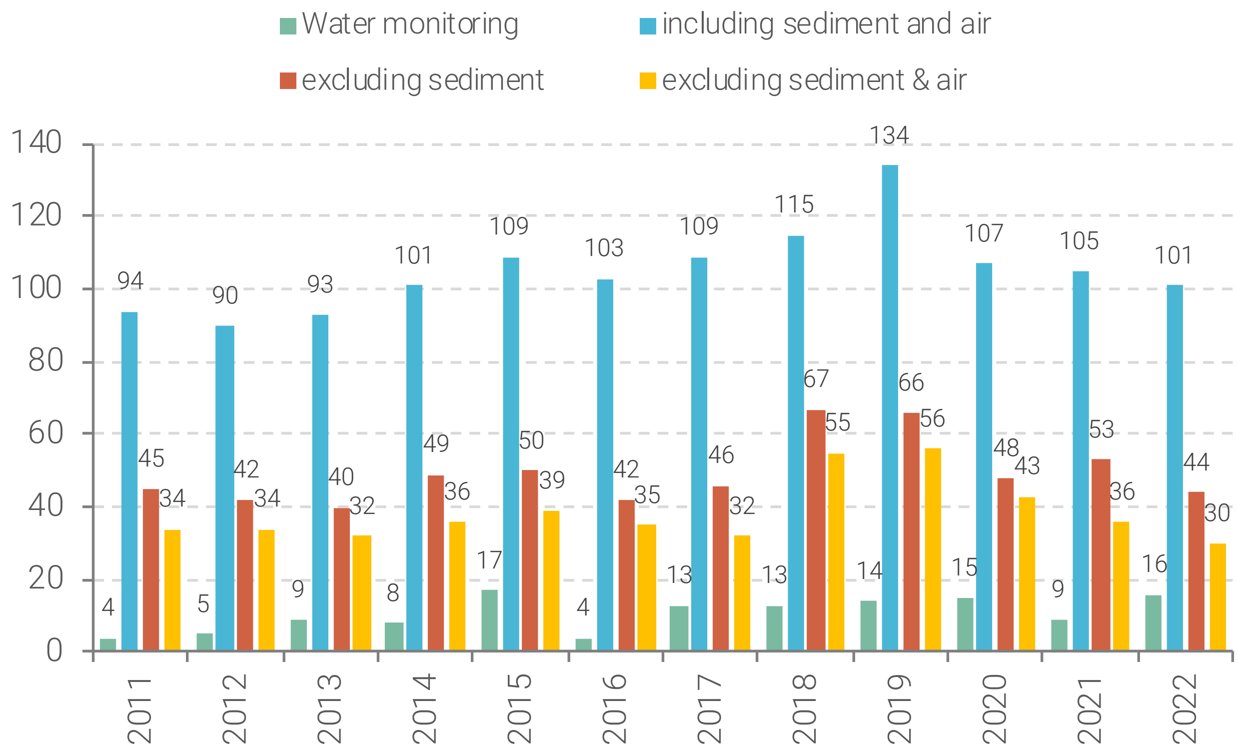
Country	Name Country or ocean/sea for ship-based measurement
Location	River, lake, name of urban or rural area or region
Water type	Marine or Freshwater. Estuaries were labelled as "freshwater"
Latitude	Decimal degrees (negative for degrees south)
Longitude	Decimal degrees (negative for degrees west)
Analytical method	Details including sampled/analysed water volume, extraction method (solvent, or solid phase column, or passive sampler), chromatographic cleanup step (eg silica column), instrumental analysis, *e.g.* Gas chromatography-mass spectrometry (GC-MS)
Year	Sample collection year. If multiple years at the same site, used most recent year
Compounds	List as reported. Nomenclature standardized
Original Conc.	Concentrations as reported if individual latitude/longitude available. Results for lake, river and coastal sites in close proximity were averaged
Range or SD	Ranges or standard deviations as reported or calculated for lake, river and coastal sites in close proximity
Analytical lab	Full address of the corresponding author and/or analytical lab if specifically identified

The regional reports for the 3rd Global Monitoring Plan for Asia-Pacific, GRULAC and Africa (Stockholm Secretariat n.d.) were also reviewed for reports on POPs in water. The most extensive programme was in Japan, where the Ministry of Environment has had a long term programme for chlorinated pesticides, PCBs, and dioxins/furans in rivers and lakes (Japan, Ministry of Environment [JMoE] 2020a; JMoE 2020b). These data are not included in the review of the published literature in Chapter 5.1 because only summary tables are available online (JMoE 2019). Nevertheless, they represent a unique dataset that could be used to assess trends of POPs in freshwater and nearshore marine waters in East Asia.

5.1. Review results

Screening of the published literature yielded 129 articles for the period 2011 to 2022 which included data for POPs in surface waters of Africa, Asia-Pacific, GRULAC and a selected reports from the CEE and WEOG regions, as well as oceans and seas adjacent to all regions (Figure 17). These articles represent a relatively small subset of all articles on POPs that include the keyword "water" because many articles that included sediment and atmospheric measurements also mention water in the abstract. The literature search captured many review articles and exposure assessments that include water in the title or abstract but did not include original data. The great variety of topics with water as a keyword as well as the overlap with sediment and atmospheric measurements of POPs made it challenging to identify all relevant studies using the bibliometric search method and required manual searches as discussed above. It should be noted that the total numbers of articles with water, air and sediment in Figure 17 (orange bars) includes the WEOG region. Identifying articles solely from WEOG was difficult because several groups based in Europe, USA, and Canada were also collaborating on analysis of samples from other regions. Nevertheless, by eliminating the 16 WEOG countries using the number of articles including water, sediment and air was reduced from 1261 to 657.

Figure 17: Numbers of publications identified with a search of SCOPUS



Note: The "water monitoring" group includes POPs in surface waters of Africa, Asia-Pacific, GRULAC and selected countries in the CEE region only, along with ship-based sampling of adjacent seas and oceans. (See Annex 3 for search terms).

5.1.1. Methods for sampling and analysis used in Africa, Asia-Pacific and GRULAC regions

Sampling methods: Water sampling is obviously a key first step in conducting studies on POPs in water. "Active" sampling, by collection of a defined volume at given location was the most widely used technique (Table 6). This involved both small and large volume sampling. Smaller "grab" samples of 1 to 4 L were collected into pre-cleaned glass bottles, dipping them by hand. Then subsamples (0.2 to 2.5 L) were extracted, generally after filtration through glass fibre filters (GFF). Larger "active" samples were collected, mainly in ship-based studies. This involved pumping water collected through a portal under the ship, through GFF and then through a XAD-2 resin or polyurethane foam cartridge located in a lab on the ship. The 3rd sampling method was by passive sampling with semi permeable membrane devices (SPMDs), silicone or low density polyethylene (LDPE) samplers. Passive sampling is considered to be a robust technique for monitoring of dissolved concentrations of nonpolar organics (Booij *et al.* 2016; Vrana, Smedes and Hilscherová 2020). However, it was used for a relatively small number of studies (14 of 129) in the Africa, Asia-Pacific and GRULAC regions. Passive samplers were generally deployed in lakes and rivers inside stainless steel cages for 21 to 48 days. In addition, flow-through passive (silicone) samplers were utilized in a ship based study in the South Atlantic and the Black Sea (Sobotka *et al.* 2021) by pumping water from under the ship into a 200 L stainless steel barrel which held the silicone passive media. The number of "active" sampling programmes varied over the period 2008 to 2019 but did not show any clear trend. Similarly, the use of passive samplers did not show a clear trend. The AQUA-GAPS-Monet study using passive silicone and samplers in lakes, rivers and nearshore marine environments including 22 sites (Africa (1), Asia-Pacific (6), GRULAC (11) and CEE (4)) regions, deployed for up to one year over the period July 2016 and October 2020 (Lohmann *et al.* 2023). Those deployments are included in Table 6 and in the database for POPs in water and for assessment of geospatial trends of selected POPs in water discussed below.

Table 6: Sampling and extraction methods for water samples reported for studies conducted in Africa, Asia-Pacific and GRULAC regions and adjacent seas/oceans

	"Active" sampling		Extraction technique		
Sampling year[1]	"Active grab" 0.5-4 L	"Active pumped" XAD/PUF	SPE extraction	DCM or hexane extraction	Passive sampling[2]
2008	4	0	0	0	0
2009	5	2	1	4	2
2010		1			0
2011	4	2	1	4	2
2012	8	3	1	5	3
2013	11	2	1	10	0
2014	6	3	3	2	1
2015	9	3	6	8	1
2016	6	1	4	2	2
2017	5	2	3	5	2
2018	6	0	3	3	2
2019	10	0	5	2	1

[1]Based on articles published from 2011 to 2022. Sample collection was conducted from 2 to over 10 years prior to publication; [2]Passive sampling using Semi permeable membrane devices (SPMDs), silicone or low-density polyethylene samplers

Extraction methods: Small volume "active" samples were extracted either with organic solvents or using C18 octadecyl silyl solid phase (SPE) extraction cartridges or extraction disks containing C18 bonded sorbents. Dichloromethane (DCM) or hexane were the most widely used solvents. The USEPA method 3510 (United States, Environmental Protection Agency [US EPA] 1996) which provides step by step details for liquid-liquid extraction was cited by several studies. Several authors from south Asian countries also cited extraction procedures for PCBs in water prescribed by United Nations University project (United Nations University [UNU] 2016). Also one study (Necibi and Mzoughi 2020) reported the use of methodology recommended by the International Atomic Energy Agency although the specific publication could not be found. Large volume media (XAD resin or PUFs) were also solvent extracted, generally with Soxhlet extraction apparatus. SPMDs, silicone and LDPE passive samplers were extracted with hexane.

Cleanup methods: Most water sample extracts received further cleanup to remove co-extractives that might interfere with gas chromatographic (GC) analysis. Silica, alumina-silica, or Florisil columns were the most commonly used (80 of 129 studies) with POPs eluted using hexane to elute non-polar compounds such as PCBs, followed by mixtures of DCM/hexane or ethyl acetate/hexane, to recover moderately polar compounds such as hexachlorocyclohecanes, dieldrin and endosulfan. Some authors skipped the cleanup step entirely, choosing to prepare the samples directly for GC analysis. Fifteen laboratories reported the use of sulfuric acid-silica cleanup columns to remove co-extractives. Three labs reported the use of gel permeation chromatography as part of the cleanup steps for SPMDs (where residual triolein may have been present) while 3 labs used GPC to cleanup large volume (>100 L) water extracts.

Instrumental analysis: POPs in water extracts were quantified by GC with electron-capture detection (GC-ECD) or by low resolution GC-mass spectrometry (GC-MS) (Table 7). GC-ECD continues to be widely used for analysis of organochlorine pesticides as indicated in the most recent UNEP intercomparison for POPs in air, sediment, fish and human milk (Fiedler, van der Veen and de Boer 2021). However, it often results in more deviation between laboratories and fails to resolve differences between co-eluting analytes such as 2,4-DDT and dieldrin. GC-MS instrumentation included single quadrupole instruments (55/129 studies), as well as triple quad or tandem MS instruments. The latter are generally regarded as providing better sensitivity and specificity due to the detection of individual mass fragments of precursor ions with the second quadrupole (Snow 2021). Gas chromatography-high resolution mass spectrometry (GC-HRMS) was used in 8 studies. Several labs used HRMS for quantification of PBDEs in water while using low resolution GC-MS for chlorinated POPs. Six studies with HRMS involved laboratories in the USA, Canada or Western Europe, while one was in Türkiye and the other in China. The high cost and special laboratory infrastructure requirements for high resolution instruments are a barrier to their wider use for POPs analysis in water.

Two studies utilizing enzyme-linked immunosorbent assay (ELISA) to detect POPs in water. Welch *et al.* (2019) analysed 4,4'-DDE-related compounds in surface waters in Samoa by direct analysis of water samples with a commercial ELISA kit (detection limit ~ 500 ng/L). Oğuz and Kankaya (2013) detected DDE in water from Lake Van in Türkiye using a similar ELISA test kit. The authors significantly improved the detection limits of the method (~ 1 ng/L) by first extracting DDE/DDT from the water with C18-SPE and concentrating the extract to a small volume.

Quality assurance (QA): All studies that were included in the database provided basic QA information such as citations related to the analytical method, use of field and laboratory blank samples, source of solvents and reagents, sources of native and (^{13}C) mass labelled analytical standards, and detection limits. Almost all studies indicated the use of internal standards to monitor recoveries, however, not all provided the recovery data. With the exception of 2 laboratories which mentioned participation in the UNU project on POPs in water in Asia (UNU 2016), no studies indicated participation in interlaboratory comparisons. However, given the large number of laboratories that have participated in the UNEP bi-biennial interlab comparisons for analysis of POPs in fish, sediment and human milk (Fiedler, van der Veen and de Boer 2021) some of the laboratories reporting measurements in water may have been participants. A review of the participant contacts and institutions extracted from the 2018-19 intercomparison report did not identify names or institutions but a more detailed examination could be done. Future intercomparisons could also reach out to the laboratories analysing water samples that have been identified in this report.

Table 7: Instrumental methods for quantification of chlorinated and brominated POPs in water used in studies conducted in Africa, Asia-Pacific and GRULAC regions and adjacent seas/oceans

Instrumental method	Number of labs
Enzyme-linked immunosorbent assay (ELISA)	2
Gas chromatography- electron capture detection (GC-ECD)	52
Gas chromatography-Mass spectrometry (low resolution; single quadrupole)	55
Gas chromatography-Tandem Mass spectrometry (GC-MS/MS)	13
Gas chromatography-High resolution mass spectrometry (GC-HRMS)	8
Two dimensional gas chromatography-Time-of-flight mass spectrometry (GCxGC-TOF-MS)	1

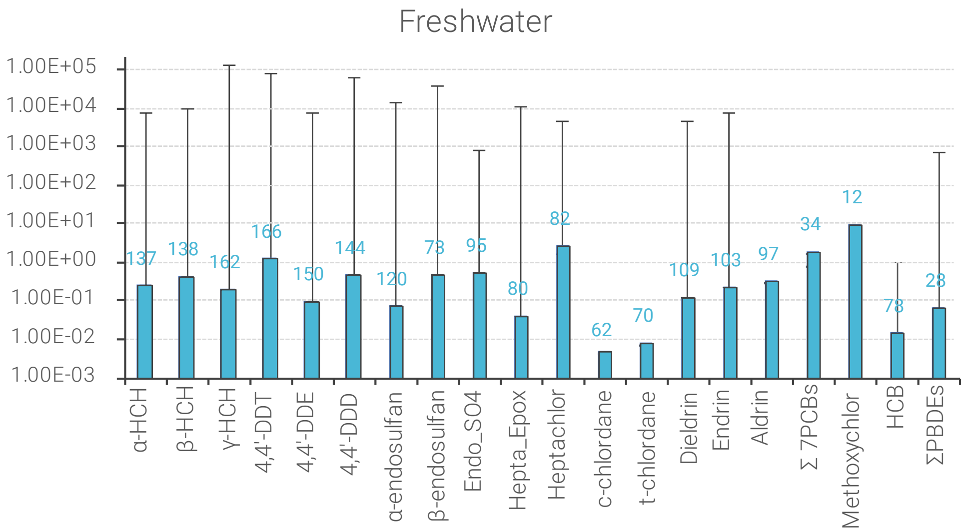
5.1.2. Overview of POPs concentrations in surface waters

Predominant compounds and range of concentrations: The large database created by screening of the published articles enabled an assessment of geo-spatial trends of selected POPs in water within the Africa, Asia-Pacific and GRULAC regions and neighboring seas and oceans. As this was not an objective of this report, only a brief discussion is provided here. However, the available data could be useful for assessment of trends of POPs in water in future GMP reports. This potential use of the available data is further discussed in this chapter.

The median and range of concentrations of the 12 most frequently reported individual POPs analytes in freshwater samples are show in Figure 18. A full list is provided in Annex 4, Table A2. As might be expected given historical uses, the individual isomers of the DDT and HCH groups predominated with over 150 reports in the cases of 4,4'-DDE, 4,4'-DDT and γ-HCH. Endosulfan, the "drins" and heptachlor (an insecticide and also a component of technical chlordane) were also among the top 12. While median concentrations of the top 12 were between 0.07 and 2.7 ng/L, the range of concentrations was very large, reaching a maximum of 123,700 ng/L for γ-HCH (lindane) (Figure 18).

The DDT and HCH groups also predominated in terms of numbers of measurements in coastal waters, neighboring seas and oceans of Africa, Asia-Pacific and GRULAC regions with over 200 reports (Figure 19). A full list is provided in Annex 4, Table A3. Endosulfan isomers and the transformation product, endosulfan sulfate, were widely reported as were HCB and trans-chlordane. Median concentrations of the top 12 ranged from <0.0001 ng/L (endosulfans) to 0.08 ng/L for δ-HCH. The appearance of δ-HCH in the top 12 was surprising but it may reflect a large number of ship-based samples from East Asian waters.

Figure 18: Median (bar) and maximum (vertical line) concentrations of the 20 most frequently reported individual POPs analytes in freshwater samples of Africa, Asia-Pacific and GRULAC regions.

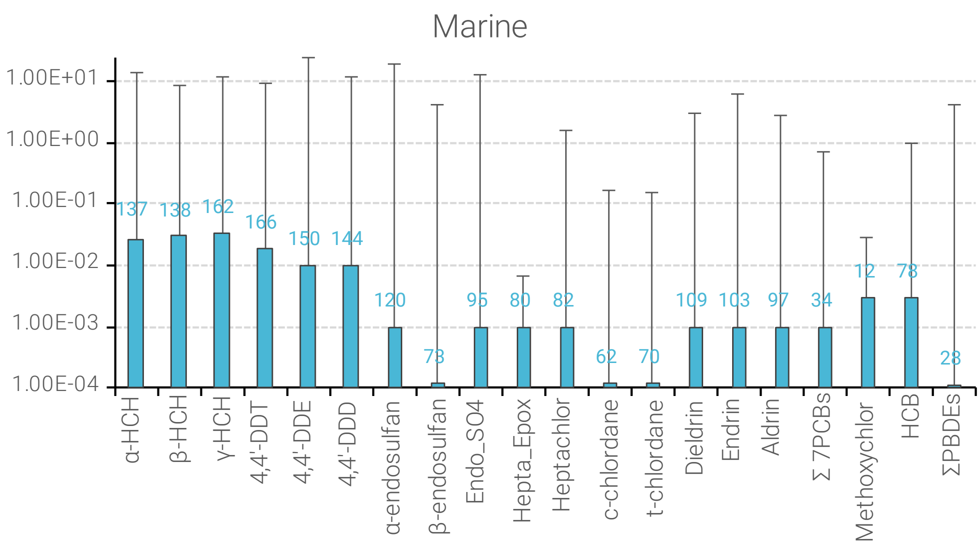


Note: The number of results reported for each compound is shown to the right of each bar. The vertical axis is a log10 scale.

Maximum concentrations of the top 12 in marine waters were lower than in freshwater with 4,4'-DDE and α-endosulfan having the largest values 24.3 ng/L and 19.8 ng/L, respectively (Figure 19, Annex 4, Table A3).

Sampling locations and geo-spatial trends: The spatial coverage of results for 6 of the major individual POPs analytes, based on sampling from 2008 to 2019, is shown in the maps in Figure 20, Figure 21and Figure 22. China, India, Kenya, Ethiopia, and South Africa had the best coverage. For measurements of α- and γ-HCH in freshwater samples; results were generally more limited in GRULAC and no results could be found for the Pacific islands (Figure 20). Highest α- and γ-HCH concentrations (illustrated qualitatively with heat maps) were in samples from Kazakhstan, Kenya and Mexico. In the marine environment, results were available from ship-based monitoring in all oceans as well as from coastal sampling (Chile, Egypt, Singapore). The most intensive sampling for α- and γ-HCH was in the East China Sea and Yellow Seas and along a transect through the Sea of Japan to the Bering and Chukchi Seas (Figure 20). Highest concentrations of α- and γ-HCH were present in the East China Sea and Yellow Seas and Sea of Japan. Concentrations of HCH isomers were also relatively higher in the Baltic Sea (results from 2014-15; Abraham, Theobald and Schulz-Bull (2017)) than in the Black Sea or the Mediterranean.

Figure 19: Median (bar) and maximum (vertical line) concentrations of the 20 most frequently reported individual POPs analytes in marine waters of coastal seas and oceans of Africa, Asia-Pacific and GRULAC regions.



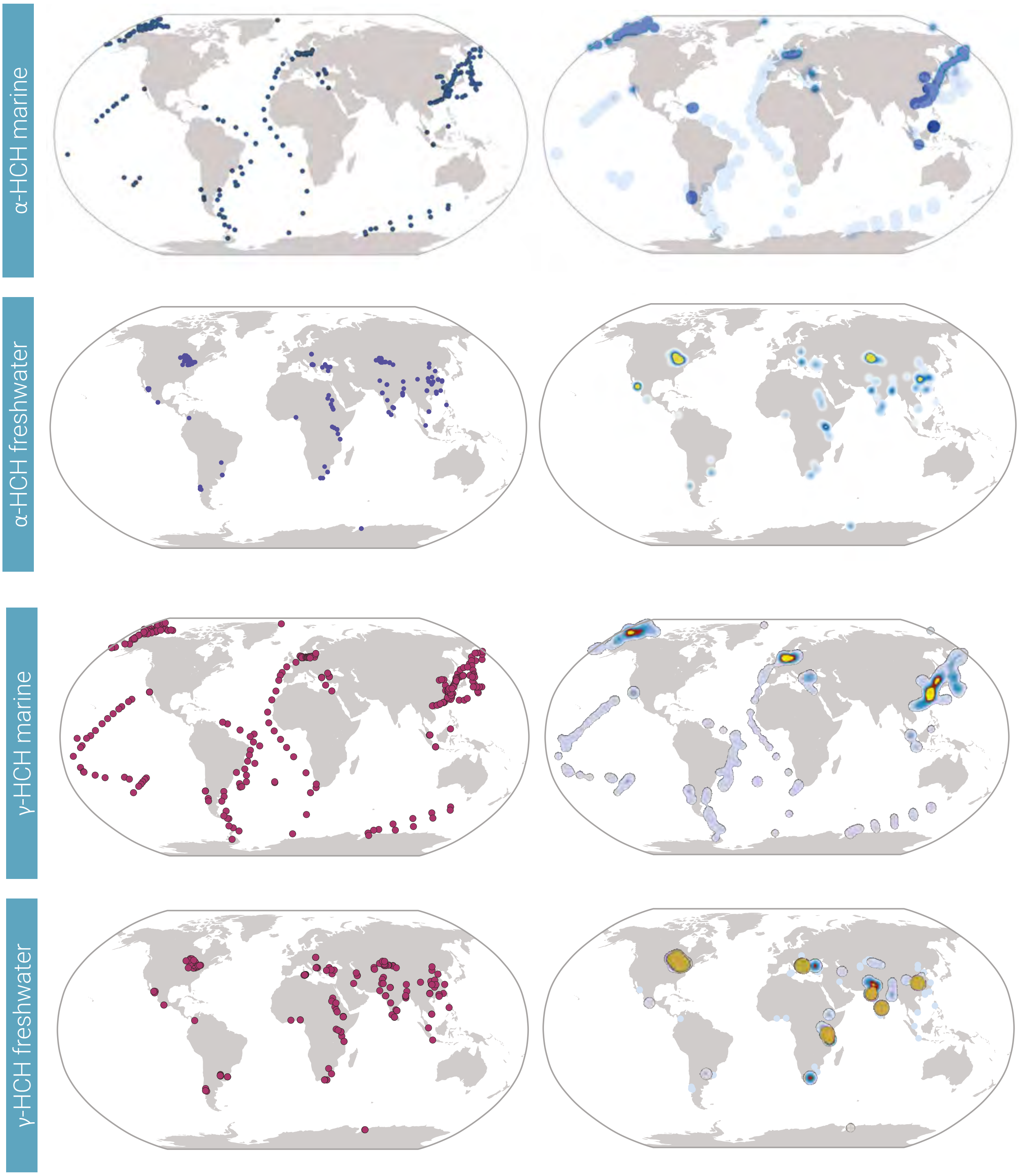
Note: The number of results reported for each compound is shown to the right of each bar. The vertical axis is a log10 scale.

Similar numbers of freshwater sampling locations for α-endosulfan were found for GRULAC, Africa, and South Asia (Figure 21). Highest concentrations were reported for river and lake waters in Kazakhstan. Several sampling sites in Pakistan, India and China (Figure 21). In the marine environment the largest number of sampling sites for α-endosulfan were in the East China Sea and Sea of Japan and on a transect from that region to the Chukchi Sea (Figure 6). Concentrations of α-endosulfan in seawater in the Chukchi Sea were higher than all locations in the southern Atlantic, Southern Indian Ocean and ocean waters near Antarctica. Overall, the highest α-endosulfan concentrations were also in the East China Sea and Yellow Sea although the North Sea also had similar levels (Figure 21).

Africa, south Asia and China had the most freshwater sampling sites for 4,4'-DDE; coverage was more limited for GRULAC (Figure 5). Highest concentrations of 4,4'-DDE were found in samples from Kazakhstan but were also relatively elevated in Tunisia, Kenya, Ethiopia. However, concentrations of 4,4'-DDE in the lower Great Lakes were also relatively high compared to most other locations in the database (Figure 21).

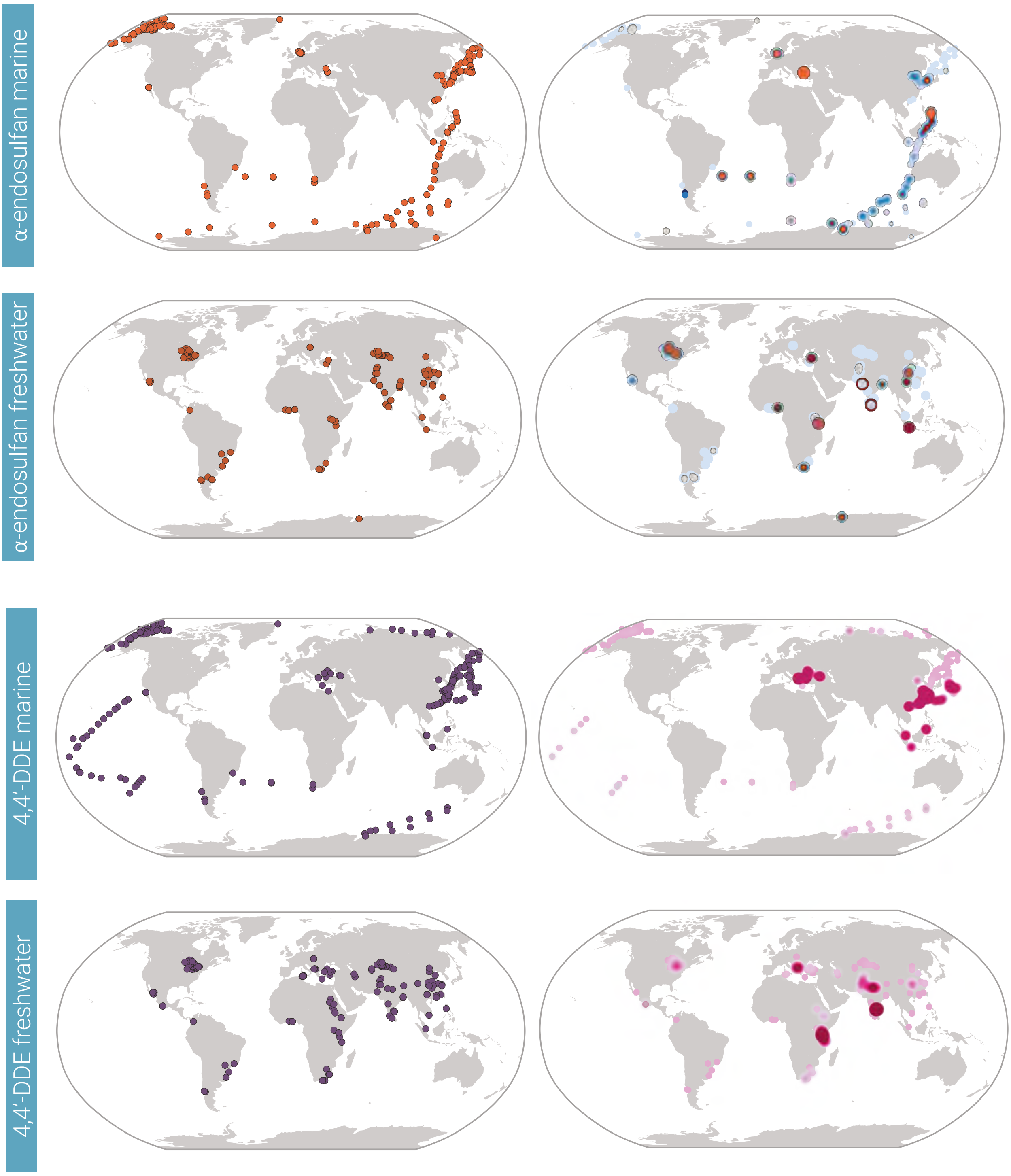
HCB was not among the top 12 POPs in terms of number of sampling sites in freshwater (it was 16th; Annex 4, Table A2), however, it was in the top 12 for marine sampling and therefore was included in Figure 22. An intensive water sampling programme on the Indus River in Pakistan included HCB (Sohail *et al.* 2022) but it was analysed in only a limited number other sites in south Asia. Highest concentration in freshwater were in samples from the Yangtze, Qinhuai rivers in China (Chen *et al.* 2021), in rivers in Albania and Tunisia, as well as in the lower Great Lakes in Canada/USA (Figure 22). In the marine environment HCB concentrations were highest in the eastern Indian Ocean (Huang *et al.* 2014) and in coastal waters of Singapore (Zhang, Bayen and Kelly 2015). In comparison with the WEOG region, some of the higher levels were from the North Sea (Figure 22).

Figure 20: Marine and freshwater sampling sites (from 2008-2019) and relative concentrations for a-HCH and g-HCH for studies conducted in Africa, Asia-Pacific, and GRULAC regions and adjacent seas/oceans.



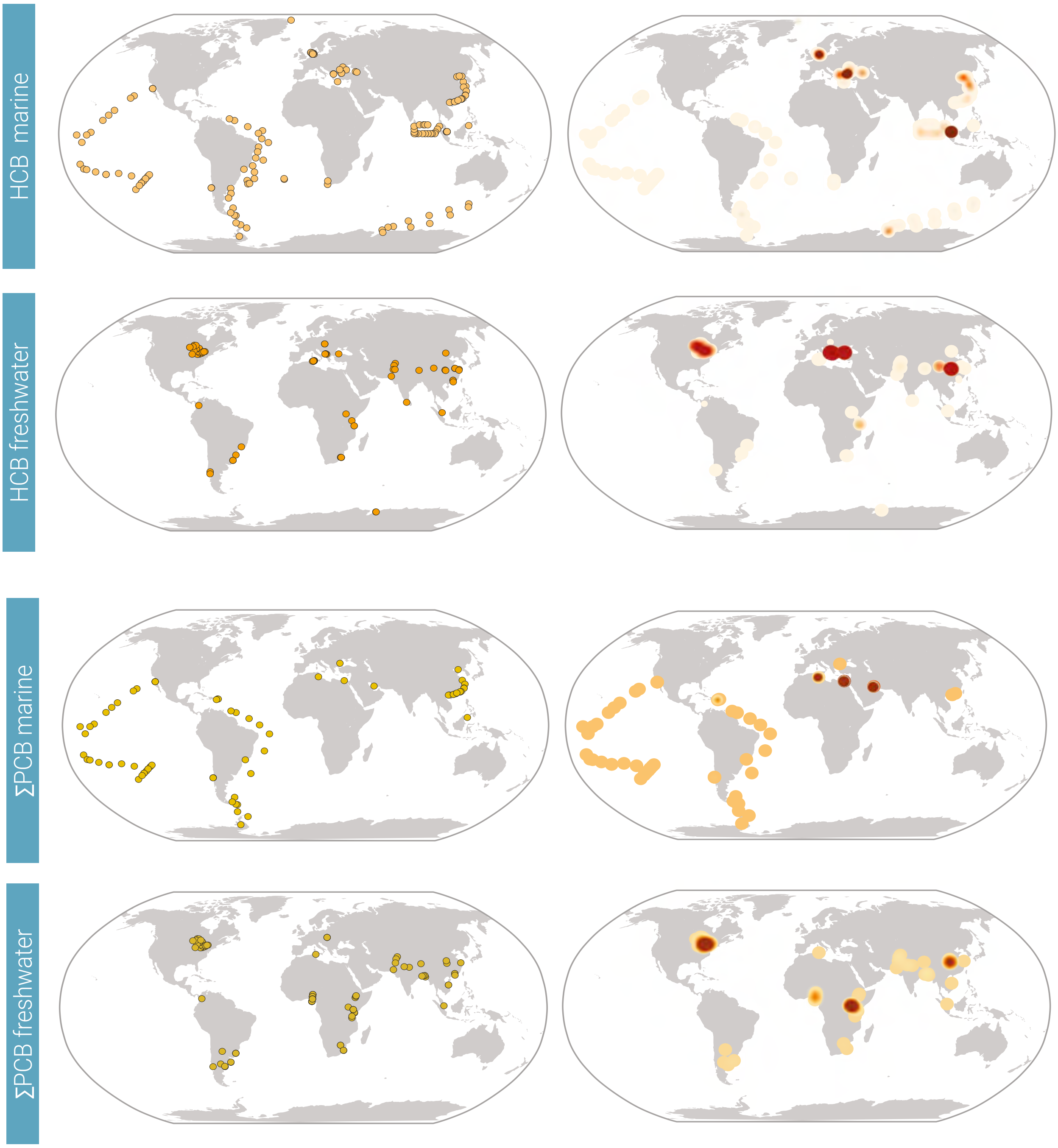
Note: Results for selected sites in CEE (*e.g.* Black Sea), and in WEOG (the Great Lakes, the North Sea, Chukchi Sea) are included. Left hand panels show locations and right-hand panels show heat maps qualitatively illustrating the range of concentrations with yellow as the highest.

Figure 21: Marine and freshwater sampling sites (from 2008-2019) and relative concentrations for α-endosulfan and 4,4'-DDE conducted in Africa, Asia-Pacific, and GRULAC regions and adjacent seas/oceans.



Notes: Results for selected sites in CEE (*e.g.*, Black Sea) and in WEOG (the Great Lakes, the North Sea, Chukchi Sea) are included. Left-hand panels show locations and right-hand panels show heat maps qualitatively illustrating the range of concentrations with yellow and red as the highest.

Figure 22: Marine and freshwater sampling sites (from 2008-2019) and relative concentrations for HCB and ΣPCBs conducted in Africa, Asia-Pacific, and GRULAC regions and adjacent seas/oceans.



Notes: Results for selected sites in CEE (*e.g.*, Black Sea) and in WEOG (the Great Lakes and the North Sea) are included. Left- hand panels show locations and right-hand panels show heat maps qualitatively illustrating the range of concentrations with orange and yellow as the highest.

Sampling sites and concentrations of total (Σ) PCBs were also of interest although they ranked 13th in terms of numbers of measurements of POPs in freshwaters and 16th in marine waters (Annex 4, Table A2 and Table A3). Relatively few sampling programmes for POPs in freshwater in GRULAC, Africa or South Asia have included PCBs.

Further complicating the assessment of PCBs was the wide variation in numbers of congeners measured ranging from 7 (generally PCB-28, 52, 101, 118, 138, 153 and 180) to more than 30. Thus ΣPCBs was difficult to compare among studies. Greater numbers of sites have been sampled in China and in the eastern Mediterranean and the Black Sea (Figure 22). Highest concentrations of ΣPCBs were in the Niger River in Nigeria (Unyimadu, Osibanjo and Babayemi 2018) and in the Nairobi River in Kenya (Ndunda and Wandiga 2020). Recent (2008-2019) sampling for ΣPCBs in marine waters was quite limited. In contrast to the extensive dataset for HCH isomers and endosulfan in East Asian waters, no measurements have been reported in that region for ΣPCBs. Coastal sampling in southern China was conducted as part of AQUAGAPS-MONET (Lohmann *et al.* 2023) and analyses of PCBs were also included in nearshore waters in Tunisia and in the Persian Gulf (Figure 22). Highest concentrations of ΣPCBs were found in near-shore coastal waters of Alexandria, Egypt (Said *et al.* 2015) and in an oil refinery industrial area of coastal Iran (Ghadrshenas *et al.* 2023).

Temporal trends of POPs in water: The information assembled for this review could be useful for future assessments of POPs under the GMP, possibly under the "Other media" category since water is not a core media, except for PFAS. Combined with older data (pre-2008) or new, forthcoming, results it may be possible to assess temporal trends in water of the above group of POPs. At present assessment of temporal trends appears unfeasible because of lack of data from the same locations. The exception is Japan, where long term monitoring of POPs in river, lake and nearshore marine waters has enabled trends assessments (JMoE 2020a). Results summarized in the 3rd Asia-Pacific report for the GMP showed declines for PCBs, HCB, HCHs, DDTs, chlordanes and pentabromo-PBDEs in water (UNEP and Stockholm Secretariat 2021b). There are several good examples from the WEOG region illustrating that temporal trends can be assessed in water despite the dynamic nature of the aquatic environment (UNEP and Stockholm Secretariat 2023). Abraham, Theobald and Schulz-Bull (2017) assessed temporal trends of α-HCH, β-HCH and γ-HCH in the southern Baltic Sea using data from 1975 to 2015. An interesting observation from that study, relevant to future global monitoring, was the growing predominance of the more persistent and bioaccumulative β-HCH isomer. In the Great Lakes region, Bidleman *et al.* (2021) was able to estimate the environmental half-lives of α-HCH and β-HCH in Lake Superior waters based on data from 1986 to 2016. The long term trend data for the Baltic Sea, Lake Superior, and Japanese waters, reflect the need for sustained water quality monitoring programmes that support land and ship-based sampling, as well as laboratory infrastructure and trained scientific staff.

5.1.3. Overview of the availability of POPs data in water by UNEP region

The heat map tables (Table 8 and Table 9) provide a qualitative summary of the status measurements of the 30 substances listed as POPs as of 2022, in water in Africa, GRULAC, South-Asia (including Iran, India, Korea, and Pacific islands as well as neighboring countries in CEE (Türkiye, Kazakhstan)), China, and Japan. The results are drawn from data in Annex 4, Table A2 and Table A3. Several POPs have no measurements in water in these regions (or indeed globally) over the sampling period 2008-2019 (chlordecone, PCNs), while several have only measurements in single studies (methoxychlor, HBCD, dicofol, HCBD, SCCP). Japan was the only country with a relatively comprehensive list of frequently measured analytes although not all 34 POPs listed as of 2023 were part of the national monitoring program. Multiple studies conducted in freshwaters and coastal marine waters in China also included a large list of POPs. The gaps in terms of POPs being analysed also reflect the growing analytical challenges with some substances recently added to the Stockholm Convention such as dicofol, HBCD and SCCPs.

Table 8: Overview of POPs in surface waters of rivers and lakes in Africa, Asia-Pacific, and GRULAC for the period 2010-2022

No information	Single study	2 to 5 studies	>5 studies

POP	Africa	South-Asia & Pacific islands	China	Japan[1]	GRULAC
Aldrin	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
Chlordane	Single study	No information	>5 studies	>5 studies	2 to 5 studies
Chlordecone	No information	No information	No information	No information	No information
Dicofol	Single study	No information	No information	No information	No information
DDT	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
Dieldrin	Single study	2 to 5 studies	>5 studies	>5 studies	Single study
Endosulfan	2 to 5 studies	2 to 5 studies	>5 studies	No information	2 to 5 studies
Endrin	No information	2 to 5 studies	>5 studies	>5 studies	No information
HBB	Single study	No information	No information	No information	No information
HCBD	Single study	No information	No information	No information	No information
HBCD	No information	No information	No information	No information	No information
HCB	2 to 5 studies	No information	>5 studies	>5 studies	Single study
a-HCH	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
b-HCH	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
g-HCH	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
Heptachlor	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
Methoxychlor[2]	Single study	No information	No information	No information	No information
Mirex	Single study	No information	No information	>5 studies	No information
Penta/octa PBDE	Single study	No information	No information	No information	No information
BDE-209 (DecaBDE)	No information	2 to 5 studies	No information	No information	No information
PCP (+anisole)	Single study	No information	No information	2 to 5 studies	No information
PCN	No information	No information	No information	No information	No information
PCB	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
PCDD/PCDF	Single study	No information	No information	>5 studies	No information
PFHxS	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
PFOS	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
PFOA	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
PeCB	Single study	Single study	No information	>5 studies	No information
SCCP	Single study	No information	>5 studies	No information	No information
Toxaphene	No information	No information	No information	>5 studies	No information

[1]Results for Japan are based on the forthcoming Asia-Pacific GMP regional report

[2]Proposed for listing to the SC, chemical under review.

Table 9: Overview of POPs in coastal and offshore marine waters of Africa, Asia-Pacific, and GRULAC for the period 2010-2022

No information	Single study	2 to 5 studies	>5 studies

POP	Africa[1]	South-Asia & Pacific islands[2]	China[3]	Japan[4]	GRULAC[5]
Aldrin		2 to 5 studies	2 to 5 studies	2 to 5 studies	
Chlordane		Single study		2 to 5 studies	
Chlordecone					
Dicofol		Single study			
DDT	2 to 5 studies	2 to 5 studies	2 to 5 studies	2 to 5 studies	2 to 5 studies
Dieldrin		2 to 5 studies	2 to 5 studies	2 to 5 studies	
Endosulfan		2 to 5 studies	2 to 5 studies	2 to 5 studies	
Endrin		Single study		2 to 5 studies	
HBB	Single study				
HCBD					
HBCD	Single study				
HCB	2 to 5 studies	2 to 5 studies	2 to 5 studies	2 to 5 studies	2 to 5 studies
a-HCH		2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
b-HCH		2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
g-HCH		2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
Heptachlor		2 to 5 studies			
Methoxychlor		Single study			
Mirex		Single study			
Penta/octa PBDE	Single study		2 to 5 studies	2 to 5 studies	2 to 5 studies
BDE-209 (DecaBDE)	Single study				Single study
PCP (+anisole)			2 to 5 studies	Single study	
PCN					
PCB	2 to 5 studies	2 to 5 studies	2 to 5 studies	2 to 5 studies	2 to 5 studies
PCDD/PCDF					
PFHxS	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
PFOS	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
PFOA	2 to 5 studies	2 to 5 studies	>5 studies	>5 studies	2 to 5 studies
PeCB	2 to 5 studies			2 to 5 studies	2 to 5 studies
SCCP					
Toxaphene		Single study		2 to 5 studies	

[1]Includes coastal Mediterranean, coastal South Atlantic

[2]Includes Indian Ocean, Southern Ocean, Western Pacific, Bering Sea, Chukchi Sea

[3]Includes Yellow Sea, East China Sea, and coastal waters

[4]Includes cruises through the Sea of Japan and coastal waters

[5]Includes South Atlantic and coastal waters of Brazil, Chile and Mexico

INTERLABORATORY QUALITY CONTROL/QUALITY ASSURANCE SCHEME FOR POPS IN WATER

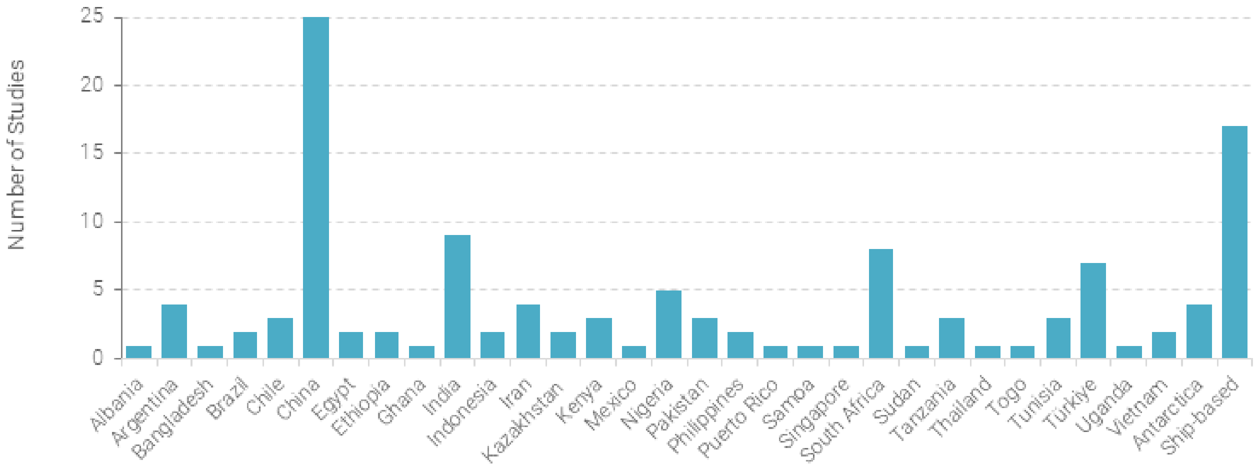
6 CHAPTER

6.1. Regional institutions and analytical capacity

An extensive set of relatively recent data is available for DDT related compounds, HCH and endosulfan isomers, "drins", HCB, and chlordane related compounds in freshwater and marine waters of Africa, Asia-Pacific, and GRULAC regions. The large number of studies from GRULAC, Africa and south Asia, led by universities and government agencies, demonstrate that there is expertise and lab capacity at the national level. Multiple publications from the same groups were noted in the literature review suggesting that there continued interest and support which might be the basis for a sustained programme on monitoring of POPs in water.

Studies on monitoring of POPs in surface waters were available from 30 countries within Africa, Asia-Pacific, GRULAC and selected countries in the CEE region (Figure 23). The majority were from the Peoples Republic of China (24), followed by India (11) and South Africa (9). Only one study was found for Pacific Island nations (Samoa). From a UNEP Region perspective, Africa and Asia-Pacific had the largest number of countries with monitoring studies (11 each) while GRULAC had 5.

Figure 23. Number of studies of POPs in surface waters of Africa, Asia-Pacific, and GRULAC, as well as selected countries in the CEE region.



Note: Studies in Antarctica and ship-based measurements in coastal seas and oceans are also included.

The list of institutions associated with the studies is provided in Annex 5. University chemistry and environmental science departments were responsible for the majority of the studies particularly in India, other countries in South Asia, Africa, and GRULAC. In China, institutes of the Chinese Academy of Sciences (included in the government based category) accounted for half of the studies (Table 10). University and government labs in WEOG region were involved with studies in GRULAC, South Asia, and Africa. The most active labs were Graduate School of Oceanography, University of Rhode Island, USA, the Centre RECETOX at Masaryk University in Brno, Czech Republic, the Helmholtz-Zentrum Geesthacht, Institute of Coastal Research in Germany, and the Institute of Environmental Assessment and Water Research, Spanish National Research Council, Spain. In addition to collaborating with researchers in other UNEP regions these institutes also accounted for the majority of ship-based studies.

Table 10: Regional or individual country affiliations of laboratories reporting analysis of POPs in surface waters.

	China	India	S Asia	Africa	GRULAC	CEE	WEOG	Total
University	12	7	11	18	8	7	11	74
Government	12	5	2	5	1	0	3	27
Private lab	0	0	0	0	0	1	1	2

Note: Based on the affiliation of the corresponding author and/or the identified laboratory.

6.2. Related analytical capacity

In addition to measurements of POPs in water, many studies included other matrices and other contaminants (Table 11). Studies which included sediment or air accounted for 41% and 35% of the articles. The sediments were mainly from freshwater sampling sites in Africa, GRULAC, and Asia-Pacific. The air sampling was mainly from ship-based coastal and open ocean sampling. Studies which mentioned the analysis of fish or biota tissues or the uptake of POPs by biota, accounted for 15% of the published articles. A smaller percentage of studies involved drinking water (8%) or ground water (8%) and these studies generally included assessment of the risk of human exposure to POPs via potable water. Overall, it is clear that many of the laboratories involved in studies on POPs in water had the expertise for sampling and analysis of other environmental matrices, particularly abiotic samples.

Table 11: A. Number of published articles including other media analysed in the same study that included POPs in surface waters. B. Other contaminants measured in the same study.

A. Media	Number	%		B. Other contaminants	Number	%
Sediment	53	41%		Polycyclic aromatic hydrocarbons (PAH)	21	16%
Air	45	35%		Current use pesticides (CUPs)	15	12%
Drinking water	10	8%		Phthalates	4	3%
Groundwater	10	8%		Pharmaceuticals	6	5%
Fish and other biota	19	15%		Organophosphates[1]	9	7%
				Pyrethroid insecticides	4	3%

[1]Organophosphates included insecticides and flame retardants

Note: There is overlap given that multiple media or chemical classes were included in some studies

A subset of the 129 articles on POPs in water that were reviewed in Chapter 5.1 also included measurements of other contaminants with PAHs being the most commonly reported (16%). Current use pesticides (CUPs) were measured along with POPs in 12% of the studies. The main CUPs were organophosphates, especially chlorpyrifos (proposed to be listed under the SC), and the pyrethroid insecticides. Other contaminants included phthalate ester plasticizers (3%) and pharmaceuticals (5%). For example, articles by Zhao *et al.* (2022), Nantaba *et al.* (2021) and Kandie *et al.* (2020) included phthalates and pharmaceuticals in African waters. In general, laboratories reporting CUPs were not reporting PAHs, plasticizers or pharmaceuticals ie were focussed on food or soil contamination due to pesticide use. Overall, the inclusion of other analytes indicates that a significant proportion, around 30%, of the laboratories in the Africa, Asia-Pacific and GRULAC regions to do a broader range of organic contaminants.

1.1. Interlaboratory and quality control programmes for POPs in water

General guidance for quality control procedures for water sampling and analysis programmes is provided in a report prepared by the Stockholm Convention GMP (UNEP 2021). The Bi-ennial Global Interlaboratory Assessment on Persistent Organic Pollutants has included water in its 2nd, 3rd and 4th rounds (Fiedler, van der Veen and de Boer 2021). However, only PFAS has been included to date. Nevertheless, the successful involvement of numerous laboratories in Asia-Pacific (11), CEE (2), GRULAC (1) and WEOG (25) for analysis of PFAS in water is an indication of the feasibility of an interlaboratory comparison for POPs in small volume water samples. A practical challenge would be to avoid losses of hydrophobic POPs to the walls of containers or degradation. This was less of an issue for PFAS because most (eg PFOS, PFOA, PFHxS) are water soluble and essentially undegradable in water.

The QUASIMEME (Quality Assurance of Information on Marine Environmental Monitoring in Europe) proficiency testing programme has organized an interlab comparison for chlorinated pesticides and related by products (23) and PCBs (11) in seawater using essentially the same approach as described above. The samples were of filtered Eastern Atlantic Ocean seawater and were distributed in 1L bottles. To avoid losses to container walls, the participants were asked to dilute a separately supplied standard solutions using the supplied seawater test materials to produce the spiked test materials. The final range of concentrations for the 34 analytes were in the 0.5 to 500 ng/L range. QUASIMEME also initiated a similar test programme for pentachlorophenol (PCP) in filtered seawater at concentrations in the range of 2-2000 ng/L. The seawater tests for POPs began in April 2022; results of these interlab comparison are not yet available. The relatively high cost of participation 600 Euros/sample could be a barrier for some laboratories in developing countries.

Interlaboratory studies with passive water samplers have been conducted to validate passive sampling for PCBs, pesticides and PAHs an alternative to "active" or "spot" sampling (Booij, Smedes and Crum 2017; Miège *et al.* 2012). The study by Booij, Smedes and Crum (2017), which used silicone strips, indicated that while there was considerable interlab variation, laboratories do not experience more difficulties with the analysis of passive samplers than with the analysis of biota. Therefore, an alternative to circulating water samples for POPs analysis would be to circulate passive samplers (eg silicone strips pre-spiked with performance reference compounds) that had been deployed in natural waters. This would test the ability of labs to handle the passives under laboratory conditions, simulating the process of retrieving and removing periphyton growth on the samplers, as well as the extraction and GC analysis steps. The QUASIMEME interlaboratory testing programme has organized 5 interlab comparisons of passive samplers using the approach described in Booij, Smedes and Crum (2017).

The United Nations University project "Monitoring and Management of Persistent Organic Pollutants in Asia" began in 1996, contributed to the establishment of capacity-building for POPs in water and other environmental media (Iino *et al*. 2007). The highlights of monitoring results obtained by the project's activities are described in a book available from the UN online library (UNU 2016) with several contributions including measurements in water. The results were not included in Chapter 5 because sampling was conducted prior to 2008 and full details on locations and methods were not available. Nevertheless, the programme represents another approach as it included quality assurance programme as well as analytical methodology guidance. An instrument manufacturer, Shimadzu Corporation, partnered with the UNU and was involved with providing guidance on analytical procedures and quality control protocols that suited the capacities and resources of the institutes participating in the monitoring project.

The environmental laboratories of the International Atomic Energy Agency (IAEA) Marine Environment Studies Laboratory in Monaco has supported the Stockholm Convention with interlaboratory proficiency testing for POPs in environmental samples including seawater in the Mediterranean (UNEP/Mediterranean Action Plan), the Gulf (Regional Organization for the protection of the Marine Environment - ROPME), the Black Sea (Black Sea Commission), the Red Sea - Gulf of Aden (Regional Organization for the Conservation of the Environment of the Red Sea and the Gulf of Aden - PERSGA), the South Asia Co-operative Environment Programme (SACEP) and the Pacific Region (Secretariat of the Pacific Regional Environmental Programme - SPREP) (UNEP 2019c). This agency thus provides another possible platform for implementing interlaboratory testing programmes on POPs in water.

ESTABLISHMENT OF COORDINATION MECHANISMS IN DEVELOPING COUNTRIES FOR POPS MONITORING IN WATER

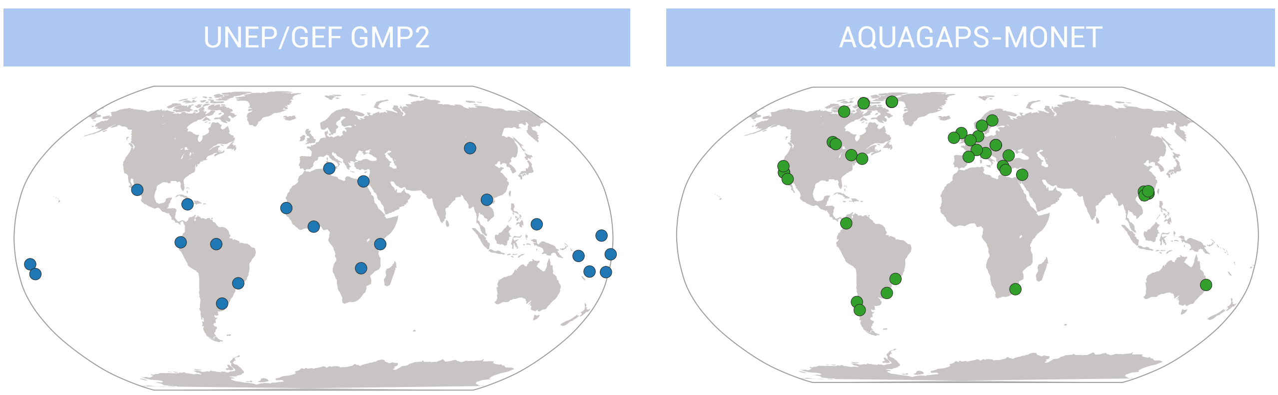
7

CHAPTER

The results presented in Chapters 5 and 6 identify lab and institutional capacity, expertise, data availability, and existing interlab programmes that could form the basis of future monitoring of POPs in water. The situation for monitoring of water differs from core media air or human milk, where a wide range of POPs have been reported under the 3rd GMP report (UNEP and Stockholm Secretariat 2021b) and the earlier reports. No formal global monitoring programmerogramme exists for POPs in water. However, for PFAS, the UNEP/GEF GMP2 Project included measurements in surface waters of 22 countries in Asia-Pacific, Africa and GRULAC and, combined with measurements from WEOG and CEE, provided the first detailed global picture of PFAS in water (Baabish, Sobhanei and Fiedler 2021) (Figure 24).

The recently completed AQUAGAPS-MONET passive sampling study has provided a limited global picture for non-polar POPs in surface waters (Lohmann *et al.* 2023). This programme included 22 sites (Africa (1), Asia-Pacific (6), GRULAC (11) and CEE (4)) regions (Figure 24).

Figure 24: Sampling sites for surface waters in the UNEP/GEF project for PFAS (Source: Baabish, Sobhanei and Fiedler 2021) and the AQUAGAPS-MONET passive sampling programme for non-polar POPs



The UNEP/GEF and the AQUAGAPS-MONET projects had similar designs following the guidance of the Stockholm Convention GMP and in order to generate globally comparable data to support the effectiveness evaluation of the Convention. The sampling media (bottles for "active" sampling of water for PFAS and silicone sheets for non-polar POPs) were prepared by a central expert lab. Volunteers in each selected location, followed a detailed sampling protocol for collection of "active" samples for PFAS analysis previously developed for the GMP (UNEP 2017). Similarly, the AQUAGAPS-MONET programme provided sampling frames and cages to hold the silicone sheets and provided guidance on handling, deployment and recovery of the passive samplers. In both programmes a single expert lab analysed all samples (PFAS: Orebro University, School of Science and Technology, Orebro, Sweden and non-polar POPs: RECETOX, Masaryk University, Brno, Czech Republic). The use of a central expert lab for global studies of POPs is generally recommended as it has been demonstrated to yield more consistent results as demonstrated recently for passive air sampling (Melymuk *et al.* 2021). It also facilitates the analysis of a consistent list of POPs including the less frequently measured chemicals identified in Table 8 and Table 9.

The central lab approach does not provide for capacity building at the national and regional level. An alternative is the long term support of individual labs within UNEP regions in terms of training and capacity for trace organics analysis. The UNU project "Monitoring and Management of Persistent Organic Pollutants in Asia" that was active between 1996 and 2016 is a possible model for the regional approach. The Bi-ennial Global Interlaboratory Assessments also have a capacity building role by testing the performance of many labs for relatively wide range of non-polar POPs in core matrices (as well as PFAS in water). Approximately 110 labs from the UNEP regions (GRULAC, Asia-Pacific, Africa and CEE) that are the focus of this report participated in the 4th Interlab assessment (Fiedler, van der Veen and de Boer 2021). While most of these labs focused on traditional core media for the interlab study they nevertheless clearly have expertise that could be applied to analysis of POPs in water samples and possibly would be able to develop local or regional collaborations for "active" water sampling or deployment of passive samplers.

Taking the above points into consideration, a future framework for water sampling and analysis at the national and subregional level would ideally be based on passive sampling. The passive samplers could be standardized by being provided by a central lab but would be analysed by individual labs. This strategy has already been used for interlab comparisons (Booij, Smedes and Crum 2017). The results would contribute to the GMP but would provide information on concentrations in water at the national level that could be useful for broader water quality assessment goals. Ideally, the participants would be labs that have previous experience on reporting data to the GMP or that routinely analyse non-polar organic contaminants. The 4th Bi-ennial Global Interlaboratory Assessment made similar recommendations for participants in lab proficiency testing. To support the water sampling framework, the Global Interlaboratory Assessments would need to be expanded to include non-polar POPs in water or to enroll participants in the QUASIMEME proficiency testing for POPs in water.

Additional support could come from the regular updates of the guidance document for the Stockholm Convention GMP, which currently has useful information on water sampling techniques and quality assurance but with a focus on PFAS (UNEP 2021b). Regional Centres of the Stockholm Convention could play a role in the water sampling and analysis framework either directly or by identifying expertise for deployment and analysis of samplers.

There is also the potential for a "citizen science" component to the water sampling programme whereby local volunteers could be identified, possibly via environmental NGOs, to deploy and retrieve passive samplers or conduct "active" sampling. A global review of citizen science projects related to water quality found that most were conducted in developed countries (North America and Europe) with only a limited number in Africa (8%), Asia (11%) and GRULAC (14%) (Capdevila et al. 2020). Nevertheless there are many examples of citizen science projects for water quality monitoring (International Institute for Sustainable Development [IISD] 2018). Guidance may be available from UNEP's citizen science programme "Citizen Data for SDG Indicator 6.3.2" (UNEP 2023b). In this regard, there would likely be common ground with the passive air sampling programme which could also involve environmentally aware members of the public **see Chapter 4.**

CONCLUSIONS AND RECOMMENDATIONS

8 CHAPTER

8.1. Air

This report has provided a snapshot of the current situation in terms of POPs reporting in air under the GMP and summarized the latest thinking on intersecting issues of national and international relevance to POPs measurements in air. This report has also reviewed and assessed available resources for enhancing POPs measurements in air and placed focus on developing countries and the application of cost-effective methods such as passive air sampling.

Large gaps in reporting have been shown for many listed POPs, especially the newer POPs due to lack of measurements (and/or analysis for specific POPs) by programmes currently reporting to the GMP. Challenges with reporting will only become more intense as additional POPs are listed and with growing awareness of future monitoring and research needs.

A revision to criteria presented in the GMP guidance document may be warranted to promote awareness and recognition of other available and credible data sets on POPs in air. This change will support the GMP and lead to better inclusivity and communication across the science-policy interface to help resolve the increasing data and information needs.

A greater level of inclusion and integration of expertise related to POPs monitoring in air will help to address national/regional POPs monitoring capacity needs for air. These changes will also better inform and address future priorities under the GMP so that it remains capable and relevant and able to adequately reflect and inform on the effectiveness of the Convention. These changes can also be linked to broader activities under the Stockholm Convention (Articles 3-15) as well as separate but related national and international issues linked to, inter alia, human health, climate change and biodiversity.

There continue to be significant data gaps in GMP reporting despite the existence of many air monitoring programmes reporting data on POPs to the GMP. These gaps include both regional/sub-regional gaps as well as almost entirely missing information for specific POPs. These challenges are expected to continue as more POPs are listed, especially in developing regions.

To take advantage of broader sources of existing data, it will be necessary to re-assess the current approaches for reporting and how data are evaluated for inclusion in the GMP. In particular, data arising from studies using PUF-PAS samplers are abundant and could support GMP reporting.

The expansion and better integration of PUF-PAS monitoring into the GMP is a cost-effective measure towards resolving data gaps for both gas-phase and particle-phase POPs; it may also lead to other co-benefits. For instance, by having a more inclusive framework under the GMP that better recognizes POPs experts in the field. This will promote improved communication and collaboration across the science-policy interface; this, in turn, can foster new and diverse teams and partnerships for enhancing POPs measurements in air and resolving information gaps. The improved air monitoring data will support model development and testing, including "top-down" approaches to better understand regional and global transport of POPs in air. Although many labs are shown to perform adequately in terms of data quality, there are definite advantages (*e.g.*, comparability of data) and efficiencies from using central labs.

This report proposes an approach for enhancing POPs monitoring capacity in developing countries to address national needs as well as regional reporting needs under the GMP of the Stockholm Convention. The proposed approach deals less with investments in new capital equipment (*e.g.*, analytical instrumentation which are expensive to purchase and operate) and has more to do with human capital and tapping into existing national/regional/global experts and opening better communication across the science-policy interface. It is believed that this more inclusive approach will lead to diverse perspectives and more informed approaches to resolving the challenges of the GMP as well as other national priorities for POPs monitoring. Through this approach, countries are not expected to do everything by themselves, recognizing that better and more pragmatic options exist and that financial resources are scarce and should be directed to more pressing matters.

The future reporting under the GMP is re-cast in a way that considers integration of "bottom-up" and "top-down" information flows. In addition, engagement of regional experts are proposed as key and essential elements of the process. In addition to improving collaboration across the science-policy interface, this more inclusive approach to GMP reporting is likely to lead to synergies across the policy-policy interface. The greater participation by experts will also foster outreach across the public-science and public-policy interfaces, and to greater awareness of monitoring and related activities under the Stockholm Convention.

8.2. Water

This report has addressed the assessment of regional initiatives and national capacities, the establishment of a sustainable interlaboratory quality control program, and suggested a national and subregional coordination framework for POPs in water. The literature review identified 129 articles on non-polar POPs in surface waters from 30 countries within Africa, Asia-Pacific, GRULAC and CEE regions and neighboring seas/oceans, from 103 institutions/agencies. This demonstrates that there is significant capacity in all four UNEP regions to undertake POPs analysis in water. However, the majority of studies were on a limited number of POPs, with the DDT and HCH groups, predominating. Analysis of a broader range of POPs in water should be encouraged although it has to be recognized that many analytes are present at picogram per liter (pg/L) concentrations that are often below the detection limits for analysis of POPs in 1L samples, the most common volume used. Passive sampling was used in 14 of the 129 studies, and generally provided lower detection limits than 1L "grab" samples, however the analyses of passives was mainly conducted by experienced well equipped laboratories. In this regard the use of GC-MS/MS for analyzing non-polar POPs should be encouraged as this instrumentation has better detection limits and greater specificity than more commonly use single quadrupole GC-MS or GC-ECD. The 4^{th} Bi-ennial Global Interlaboratory Assessment report has also recommended that labs adopt GC-MS rather than use GC-ECD for POPs analysis in tissue samples.

The combined data for POPs from the 129 articles created a dataset with 242 freshwater sampling sites and 433 marine sites totaling approximately 7400 individual results for concentrations of POPs in surface waters. This data could be useful for assessment of geo-spatial and temporal trends of POPs in water in future GMP reports. Inclusion of results for non-polar POPs in water data in regional GMP reports as part of "other media" is quite feasible, as demonstrated in the Asia-Pacific report. Comparison of geo-spatial trends of POPs concentrations at the global GMP reporting level would help to identify hot spots of contamination which are currently not identified with air and human milk.

The successful involvement of laboratories in Asia-Pacific, CEE, GRULAC, and WEOG (25) for analysis of PFAS in water (Fiedler, van der Veen and de Boer 2021) is an indication the feasibility of conducting an interlaboratory comparison for POPs in water samples. The new (2022) QUASIMEME proficiency test for non-polar POPs and PCP in water presents an opportunity to involve laboratories in these regions who prefer to use conventional 1L samples and extractions with solvents or C18 solid phase cartridges. QUASIMEME has also organized interlaboratory comparisons using passive samplers. Participation of labs in Asia-Pacific, CEE, GRULAC, and Africa in the passive sampler proficiency testing should be encouraged by funding the cost of participation. Future intercomparisons could also reach out to the laboratories analysing water samples that have been identified in this report.

The UNEP/GEF and the AQUAGAPS-MONET projects that have recently developed results for PFAS and non-polar POPs, respectively, are possible models for future monitoring projects. In both programmes a single expert lab analysed all samples and therefore these programmes had limited capacity building at the national and regional level. A future framework for water sampling and analysis at the national and subregional level would ideally be based on passive sampling with silicone samplers that are now widely accepted as offering the best performance for non-polar organics (Booij, Smedes and Crum 2017). The programme could utilize passive samplers provided by a central lab while permitting the analysis to be done by the recipient labs.

Enhancing the capacity to conduct analyses of POPs in water at the national and subregional level would connect the GMP and Regional Centres of the Stockholm Convention to other studies such as measurements in air, sediments and biota. The review of publications showed that many laboratories involved with water sampling and analysis were also involved with collection and analysis of sediment and air.

There is also the potential for a "citizen science" component to the water sampling programme whereby local volunteers could be identified, possibly via environmental NGOs, to deploy and retrieve passive samplers or conduct "active" sampling. While there are many examples of successful citizen science projects for water quality monitoring, including UNEP's citizen science programme "Citizen Data for SDG Indicator 6.3.2", they are mainly focused on standard water chemistry parameters. Thus, application to studies on POPs at ng/L and pg/L levels in water would need careful planning and volunteer training.

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ANNEXES

10.1. Annex 1: Supporting File / Database: Catalogue of POPs Measurements in Air

Table A1*:* List of institutions found to have analyzed POPs air samples since 2005.

Country	Institution
Algeria	Centre de Recherche Scientifique et Technique en Analyses Physico-Chimiques
Argentina	Universidad Nacional de Córdoba
Argentina	Universidad Nacional de Mar del Plata
Australia	Griffith University
Australia	University of Queensland
Brazil	Environmental Agency of Sao Paulo State
Brazil	Laboratório de Radioisótopos
Brazil	Sao Paulo State Environmental Company
Bulgaria	University of Sofia "St. Kl. Okhridski"
Canada	AirZoneOne Laboratories
Canada	ALS Global
Canada	Canada Centre for Inland Waters
Canada	Environment and Climate Change Canada
Canada	Meteorological Service of Canada
Canada	Royal Military College of Canada
Canada	University of Ottawa
Canada	University of Toronto
Canada	University of Toronto Scarborough
Chile	Universidad Andres Bello
Chile	Universidad Catolica de la Santisima
Chile	Universidad de Conception
China	Beijing Normal University
China	Chinese Academy of Geological Sciences
China	Chinese Academy of Sciences

China	Dalian University of Technology
China	Fudan University
China	Guangzhou Insitute of Geochemistry
China	Harbin Institute of Technology
China	Henan Normal University
China	Lanzhou University
China	Minzu University of China
China	Nankai Unviersity
China	National Research Center for Environmental Analysis and Measurement
China	National Research Center for Geoanalysis
China	Northeastern University
China	Peking University
China	Shandong Jianzhu University
China	Tsinghua University
China	University of Science and Technology of China
China	Xiamen University
China	Zhejiang University
Colombia	Universidad nacional de Colombia Sede Manizales
Colombia	Universidad Nacional de Colombia
Croatia	Institute for Medical Research and Occupational Health
Czech Republic	Masaryk University
Denmark	Aarhus University
Denmark	University of Aarhus (national Environmental Research Institute)
Estonia	Estonian Environmental Research Institute
Finland	Finnish Meterological Institute
France	University of Toulon
France	Universite de Strasbourg
Germany	Center for Environmental Research Leipzig-Halle
Germany	Eurofins GfA GmbH
Germany	Federal Maritime and Hydrographic Agency (BSH)
Germany	German Research Center for Environmental Health
Germany	GKSS Research Center, Institute of Coastal Research (Department of Environmental Chemistry)
Germany	Max Planck Institute for Chemistry
Germany	Max Planck Institute for Meteorology
Ghana	Kwame Nkrumah University of Science and Technology
Greece	Mass Spectrometry and Dioxin Analysis Laboratory, INRASTES, NCSR "Demokritos"
India	Indian Institute of Technology Kanpur
India	Ravishankar Shukla University
India	SRM Institute of Science of Technology
India	SRM University
Italy	Ca' Foscari University
Italy	Environmental Protection Agency of Apulia
Italy	Institute for Atmospheric Pollution Research
Italy	Instituto di Scienze Marine
Italy	Italian National Research Council
Italy	Sapienza University of Rome
Italy	University of Insubria
Italy	University of Siena

Italy	University of Venice
Jamaica	University of Technology
Japan	Kanazawa University
Japan	National Institute for Agro-Environmental Sciences
Japan	Yokohama National University
Jordan	University of Jordan
Republic of Korea	Gyeonggi-do Institute of Health and Environment
Republic of Korea	National Institute of Environmental Research
Republic of Korea	Pohang University of Science and Technology
Kuwait	Environment and Life Sciences research Center
Kuwait	Kuwait Institute for Scientific Research
Mexico	National Autonomous University of Mexico
Norway	NILU
Norway	Norwegian Institute for Air Research
Pakistan	Quaid-i-Azam University
Russian Federation	Institute of Geochemistry SB RAS
Russian Federation	Russian Academy of Sciences
Russian Federation	Russia's Hydrometeorology and Environmental Monitoring Agency
Russian Federation	Taifun Research and Production Association
Saudi Arabia	King Saud University
Serbia	University of Novi Sad (Faculty of Technical Sciences)
Singapore	National University of Singapore
Spain	Center for Energy, Environmental and Technological Research (Spain)
Spain	Department of Environment (Spain)
Spain	IDAEA-CSIC
Spain	Institute of Environmental Assessment and Water Research (Spain)
Spain	Institute of Organic Chemistry (Spain)
Spain	Laboratory for Microanalysis, IDAEA-CSIC
Spain	Spanish National Research Council
Spain	Universitat Rovira I Virgili
Spain	University of the Basque Country
Sweden	IVL Swedish Environmental Research Institute
Sweden	Swedish Environmental Research Institute
Sweden	Umea University
Switzerland	ETH Zurich
Switzerland	Institute for Chemical and Bioengineering
Switzerland	Swiss Federal Laboratories for Materials Science and Technology
Taiwan, Province of China	Cheng Shiu University
Taiwan, Province of China	National Central University
Taiwan, Province of China	National Cheng Kung University
Taiwan, Province of China	National Pingtung University of Science and Technology
Taiwan, Province of China	National Sun Yat-sen University
Taiwan, Province of China	National Yang Ming University
Thailand	Asian Institute of Technology
Türkiye	Bursa Uludag University
Türkiye	Dokuz Eylul University
Türkiye	Izmir Institute of Techonology
Türkiye	Selcuk University (Department of Environmental Engineering)

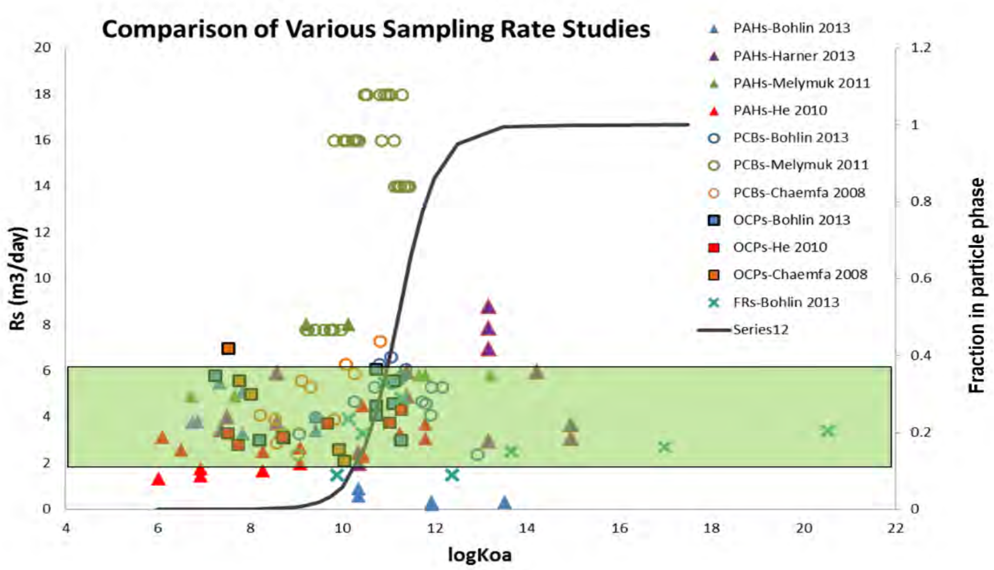
Türkiye	Uludag University
Türkiye	Yildiz Technical University
Uganda	Makerere University
United K. of G.B. & N. Ireland	Lancaster University
United K. of G.B. & N. Ireland	University of Birmingham
United K. of G.B. & N. Ireland	University of Nottingham
United K. of G.B. & N. Ireland	University of York
United States of America	Battelle
United States of America	Boise State University (Department of Civil Engineering)
United States of America	College of William and Mary
United States of America	Indiana University
United States of America	NWQL
United States of America	Oregan State University
United States of America	Rutgers University, Department of Environmental Sciences
United States of America	Simonich Environmental Chemistry Laboratory
United States of America	TRC Environmental Corporation
United States of America	University of Iowa
United States of America	University of Rhode Island
United States of America	University of South Florida St Petersburg (Department of Environmental Science)
United States of America	USGS National Water Quality Laboratory
Viet Nam	Ehime University
Viet Nam	VNU University of Science

Note: Some results may be unintentionally omitted, as not all publications explicitly stated where analysis was conducted. Where not stated, analyzing institution is assumed to be that of the primary author. Bold indicates private laboratories.

10.2. Annex 2: Characterization of PUF-PAS and SIP-PAS samplers for POPs

The PUF-PAS sampler is the most widely used passive air sampler for measuring POPs in air. Numerous calibrations of the PUF-PAS against high volume samplers have shown that sampling rates for the conventional PUF disk sampler are on the order of about 4 m³/day across almost two decades of Log Koa values (Koa = octanol–air partition coefficients) (Figure A1), spanning chemicals that exist entirely as gases and others that exist entirely on particles. This demonstrates the wide range of applicability of the PUF-PAS sampler (Harner *et al.* 2014).

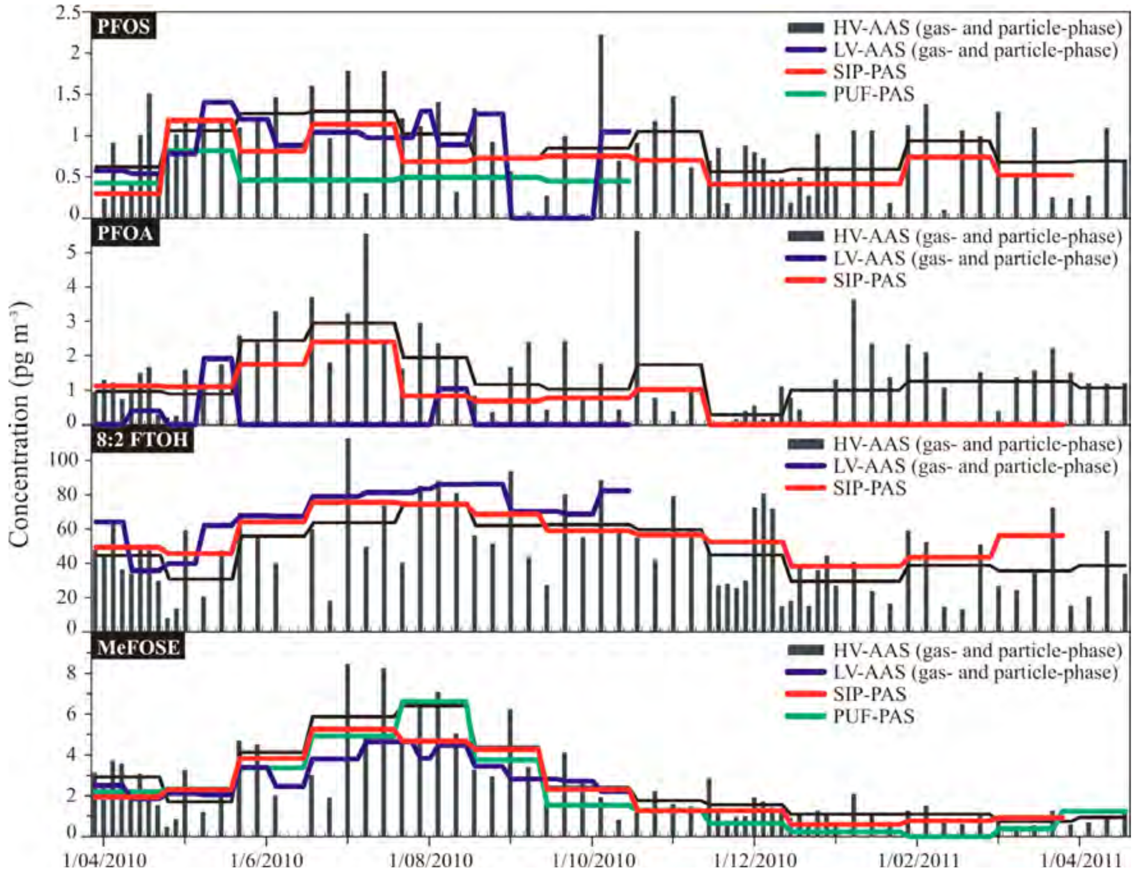
Figure A1: Summary of independent calibration studies of the PUF-PAS sampler.



Harner and co-workers have developed an Excel template tool (see Annex) to help users of PUF-PAS and SIP-PAS (introduced below) to estimate effective air sample volumes for PUF disk deployed in the field at different temperatures and for different deployment times. The template includes numerous classes of POPs and emerging chemicals, and is routinely updated.

Although the PUF-PAS can be applied for monitoring a wide range of POPs, the most volatile POPs (*e.g.* log K_{OA} values less than ~6) present a challenge as they come to equilibrium with the PUF disk during the course of typical deployment periods (*e.g.*, months), resulting in non-linear sampling. Although the GAPS template takes this into account in calculating an effective air sample volume, the sample itself is not truly time-weighted over the whole deployment period. For the most volatile POPs (*e.g.*, pentachlorobenzene, fluorotelomer alcohols) a modified version of the PUF-PAS sampler, the SIP-PAS has been developed (SIP - sorbent impregnated polyurethane foam). SIP-PAS are made by impregnating PUF with finely ground XAD-4 resin (Shoeib *et al.* 2008), which effectively enhances the sorption capacity of the sampler and allows for longer durations of the linear phase sampling period. The production of SIP-PAS has been described in the literature (Shoeib *et al.* 2008), however, they are now also commercially available and produced in a consistent manner (ANECO, Institute for Environmental Protection GmbH & Co, Germany). Figure A2 summarizes results comparing performance of SIP-PAS, PUF-PAS, low volume active sampling and high volume active sampling for different classes of perfluoroalkyl substances (Ahrens *et al.* 2013). Agreement is generally good among the different approaches and sampling methods.

Figure A2: PFOS, PFOA, 8:2 FTOH, and MeFOSE concentrations in air measured by four different sampling techniques over one year.



Note: HV-AAS (sum of gas and particle phase; integrated over 24 h (black bars) and average concentration over one month) and LV-AAS (sum of gas and particle phase; integrated over 14 days), and SIP-PAS and PUF-PAS (integrated over one month).

For more accurate estimations of the PUF-PAS sampling rate, site-specific estimates achievable through the use depurations compounds (DCs). DCs are isotopically labelled chemicals added to PUF disk prior to deployment. The loss of DCs in the PUF disk during deployment through evaporation can be directly related to the average air sampling rate for the deployment period. Higher PUF-PAS air sampling rates are generally associated with extremely windy sites (*e.g.* coastal or mountain sites) due to a wind-speed effect on the air-side mass transfer coefficient. The use of DCs increases the analytical cost and burden for users of PUF-PAS samplers so alternate methods for estimating the sampling rate are desirable.

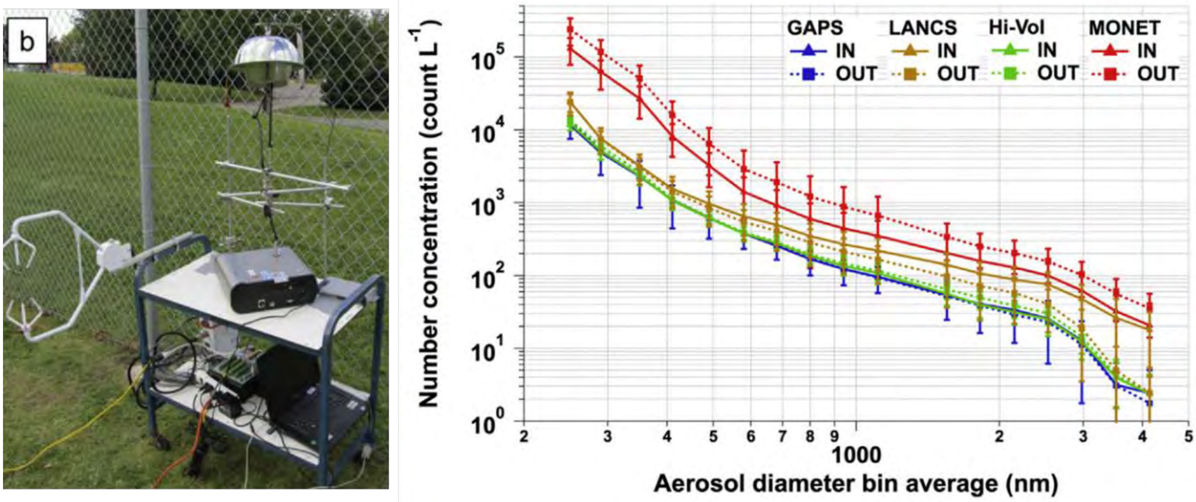
In an effort to alleviate the need to use DCs, Herkert *et al.* (2018) have applied a meteorological based model for estimate site specific wind speeds and sampling rates, doing away with the need to apply DCs. Schuster *et al.* (2021) have recently applied the Herkert model to derive site specific sampling rates and have updated 10 years of POPs monitoring data under the GAPS Network. They caution of certain conditions under which the Herkert model may not generate accurate windspeeds – for instance, in forested areas and some coastal and mountain sites. In these cases the derived wind speeds for estimating the sampling rate should be confirmed with local wind speed information, and replaced with this information if needed. Schuster *et al.* (2021) advise on how to estimate the PUF-PAS sampling rates, R, in these cases.

10.2.1.Particle-phase sampling and comparability among PUF-PAS types

In addition to sampling gas-phase POPs, the PUF-PAS sampler has been shown to effectively capture particle-phase compounds (Markovic *et al*. 2015). This is important as many POPs are associated with particles and a growing number of newly listed POPs are mainly particle-bound. Particles, including microplastics and nanoplatsics, have been shown to be an important transport vector for POPs, especially those which are added to plastics and rubber (Evangeliou *et al.* 2020; Brahney *et al.* 2021). The extent of particle-phase sampling of the PUF-PAS depends on the sampler housing design and the degree to which particles are able infiltrate the housing where PUF disk is located. The particle-phase sampling rate for different housing designs is often compared to particles collected by conventional active air samplers, which is also dependent on their inlet configuration.

Markovic *et al.* (2015, Figure A3) compared several PUF-PAS sampler housings for extent of particle sampling. They confirmed that for the GAPS-type sampler housing (Tisch Environmental, Cleaves, Ohio), particle infiltration efficiencies (derived by measuring the particle size distribution inside vs outside the sampler housings) were close to 1. We note that similar results were observed for a few other housing designs although some housing designs did show reduced particle infiltration efficiencies. In addition, the particle size distribution collected by the GAPS housing were nearly identical to that of a conventional PS-1 type active air sampler, which was also tested. This comparability of particle phase sampling between active and PUF-PAS has also been confirmed through field–based calibration measurements targeting polycyclic aromatic compounds (PACs) across multiple sites where GAPS-type PUF-PAS and PS-1 type active air sampler were co-located. Therefore, PUF-PAS samplers are able to provide similar gas- and particle phase sampling rates and comparable particle-sampling to that of conventional active air samplers.

Figure A3: Field assessment of particle-infiltration efficiency of different PUF-PAS sampler housings and PS-1 type active air sampler.



The application of the PUF-PAS for targeting particle associated species in air, allows for co-benefits for passive sampling programmes beyond just POPs. For instance, the PUF-PAS has recently been applied for measuring trace metals in air (Gaga *et al.* 2019). A new method has also been demonstrated for using PUF-PAS for mapping elemental carbon in air, which has been shown to provide comparable data to conventional method required electricity and active sampling (Zhang *et al.* 2022). The role of micro- and nano-plastics in POPs long-range transport is another growing area of research which can benefit from simple passive sampling methods using PUF-PAS.

It is important to note that other types of passive sampling substrates (*e.g.* XAD, SPMD, PE, PDMS sheets) may be less suitable for measuring particle-associated chemicals in air. Eng, Harner and Pozo (2013) have shown that particles may be lost from smoother substrates due blow-off of particles; whereas the porous surface of the PUF disk sampler allows deposited particles to be retained.

10.3. Annex 3: Search terms used in SCOPUS:

Within keywords, title or abstract and published from Jan 1, 2011 to Dec 31, 2022:

pops OR hch OR polychlorinated* OR ddt OR dde OR *chlordane OR pbde OR polybrominated OR endosulfan OR hexachlorobenzene OR heptachlor OR pentachlorobenzene

AND: Monitoring AND: water

AND NOT: *plastic OR soil OR fish OR seals OR whales OR seabirds OR eggs OR tissue OR blood OR plasma OR food OR waste* OR *plankton OR daphnia OR avian OR mammal*

Separately also

AND NOT: sediment or air or atmosphere*

AND NOT: AFFILCOUNTRY

(belgium OR canada OR “united states” OR “united kingdom” OR netherlands OR sweden OR germany OR france OR italy OR switzerland OR austria OR norway OR finland OR Australia or Spain or Portugal)

10.4. Annex 4: List of analytes reported in freshwater and marine waters, sorted by number of reports for each analyte.

Table A2: Freshwater. from Africa, Asia-Pacific, GRULAC and selected locations in the CEE region and neighboring oceans and seas.

Analyte	Media	N	Average	Median	Maximum	Minimum
4,4’-DDT	Fresh	166	604.58	1.20	79550.00	0.000E+00
γ-HCH	Fresh	162	1250.74	0.20	123703.33	0.000E+00
4,4’-DDE	Fresh	150	176.30	0.10	7200.00	0.000E+00
4,4’-DDD	Fresh	144	551.39	0.45	65030.00	0.000E+00
β-HCH	Fresh	138	255.24	0.42	10030.00	0.000E+00
α-HCH	Fresh	137	220.90	0.24	7520.00	0.000E+00
α-endosulfan	Fresh	120	238.44	0.07	14140.00	0.000E+00
Dieldrin	Fresh	109	91.69	0.12	4394.44	0.000E+00
Endrin	Fresh	103	28.93	0.22	700.00	0.000E+00
ΣDDT	Fresh	103	128.73	1.03	9790.00	0.000E+00
Aldrin	Fresh	97	163.46	0.31	7876.19	0.000E+00
Endosulfansulfate	Fresh	95	29.56	0.51	800.00	0.000E+00
ΣPCBs	Fresh	84	46.18	0.84	429.84	0.000E+00
Heptachlor	Fresh	82	178.71	2.65	4580.00	0.000E+00
Heptachlorepoxide	Fresh	80	234.22	0.04	10500.00	0.000E+00
HCB	Fresh	78	68.33	0.01	1950.00	0.000E+00
β-endosulfan	Fresh	73	1087.37	0.45	36610.00	0.000E+00
Trans-chlordane	Fresh	70	7.84	0.01	272.67	0.000E+00
d_HCH	Fresh	68	4002.17	3.60	189000.00	0.000E+00
Cis-chlordane	Fresh	62	16.86	0.01	700.00	0.000E+00
ΣHCH	Fresh	58	343.41	2.83	18570.00	0.000E+00
PCB-101	Fresh	57	8.28	1.76	80.00	0.000E+00

Table A2 continued

Analyte	Media	N	Average	Median	Maximum	Minimum
PCB-28	Fresh	54	23.42	4.05	265.93	0.000E+00
PCB-138	Fresh	53	12.66	1.98	75.49	0.000E+00
PCB-153	Fresh	52	9.09	4.03	64.15	0.000E+00
PCB-52	Fresh	52	4.85	1.06	65.00	0.000E+00
PCB-180	Fresh	48	8.91	2.19	97.30	0.000E+00
oxychlordane	Fresh	46	0.01	0.01	0.09	0.000E+00
PCB-118	Fresh	44	7.19	3.03	87.40	0.000E+00
β-Endosulfan	Fresh	39	44.69	0.00	1710.83	0.000E+00
Methoxychlor	Fresh	34	128.63	1.88	1100.00	0.000E+00
2,4'-DDT	Fresh	32	4.55	0.00	145.25	0.000E+00
Σendosulfan	Fresh	29	153.01	0.68	4165.00	0.000E+00
2,4'-DDD	Fresh	28	6.28	0.01	175.25	0.000E+00
ΣPBDEs	Fresh	28	0.19	0.06	1.19	1.100E-02
PCB-189	Fresh	26	5.63	2.00	29.00	0.000E+00
Endrinaldehyde	Fresh	25	633.99	2.90	3700.00	0.000E+00
methoxychlor	Fresh	25	9.02	0.00	225.00	0.000E+00
Trans-nonachlor	Fresh	25	0.04	0.00	0.66	0.000E+00
Cis-nonachlor	Fresh	23	0.01	0.00	0.09	0.000E+00
Dechlorane	Fresh	23	0.00	0.00	0.02	0.000E+00
HBCD	Fresh	23	0.00	0.00	0.01	0.000E+00
ΣPBDEs-209	Fresh	23	0.05	0.03	0.32	0.000E+00
PCB-105	Fresh	17	3.44	0.34	19.75	0.000E+00
4,4-DDE	Fresh	16	11.43	0.21	65.00	0.000E+00
2,4´-DDD	Fresh	14	110.47	0.05	1522.22	0.000E+00
Endrinketone	Fresh	13	42.10	5.50	200.00	3.300E+00
PCB-156	Fresh	12	1.42	0.08	5.09	0.000E+00
Σ7PCBs	Fresh	12	21.62	9.22	91.00	3.000E-02
2,4´-DDE	Fresh	11	8.27	0.01	80.00	0.000E+00
Heptachlor-epoxide	Fresh	11	87.56	7.86	722.08	0.000E+00
PCB-18	Fresh	11	10.65	0.43	94.00	4.000E-03
PCB-77	Fresh	11	0.50	0.01	3.36	0.000E+00
PCB-44	Fresh	10	6.81	0.32	28.60	0.000E+00
PCB-157	Fresh	9	0.04	0.01	0.13	0.000E+00
PCB-167	Fresh	9	0.26	0.01	2.00	0.000E+00
PCB-114	Fresh	8	0.25	0.00	2.00	0.000E+00
PCB-123	Fresh	8	0.52	0.26	3.00	0.000E+00
PCB-169	Fresh	8	0.38	0.01	3.00	0.000E+00
Σ16PCBs	Fresh	8	6.45	3.45	22.50	1.750E+00
Σchlordane	Fresh	8	6.37	0.45	42.27	0.000E+00
PCB-126	Fresh	7	0.29	0.01	2.00	0.000E+00
PCB-81	Fresh	7	0.58	0.01	4.00	0.000E+00
Trans-Nonachlor	Fresh	7	1.21	0.50	3.35	0.000E+00
2,4-DDE	Fresh	6	130.50	42.00	592.00	1.200E+01
PCB-170	Fresh	6	1.10	0.01	6.00	1.000E-03
PCB-194	Fresh	6	0.10	0.01	0.60	1.000E-03
Σ8PCBs	Fresh	6	7.59	0.50	43.22	1.000E-01
BDE-99	Fresh	5	0.25	0.04	1.04	0.000E+00

Table A2 continued

Analyte	Media	N	Average	Median	Maximum	Minimum
PCB-11	Fresh	5	0.76	0.73	1.97	8.000E-03
PCB-151	Fresh	5	1.00	0.01	5.00	5.000E-03
PCB-195	Fresh	5	0.01	0.01	0.01	0.000E+00
PCB-70	Fresh	5	0.16	0.01	0.68	0.000E+00
PCB-8	Fresh	5	1.56	1.53	3.41	3.100E-02
PeCBz	Fresh	4	0.04	0.04	0.07	1.000E-03
2,4'-DDE	Fresh	4	0.07	0.05	0.18	0.000E+00
BDE-100	Fresh	4	0.17	0.11	0.44	0.000E+00
BDE-153	Fresh	4	0.19	0.10	0.58	1.000E-03
BDE-47	Fresh	4	0.40	0.04	1.52	0.000E+00
HeptachlorepóxideA	Fresh	4	10.04	0.00	40.17	0.000E+00
Mirex	Fresh	4	4.76	0.65	17.74	0.000E+00
Σ25PCBs	Fresh	4	23.83	24.46	33.27	1.314E+01
Σ35PCBs	Fresh	4	3.61	3.51	4.25	3.165E+00
4,4-DDD	Fresh	3	28.94	4.67	77.50	4.667E+00
BDE-183	Fresh	3	0.03	0.01	0.07	0.000E+00
BDE-28	Fresh	3	0.23	0.01	0.69	1.000E-03
endrin	Fresh	3	336.28	1.39	1007.39	5.400E-02
PCB-128	Fresh	3	0.87	0.62	2.00	3.000E-03
PCB-143	Fresh	3	0.00	0.00	0.01	1.000E-03
PCB-187	Fresh	3	1.25	0.76	3.00	5.000E-03
PCB-20	Fresh	3	0.00	0.00	0.00	1.000E-03
PCB-31	Fresh	3	0.01	0.01	0.01	1.000E-03
Pentachloroanisole	Fresh	3	0.01	0.00	0.03	0.000E+00
Σ12dl-PCBs	Fresh	3	1.63	1.55	2.03	1.300E+00
Σdl-PCBs	Fresh	3	8.33	2.00	22.00	1.000E+00
2,4-DDD	Fresh	2	1.88	1.88	3.30	4.500E-01
anti-Dechlorane	Fresh	2	2.74	2.74	5.00	4.720E-01
Aldrín	Fresh	2	3350.00	3350.00	3700.00	3.000E+03
BDE-154	Fresh	2	0.01	0.01	0.03	0.000E+00
Dieldrín	Fresh	2	7510.00	7510.00	13420.00	1.600E+03
endosulfanaldehyde	Fresh	2	230.00	230.00	230.00	2.300E+02
endrinaldehyde	Fresh	2	4861.48	4861.48	9722.92	4.400E-02
endrinketone	Fresh	2	3864.18	3864.18	7728.33	2.300E-02
HCBD	Fresh	2	1.09	1.09	2.18	1.000E-03
Heptaclorepoxide	Fresh	2	1.21	1.21	1.97	4.500E-01
MCCP-C14H21Cl9	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C14H22Cl8	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C14H23Cl7	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C14H24Cl6	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C14H25Cl5	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C15H24Cl8	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C15H25Cl7	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C15H26Cl6	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C15H27Cl5	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C16H27Cl7	Fresh	2	0.00	0.00	0.00	0.000E+00
MCCP-C16H28Cl6	Fresh	2	0.00	0.00	0.00	0.000E+00

Table A2 continued

Analyte	Media	N	Average	Median	Maximum	Minimum
MCCP-C16H29Cl5	Fresh	2	0.00	0.00	0.00	0.000E+00
octachlorostyrene	Fresh	2	0.00	0.00	0.00	1.000E-03
PCB-132+153	Fresh	2	0.05	0.05	0.05	5.000E-02
PCB-158	Fresh	2	0.37	0.37	0.74	0.000E+00
PCB-209	Fresh	2	0.05	0.05	0.08	1.600E-02
PCB-37	Fresh	2	15.86	15.86	31.00	7.250E-01
PCB-49	Fresh	2	16.08	16.08	23.00	9.150E+00
PCB-66	Fresh	2	0.38	0.38	0.75	7.000E-03
PCB-74	Fresh	2	0.34	0.34	0.69	0.000E+00
SCCP-C10H14Cl8	Fresh	2	0.00	0.00	0.00	1.000E-03
SCCP-C11H15Cl9	Fresh	2	0.00	0.00	0.00	0.000E+00
SCCP-C12H17Cl9	Fresh	2	0.00	0.00	0.01	0.000E+00
SCCP-C13H20Cl8	Fresh	2	0.00	0.00	0.01	0.000E+00
Σ19PCBs	Fresh	2	99.50	99.50	116.00	8.300E+01
ΣMCCPs	Fresh	2	0.00	0.00	0.00	0.000E+00
ΣSCCPs	Fresh	2	0.06	0.06	0.11	4.000E-03
4,4-DDT	Fresh	1	0.00	0.00	0.00	1.000E-03
BDE154	Fresh	1	0.10	0.10	0.10	9.500E-02
BDE-17	Fresh	1	0.00	0.00	0.00	0.000E+00
BDE183	Fresh	1	0.16	0.16	0.16	1.600E-01
BDE-209	Fresh	1	0.01	0.01	0.01	7.000E-03
BDE28	Fresh	1	0.19	0.19	0.19	1.900E-01
BDE47	Fresh	1	0.36	0.36	0.36	3.600E-01
BDE-66	Fresh	1	0.00	0.00	0.00	1.000E-03
BDE-71	Fresh	1	0.00	0.00	0.00	0.000E+00
BDE-85	Fresh	1	0.01	0.01	0.01	7.000E-03
Cis-Heptachlorepoxide	Fresh	1	0.00	0.00	0.00	1.000E-03
Cis-Nonachlor	Fresh	1	0.04	0.04	0.04	4.300E-02
Dicofol	Fresh	1	5038.50	5038.50	5038.50	5.039E+03
endosulfanSulfate	Fresh	1	0.37	0.37	0.37	3.740E-01
EndrinAldehyde	Fresh	1	0.50	0.50	0.50	4.950E-01
HeptachlorEpoxide	Fresh	1	0.05	0.05	0.05	5.100E-02
MCCP-C14H20Cl10	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C15H22Cl10	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C15H23Cl9	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C16H25Cl9	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C16H26Cl8	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C17H27Cl9	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C17H28Cl8	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C17H29Cl7	Fresh	1	0.00	0.00	0.00	0.000E+00
MCCP-C17H31Cl5	Fresh	1	0.00	0.00	0.00	0.000E+00
Oxychlordane	Fresh	1	0.00	0.00	0.00	0.000E+00
PCB118	Fresh	1	0.00	0.00	0.00	3.000E-03
PCB-119	Fresh	1	6.00	6.00	6.00	6.000E+00
PCB138	Fresh	1	0.00	0.00	0.00	3.000E-03
PCB-166	Fresh	1	0.40	0.40	0.40	4.000E-01
PCB-168	Fresh	1	3.00	3.00	3.00	3.000E+00

Table A2 continued

Analyte	Media	N	Average	Median	Maximum	Minimum
PCB-177	Fresh	1	5.00	5.00	5.00	5.000E+00
PCB-179	Fresh	1	0.45	0.45	0.45	4.500E-01
PCB-183	Fresh	1	0.84	0.84	0.84	8.350E-01
PCB-198	Fresh	1	0.33	0.33	0.33	3.250E-01
PCB-206	Fresh	1	0.01	0.01	0.01	1.000E-02
PCB-207	Fresh	1	24.00	24.00	24.00	2.400E+01
PCB-60	Fresh	1	0.73	0.73	0.73	7.300E-01
PCB-82	Fresh	1	0.58	0.58	0.58	5.800E-01
PCB-87	Fresh	1	0.80	0.80	0.80	8.000E-01
PCB-99	Fresh	1	0.66	0.66	0.66	6.600E-01
SCCP-C10H13Cl9	Fresh	1	0.00	0.00	0.00	1.000E-03
SCCP-C10H15Cl7	Fresh	1	0.03	0.03	0.03	2.500E-02
SCCP-C10H16Cl6	Fresh	1	0.04	0.04	0.04	4.000E-02
SCCP-C11H14Cl10	Fresh	1	0.00	0.00	0.00	0.000E+00
SCCP-C11H16Cl8	Fresh	1	0.02	0.02	0.02	2.200E-02
SCCP-C11H19Cl5	Fresh	1	0.00	0.00	0.00	0.000E+00
SCCP-C12H16Cl10	Fresh	1	0.00	0.00	0.00	1.000E-03
SCCP-C12H18Cl8	Fresh	1	0.00	0.00	0.00	1.000E-03
SCCP-C12H21Cl5	Fresh	1	0.00	0.00	0.00	0.000E+00
SCCP-C13H18Cl10	Fresh	1	0.00	0.00	0.00	0.000E+00
SCCP-C13H19Cl9	Fresh	1	0.00	0.00	0.00	1.000E-03
SCCP-C13H21Cl7	Fresh	1	0.01	0.01	0.01	5.000E-03
SCCP-C13H22Cl6	Fresh	1	0.00	0.00	0.00	3.000E-03
syn-dechlorane	Fresh	1	0.79	0.79	0.79	7.860E-01
Toxaphene	Fresh	1	5.00	5.00	5.00	5.000E+00
Σ127PCBs	Fresh	1	0.07	0.07	0.07	6.600E-02
Σ14PBDE	Fresh	1	0.09	0.09	0.09	9.400E-02
Σ6PCBs	Fresh	1	3.70	3.70	3.70	3.695E+00
Σ7PBDEs	Fresh	1	4.27	4.27	4.27	4.265E+00
ΣDDD	Fresh	1	16.22	16.22	16.22	1.622E+01

Note: Average, Median, Maximum and Minimum values are given in ng/L

Table A3: Marine waters from Africa, Asia-Pacific, GRULAC and selected locations in the CEE region and neighboring oceans and seas.

Analyte	Media	N	Average	Median	Maximum	Minimum
γ-HCH	Marine	268	0.243	0.033	12.08	0.000E+00
α-HCH	Marine	267	0.233	0.026	14.50	0.000E+00
4,4'-DDD	Marine	247	0.15	0.01	11.67	0.000E+00
β-HCH	Marine	232	0.231	0.03	8.83	0.000E+00
4,4'-DDE	Marine	197	0.297	0.01	24.33	0.000E+00
4,4'-DDT	Marine	192	0.179	0.019	9.70	0.000E+00
α-endosulfan	Marine	153	0.237	0	19.83	0.000E+00
Endosulfansulfate	Marine	135	0.185	0	13.60	0.000E+00
β-endosulfan	Marine	128	0.073	0	4.10	0.000E+00
Σendosulfan	Marine	128	0.001	0	0.02	0.000E+00
HCB	Marine	124	0.014	0.003	0.97	0.000E+00
δ-HCH	Marine	110	0.281	0.08	4.10	0.000E+00

Table A3 continued

Analyte	Media	N	Average	Median	Maximum	Minimum
Trans-chlordane	Marine	74	0.014	0.001	0.16	0.000E+00
Cis-chlordane	Marine	70	0.013	0.001	0.17	0.000E+00
Heptachlor	Marine	64	0.052	0	1.60	0.000E+00
ΣPCBs	Marine	59	1.139	0.003	33.91	0.000E+00
PeCBz	Marine	51	0.002	0	0.03	0.000E+00
ΣDDT	Marine	43	1.017	0.002	18.00	0.000E+00
PCB-138	Marine	41	0.797	0.001	30.91	0.000E+00
4,4-DDE	Marine	40	0	0	0.01	0.000E+00
PCB-28	Marine	38	0.025	0.001	0.47	0.000E+00
PCB-52	Marine	38	0.196	0.001	6.59	0.000E+00
PCB-118	Marine	36	0.005	0	0.16	0.000E+00
BDE-47	Marine	35	0.001	0	0.01	0.000E+00
BDE-99	Marine	35	0.001	0	0.01	0.000E+00
BDE-100	Marine	33	0	0	0.00	0.000E+00
Dieldrin	Marine	33	0.236	0.001	3.10	0.000E+00
BDE-153	Marine	32	0	0	0.00	0.000E+00
BDE-154	Marine	32	0	0	0.00	0.000E+00
BDE-85	Marine	32	0	0	0.00	0.000E+00
PCB-153	Marine	32	0.051	0.002	0.91	0.000E+00
PCB-18	Marine	32	0.028	0.001	0.85	0.000E+00
PCB-206	Marine	32	0	0	0.00	0.000E+00
PCB-209	Marine	32	0	0	0.00	0.000E+00
Heptachlorepoxide	Marine	31	0.001	0	0.01	0.000E+00
PCB-101	Marine	31	0.196	0.002	5.76	0.000E+00
Aldrin	Marine	30	0.265	0	2.80	0.000E+00
PCB-8	Marine	30	0.01	0.002	0.26	0.000E+00
Σ7PCBs	Marine	30	0.006	0.003	0.03	1.000E-03
BDE-183	Marine	28	0	0	0.00	0.000E+00
BDE-66	Marine	28	0	0	0.00	0.000E+00
Endrin	Marine	28	0.383	0	6.20	0.000E+00
ΣPBDEs	Marine	28	0.227	0	4.07	0.000E+00
PCB-44	Marine	25	0.178	0	4.42	0.000E+00
PCB-180	Marine	24	0.065	0.001	1.52	0.000E+00
ΣHCH	Marine	24	1.203	0.008	8.50	1.000E-03
Mirex	Marine	21	0	0	0.00	0.000E+00
Methoxychlor	Marine	20	0.037	0	0.70	0.000E+00
Pentachloroanisole	Marine	20	0.003	0.001	0.04	0.000E+00
2,4'-DDE	Marine	18	0.014	0	0.24	0.000E+00
Oxychlordane	Marine	18	0	0	0.00	0.000E+00
2,4'-DDD	Marine	17	0.021	0	0.14	0.000E+00
BDE-28	Marine	17	0	0	0.00	0.000E+00
2,4'-DDT	Marine	16	0.016	0.001	0.18	0.000E+00
β-Endosulfan	Marine	16	1.884	0	19.00	0.000E+00

Table A3 continued

Analyte	Media	N	Average	Median	Maximum	Minimum
2,4´-DDD	Marine	15	0.008	0.002	0.03	0.000E+00
PCB-189	Marine	15	0.045	0.002	0.63	0.000E+00
BDE28	Marine	15	0	0	0.00	0.000E+00
HBB	Marine	15	0	0	0.00	0.000E+00
PCB-66	Marine	15	0.002	0	0.01	0.000E+00
HeptachlorEpoxideB	Marine	13	0.001	0	0.00	0.000E+00
Dechlorane	Marine	12	0.022	0.001	0.22	0.000E+00
PCB-3	Marine	11	0	0	0.00	0.000E+00
toxaphene(P-26)	Marine	11	0	0	0.00	0.000E+00
toxaphene(P-50)	Marine	11	0	0	0.00	0.000E+00
toxaphene(P-62)	Marine	11	0	0	0.00	0.000E+00
Dicofol	Marine	10	0.009	0.011	0.01	2.000E-03
Trans-Nonachlor	Marine	10	0	0	0.00	0.000E+00
Cis-Nonachlor	Marine	9	0	0	0.00	0.000E+00
PCB-187	Marine	7	0.006	0.002	0.03	0.000E+00
PCB-195	Marine	7	0.001	0.001	0.00	0.000E+00
HeptachlorEpoxideA	Marine	6	0	0	0.00	0.000E+00
PCB-170	Marine	6	0.003	0.001	0.01	0.000E+00
endosulfanaldehyde	Marine	5	0.003	0.003	0.00	3.000E-03
endosulfanketone	Marine	5	0	0	0.00	0.000E+00
Isodrin	Marine	5	0	0	0.00	0.000E+00
PCB-105	Marine	5	0.001	0	0.00	0.000E+00
PCB-126	Marine	5	0.002	0.001	0.01	0.000E+00
PCB-128	Marine	5	0.001	0	0.00	0.000E+00
PCB-156	Marine	5	0.001	0	0.00	0.000E+00
PCB-167	Marine	5	0.001	0	0.00	0.000E+00
PCB-169	Marine	5	0.001	0	0.00	0.000E+00
PCB-81	Marine	5	0.001	0	0.00	0.000E+00
α-HBCD	Marine	5	0.001	0	0.00	0.000E+00
β-HBCD	Marine	5	0	0	0.00	0.000E+00
γ-HBCD	Marine	5	0.001	0	0.00	0.000E+00
Σ22PCBs	Marine	5	1.373	1.21	2.23	7.150E-01
BDE-209	Marine	4	0	0	0.00	0.000E+00
Cis-Heptachlorepoxide	Marine	4	0.004	0.003	0.01	3.000E-03
methoxychlor	Marine	4	0	0	0.00	0.000E+00
octachlorostyrene	Marine	4	0	0	0.00	0.000E+00
oxychlordane	Marine	4	0	0	0.00	0.000E+00
PCB-157	Marine	4	0.001	0	0.00	0.000E+00
PCB-77	Marine	4	0.001	0	0.00	0.000E+00
Trans-Heptachlorepoxide	Marine	4	0	0	0.00	0.000E+00
Σ8PBDEs	Marine	4	0.004	0.004	0.01	3.000E-03
anti-Dechlorane	Marine	3	0.004	0.002	0.01	1.000E-03
Endrinaldehyde	Marine	3	0.8	0	2.40	0.000E+00

Table A3 continued

Analyte	Media	N	Average	Median	Maximum	Minimum
Endrinketone	Marine	3	1.233	0	3.70	0.000E+00
HeptachlorEpoxide	Marine	3	2.367	2	3.80	1.300E+00
PCB-11	Marine	3	0.003	0	0.01	0.000E+00
PCB-114	Marine	3	0	0	0.00	0.000E+00
PCB-123	Marine	3	0	0	0.00	0.000E+00
syn-dechlorane	Marine	3	0.002	0.002	0.00	2.000E-03
ΣChlordane	Marine	3	3.7	3.1	5.10	2.900E+00
2,4´-DDE	Marine	2	0	0	0.00	0.000E+00
2,4´-DDT	Marine	2	0.001	0.001	0.00	0.000E+00
4,4´-DDD	Marine	2	0.001	0.001	0.00	0.000E+00
4,4´-DDE	Marine	2	0.001	0.001	0.00	0.000E+00
4,4´-DDT	Marine	2	0.001	0.001	0.00	0.000E+00
PCB-149	Marine	2	0.614	0.614	1.22	9.000E-03
toxaphene(P26)	Marine	2	0.001	0.001	0.00	0.000E+00
toxaphene(P50)	Marine	2	0.003	0.003	0.01	1.000E-03
toxaphene(P62)	Marine	2	0.007	0.007	0.01	1.000E-03
PCB-110	Marine	1	0.001	0.001	0.00	1.000E-03
PCB-132	Marine	1	0.001	0.001	0.00	1.000E-03
PCB-141	Marine	1	0.16	0.16	0.16	1.600E-01
PCB-151	Marine	1	0.003	0.003	0.00	3.000E-03
PCB-158	Marine	1	0	0	0.00	0.000E+00
PCB-17	Marine	1	0.001	0.001	0.00	1.000E-03
PCB-171	Marine	1	0	0	0.00	0.000E+00
PCB-177	Marine	1	0.001	0.001	0.00	1.000E-03
PCB18	Marine	1	0.2	0.2	0.20	2.000E-01
PCB-183	Marine	1	0.001	0.001	0.00	1.000E-03
PCB-191	Marine	1	0	0	0.00	0.000E+00
PCB194	Marine	1	2.3	2.3	2.30	2.300E+00
PCB-194	Marine	1	0	0	0.00	0.000E+00
PCB-201/199	Marine	1	0	0	0.00	0.000E+00
PCB-205	Marine	1	0	0	0.00	0.000E+00
PCB-208	Marine	1	0	0	0.00	0.000E+00
PCB-31	Marine	1	0.495	0.495	0.50	4.950E-01
PCB-31+28	Marine	1	0.001	0.001	0.00	1.000E-03
PCB-33	Marine	1	0.001	0.001	0.00	1.000E-03
PCB-49	Marine	1	0	0	0.00	0.000E+00
PCB-70	Marine	1	0.001	0.001	0.00	1.000E-03
PCB-74	Marine	1	0	0	0.00	0.000E+00
PCB-82	Marine	1	0	0	0.00	0.000E+00
PCB-87	Marine	1	0	0	0.00	0.000E+00
PCB-95	Marine	1	0.002	0.002	0.00	2.000E-03
PCB-99+101	Marine	1	0.01	0.01	0.01	1.000E-02
Σdl-PCBs	Marine	1	0.059	0.059	0.06	5.900E-02

10.5. Annex 5: UN region, country, individual publications and analytical laboratory affiliation reporting POPs in water

Table A4: Publications from 2011 to 2022 reporting on POPs in water

UN Region	Country		Analytical lab
Africa	Egypt	(Shalaby *et al.* 2018)	National Research Center, Cairo, Egypt; Agricultural Biochemistry Department, Faculty of Agriculture, Zagazig University, Zagazig, Egypt
Africa	Egypt	(Said *et al.* 2015)	National Institute of Oceanography and Fisheries, Alexandria, Egypt
Africa	Ethiopia	(Kassegne *et al.* 2020)	Department of Environmental, Water and Earth Sciences, Tshwane University of Technology, Pretoria, South Africa
Africa	Ethiopia	(Deribe 2018)	Norwegian Institute for Agricultural and Environmental Research (Bioforsk), Chemistry and Pesticide Section, Norway
Africa	Ghana	(Gariba *et al.* 2022)	Pesticide Residue Laboratory of the Ghana Standards Authority
Africa	Kenya	(Ndunda, Madadi and Wandiga 2018; Ndunda and Wandiga 2020)	Department of Chemistry, School of Physical Sciences, University of Nairobi, P.O. Box 30197, Nairobi 00100, Kenya
Africa	Kenya	(Lisouza, Owuor and Lalah 2020)	Department of Pure and Applied Chemistry, Masinde Muliro University, P.O. Box 190, Kakamega 50100, Kenya
Africa	Kenya	(Musa *et al.* 2011)	Kegati Aquaculture Research Center, Kenya Marine and Fisheries Research Institute, P.O. Box 3259 - 40200, Kisii, Kenya
Africa	Nigeria	(Afolabi, Adeyinka and Adebisi 2023)	Chemical Engineering, Department, Mangosuthu University of Technology, Durban, South Africa
Africa	Nigeria	(Unyimadu, Osibanjo and Babayemi 2018a; Unyimadu, Osibanjo and Babayemi 2018b)	Department of Chemical and Food Sciences, College of Natural and Applied Sciences, Bells University of Technology, Km 8, Idiroko Road, Benja Villa, Ota 1015, Nigeria
Africa	Nigeria	(Akan *et al.* 2015)	Department of Chemistry, University of Maiduguri, Maiduguri, Borno State, Nigeria
Africa	Nigeria	(Ezemonye, Ogbeide and Tongo 2015)	Ecotoxicology and Enviornmentla Forensics Laboratory, Dept Animal and Environmental Biology, University of Benin, Nigeria
Africa	Nigeria	(Ogbeide, Tongo and Ezemonye 2015)	Ecotoxicology and Environmental Forensics Laboratory, University of Benin, Benin City, Nigeria
Africa	South Africa	(Olisah *et al.* 2019)	Department of Pure and Applied Chemistry, University of Fort Hare, Alice 5700, South Africa
Africa	South Africa	(Amdany *et al.* 2014)	Research Centre for Toxic Compounds in the Environment (RECETOX), Masaryk University,
Africa	South Africa	(Yahaya *et al.* 2017)	SAMRC Microbial Water Quality Monitoring Center, University of Fort Hare, Alice 5700, South Africa;
Africa	South Africa	(Adeyinka *et al.* 2018)	School of Chemistry and Physics, College of Agriculture, Engineering and Sciences, University of KwaZulu-Natal, Westville Campus, 4000 Durban, South Africa
Africa	South Africa	(Adeyinka *et al.* 2019)	School of Chemistry and Physics, College of Agriculture, Engineering and Sciences, University of KwaZulu-Natal, Westville Campus, 4000 Durban, South Africa
Africa	South Africa	(Gakuba *et al.* 2018)	School of Chemistry and Physics, University of KwaZulu-Natal, Westville Campus, Private Bag 45001, Durban 4000, South Africa
Africa	South Africa	(Gakuba *et al.* 2015)	School of Chemistry and Physics, University of KwaZulu-Natal, Westville Campus, Private Bag 45001, Durban 4000, South Africa
Africa	South Africa	(Rimayi, Odusanya and Chimuka 2022)	University of the Witwatersrand, School of Chemistry, Johannesburg, South Africa
Africa	Sudan	(Nesser *et al.* 2016; Nesser *et al.* 2020)	Department of Crop Protection, Faculty of Agriculture, University of Khartoum, Shambat, Sudan
Africa	United Republic of Tanzania	(Mwevura *et al.* 2021)	Department of Sciences, State University of Zanzibar, P O Box 146, Zanzibar, United Republic of Tanzania

Table A4 continued

UN Region	Country		Analytical lab
Africa	United Republic of Tanzania	(Hellar-Kihampa *et al.* 2013)	Government Chemists Laboratory in Dar es Salaam, United Republic of Tanzania - for GC-ECD analysis
Africa	United Republic of Tanzania	(Zhao *et al.* 2022)	Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences (NIGLAS, Nanjing, China)
Africa	Togo	(Mawussi *et al.* 2014)	Ecole Supérieure d'Agronomie, Université de Lomé, 1515, Lomé, Togo
Africa	Tunisia	(Necibi *et al.* 2015)	Departement de Physique, Chimie et Procedes, Institut Superieur des Sciences et Technologies de l'Environnement de Borj Cedria,Borj Cedria, Tunisia
Africa	Tunisia	(Necibi and Mzoughi 2020)	High Institute of Environmental Sciences and Technologies of Borj Cedria, Environmental Sciences and Technologies Laboratory, University of Carthage, Hammam Lif, Tunisia
Africa	Tunisia	(Zaghden *et al.* 2022)	Laboratory of Environmental Bioprocesses, Centre of Biotechnology of Sfax, BP 1177, 3018 Sfax, Tunisia
Africa	Uganda	(Omwoma *et al.* 2019)	State Key Laboratory of Environmental Chemistry and Ecotoxicology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P. O. Box 2871, 18 Shuangqing Road, Haidian District, Beijing 100085, People's Republic of China
Asia-Pacific	Antarctica	(Bhardwaj *et al.* 2019; Bhardwaj and Jindal 2020)	Amity Institute of Environmental Toxicology, Safety and Management (AIETSM), Amity University, Sector-125, Noida, Uttar Pradesh 201303, India
Asia-Pacific	Bangladesh	(Habibullah-Al-Mamun *et al.* 2019)	Faculty of Environment and Information Sciences, Yokohama National University, 79-9 Tokiwadai Hodogaya, Yokohama, Kanagawa 240-8501, Japan
Asia-Pacific	China	(Cao *et al.* 2021)	National Engineering Laboratory for Lake Pollution Control and Ecological Restoration, State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing
Asia-Pacific	China	(Wu *et al.* 2020)	College of Marine Ecology and Environment, Shanghai Ocean University, Shanghai 201306, China
Asia-Pacific	China	(Bai, Ruan and van der Hoek 2018)	Department of Hydrosciences, School of Earth Sciences and Engineering, Nanjing University, 163# Xianlin Road, Nanjing 210023, China
Asia-Pacific	China	(Gao *et al.* 2020)	Ministry of Natural Resources of the People's Republic of China Key Laboratory for Polar Science, Polar Research Institute of China, Shanghai, 200136
Asia-Pacific	China	(Li, Li and Liu 2015)	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing
Asia-Pacific	China	(Zhao *et al.* 2018)	Key Laboratory for Ecological Environment in Coastal Area (SOA), National Marine Environmental Monitoring Center, China, Dalian 116023, PR China
Asia-Pacific	China	(Sun *et al.* 2017)	Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, China
Asia-Pacific	China	(Cui, Wei and Wang 2017)	Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074,China
Asia-Pacific	China	(Wei, Tadesse and Wang 2019)	Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences,Wuhan
Asia-Pacific	China	(Wang *et al.* 2018)	Key Laboratory of Pollution Processes and Environmental Criteria of Ministry of Education, Nankai University, Tianjin 300071, Chin
Asia-Pacific	China	(Yang *et al.* 2021)	Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment, College of Environment and Ecology, Chongqing University, Chongqing 400030, PR China
Asia-Pacific	China	(Ren *et al.* 2017)	Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research,Chinese Academy of Sciences, Beijing, 100101, China
Asia-Pacific	China	(Zheng *et al.* 2020)	Ministry of Natural Resources Key Laboratory for Polar Sciences, Polar Research Institute of China, Shanghai, China
Asia-Pacific	China	(Liu, Zheng and Liu 2020)	School of Environmental Science and Engineering, Xiamen University of Technology, Xiamen, China
Asia-Pacific	China	(Huang *et al.* 2021)	School of Environmental Studies, China University of Geosciences, Wuhan
Asia-Pacific	China	(Li *et al.* 2017)	Shanghai Key Laboratory of Atmospheric Particle Pollution and Prevention, Institute of Atmospheric Sciences, Department of Environmental Science and Engineering, Fudan University, Shanghai,
Asia-Pacific	China	(Chen *et al.* 2022)	State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Wuhan 430078, China

Table A4 continued

UN Region	Country		Analytical lab
Asia-Pacific	China	(Chen *et al.* 2021)	State Key Laboratory of Reproductive Medicine, Center for Global Health, School of Public Health, Nanjing Medical University, Nanjing 211166, China
Asia-Pacific	China	(Liu *et al.* 2015)	State Key Laboratory of Biogeology and Environmental Geology, School of Environmental Studies, China University of Geosciences, Wuhan 430074, China
Asia-Pacific	China	(Lin *et al.* 2015)	State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002,China
Asia-Pacific	China	(Shen, Wu and Zhao 2017)	State Key Laboratory of Lake and Environmental Sciences, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
Asia-Pacific	China	(Zhi, Zhao and Zhang 2015)	State Key Laboratory of Lake Science and Environment Research, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, PR China
Asia-Pacific	China	(Chen *et al.* 2020)	State Key Laboratory of Pollution Control and Resources Reuse, College of Environmental Science and Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, People's Republic of China
Asia-Pacific	China	(Cheng *et al.* 2021)	State Key Laboratory of Reproductive Medicine, Center for Global Health, School of Public Health, Nanjing Medical University, Nanjing 211166, China
Asia-Pacific	China	(Yu *et al.* 2014)	State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China
Asia-Pacific	India	(Mondal *et al.* 2018)	Department of Agricultural Chemicals, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur-741252, Nadia, West Bengal, Indi
Asia-Pacific	India	(Chakraborty *et al.* 2016; Khuman and Chakraborty 2019; Rex and Chakraborty 2022)	Department of Civil Engineering, SRM Institute of Science and Technology, Kancheepuram district, Tamil Nadu 603203, India
Asia-Pacific	India	(Arisekar *et al.* 2019)	Department of Fish Quality Assurance and Management, Fisheries College and Research Institute, Tamil Nadu Fisheries University, Tuticorin, 628 008, Tamil Nadu, India
Asia-Pacific	India	(Hashmi and Menon 2015)	Department of Forensic Science, School of Sciences, Gujarat University, Gujarat, India
Asia-Pacific	India	(Kumarasamy *et al.* 2012)	Department of Marine Science, Bharathidasan University,Tiruchirappalli 620 024 Tamil Nadu, India
Asia-Pacific	India	(Kurakalva and Aradhi 2020)	Geochemistry Group, CSIR-National Geophysical Research Institute, Hyderabad, Telangana, India
Asia-Pacific	India	(Najam and Alam 2015)	Himalayan Bioresource Technology, Palampur, India
Asia-Pacific	India	(Kumar *et al.* 2012)	National Reference Trace Organics Laboratory Central Pollution Control Board East Arjun Nagar Delhi,110032 India
Asia-Pacific	India	(Sharma *et al.* 2015)	Norwegian Institute for Water Research (NIVA), Gaustadalleen 21, Oslo, 0349, Norway
Asia-Pacific	Indian Ocean	(Huang *et al.* 2014)	State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
Asia-Pacific	Indonesia	(Oginawati *et al.* 2022)	Faculty of Civil and Environmental, Institut Teknologi Bandung, Study Programme of Environmental Engineering, Jl Ganesa No 10, Bandung, Indonesia
Asia-Pacific	Indonesia	(Khozanah *et al.* 2022)	Research Center for Oceanography, National Research and Innovation Agency, Jl Pasir Putih 1, Ancol Timur, Jakarta Utara, Indonesia
Asia-Pacific	Iran (Islamic Republic of)	(Ghadrshenas *et al.* 2023)	Department of Environment, Bushehr Branch, Islamic Azad University, Bushehr, Iran (Islamic Republic of)
Asia-Pacific	Iran (Islamic Republic of)	(Jorfi *et al.* 2022)	Department of Environmental Health Engineering, Ahvaz Jundishapur University of Medical Sciences, A Department of Environmental Sciences, Faculty of Natural Resources, University of Zabol, Sistan P.O. Box 98615-538, Iran hvaz, Iran (Islamic Republic of)
Asia-Pacific	Iran (Islamic Republic of)	(Ranjbar Jafarabadi *et al.* 2019)	Department of Environmental Sciences, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Mazandaran, Iran (Islamic Republic of)
Asia-Pacific	Iran (Islamic Republic of)	(Behrooz, Esmaili-Sari and Chakraborty 2020)	Department of Environmental Sciences, Faculty of Natural Resources, University of Zabol, Sistan P.O. Box 98615-538, Iran (Islamic Republic of)
Asia-Pacific	Japan	(JMoE 2020a)	Ministry of Environment of Japan
Asia-Pacific	Pakistan	(Eqani *et al.* 2012)	Environmental Biology and Ecotoxicology Laboratory, Department of Environmental Sciences, Quaid-i-Azam University, Islamabad, 45320, Pakistan
Asia-Pacific	Pakistan	(Baqar *et al.* 2017)	State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, China

Table A4 continued

UN Region	Country		Analytical lab
Asia-Pacific	Pakistan	(Sohail *et al.* 2022)	University of Rhode Island, 215 South Ferry Road, Narragansett, RI 02882, USA
Asia-Pacific	Philippines	(Navarrete *et al.* 2018)	Department of Environmental Science, Ateneo de Manila University, Loyola Heights, 1108 Quezon City, Philippines
Asia-Pacific	Philippines	(Santiago and Rivas 2012)	Natural Sciences Research Institute, University of the Philippines, 1101 Diliman, Quezon City, Philippines
Asia-Pacific	Samoa	(Welch *et al.* 2019)	Department of Earth Sciences, School of Ocean Earth Science and Technology, University of Hawaií Manoa, Honolulu, HI,
Asia-Pacific	Singapore	(Wang and Kelly 2017; Zhang, Bayen and Kelly 2015)	Department of Civil and Environmental Engineering, National University of Singapore, Singapore
Asia-Pacific	Thailand	(Sangchan *et al.* 2014)	Biogeophysics, Institute of Soil Science and Land Evaluation, University of Hohenheim, 70593 Stuttgart, Germany
Asia-Pacific	Viet Nam	(Nguyen *et al.* 2019a; Nguyen *et al.* 2019b)	Institute of Environmental Science, Engineering, and Management,Industrial University of Ho Chi Minh City, 12 Nguyen Van Bao, GoVap District, Ho Chi Minh City, Viet Nam
Asia-Pacific	Viet Nam	(Quynh and Toan 2019)	Trade Union University, 169 Tay Son Street, Hanoi, Viet Nam
Central&Eastern Europe	Albania	(Dano, Neziri and Halili 2016)	ECCAT Laboratory of Environmental Consulting, Chemical Analysis and Testing, Tirana, Albania
Central&Eastern Europe	Kazakhstan	(Shen *et al.* 2021)	State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing, 210008, China
Central&Eastern Europe	Kazakhstan	(Snow *et al.* 2020)	Water Sciences Laboratory, 202 Water Sciences Laboratory, University of Nebraska, Lincoln, NE, 68583, USA
Central&Eastern Europe	Türkiye	(Aydin *et al.* 2013)	Department of Environmental Engineering, Necmettin Erbakan University, 42060 Konya, Türkiye
Central&Eastern Europe	Türkiye	(Aydın and Albay 2022)	Faculty of Aquatic Sciences, Department of Marine and Freshwater Resources Management, Istanbul University, Istanbul 34130, Türkiye
Central&Eastern Europe	Türkiye	(Sevin *et al.* 2018)	Faculty of Veterinary Medicine, Department of Pharmacology and Toxicology, Ankara University, 06110 Ankara, Türkiye
Central&Eastern Europe	Türkiye	(Karadeniz and Yenisoy-Karakaş 2015)	Faculty of Science and Art, Department of Chemistry, Abant Izzet Baysal University, 14280 Bolu, Türkiye
Central&Eastern Europe	Türkiye	(Oğuz and Kankaya 2013)	Department of Biology, Faculty of Science, Yuzuncu Yil University, 65080 Van, Türkiye
Central&Eastern Europe	Türkiye	(Karacık *et al.* 2013)	Istanbul Technical University, Faculty of Naval Architecture and Ocean Engineering, 34469 Maslak,Istanbul, Türkiye
Central&Eastern Europe	Türkiye	(Erkmen *et al.* 2013)	Aksaray University, Faculty of Science and Letters, Department of Biology, Aksaray-68100, Türkiye
GRULAC	Argentina	(Williman *et al.* 2017)	Facultad de Ciencias de la Alimentación, Universidad Nacional de Entre Ríos, Concordia, Argentina
GRULAC	Argentina	(Ballesteros *et al.* 2014)	Instituto de Investigaciones Marinas y Costeras (CONICET-UNMdP), Universidad Nacional de Mar del Plata,
GRULAC	Argentina	(Miglioranza *et al.* 2013)	Lab. de Ecotoxicología y Contaminación Ambiental, FCEyN, Universidad Nacional de Mar del Plata, Funes 3350, 7600, Mar del Plata, Argentina
GRULAC	Argentina	(Vazquez *et al.* 2022)	Laboratorio de Ecotoxicología y Contaminación Ambiental,Facultad de Ciencias Exactas y Naturales (FCEyN), Universidad Nacional de Mar del Plata
GRULAC	Brazil	(de Figueiredo, Chiavelli and Costa 2013)	Chemistry, State University of Maringa, Maringa-Parana, Brazil
GRULAC	Brazil; Offshore Brazil	(Lohmann *et al.* 2013; Meire *et al.* 2016; Lohmann *et al.* 2021)	University of Rhode Island, Graduate School of Oceanography, South Ferry Rd., Narragansett, RI, 02882, USA
GRULAC	Chile	(Luarte *et al.* 2022)	Department of Environmental Chemistry, Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Barcelona,
GRULAC	Mexico	(Sierra-Cortés *et al.* 2019)	Universidad Autónoma Metropolitana-Unidad Xochimilco, Calzada del Hueso 1100, Col. Villa Quietud, 04960 Ciudad de México, México
GRULAC	South Atlantic	(Luek *et al.* 2017)	Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, USA

Table A4 continued

UN Region	Country		Analytical lab
GRULAC	Chile	(Pozo *et al.* 2022)	Facultad de Ingeniería y Tecnología, Universidad San Sebastian, Lientur 1457, Concepcion, Chile
GRULAC	Chile	(Placencia and Contreras 2018)	Department of Environmental Chemistry, Faculty of Sciences, Universidad Católica de la Santísima Concepción, Casilla 297, Concepción, Chile
GRULAC	Puerto Rico	(Rodríguez-Sierra *et al.* 2019)	Department of Environmental Health, Graduate School of Public Health, Medical Sciences Campus, University of Puerto Rico, PO Box 365067, San Juan 00936-5067, Puerto Rico and University of Rhode Island, Graduate School of Oceanography, South Ferry Rd., Narragansett, RI, 02882, USA
WEOG	Antarctic	(Galbán-Malagón *et al.* 2013)	Institute of Environmental Assessment and Water Research, Spanish National Research Council (IDAEA-CSIC), Barcelona, Catalonia 08034, Spain
WEOG	Antarctica & Arctic Greenland	(Bigot *et al.* 2016; Bigot *et al.* 2017)	Environmental Futures Research Institute and‡ School of Environment, Griffith University, 170 Kessels Rd, Nathan, Queensland 6 4111, Australia; ALS Environmental, Burlington ON Canada and
WEOG	Antarctica	(Vecchiato *et al.* 2015)	University of Siena, Department of Physical Sciences, Earth and Environment, Via Laterina 8, 53100 Siena, Italy
WEOG	Arctic Ocean	(Carrizo *et al.* 2017)	Department of Environmental Science and Analytical Chemistry (ACES), Stockholm University, 10691 Sweden
WEOG	Central Pacific Ocean	(Li *et al.* 2020; Zhang and Lohmann 2010)	Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, 02882, USA
WEOG	Aegean Sea, Black Sea, South Atlantic	(Lammel *et al.* 2015; Lammel *et al.* 2017; Sobotka *et al.* 2021)	Research Centre for Toxic Compounds in the Environment, Masaryk University, Brno, Czech Republic
WOEG	Atlantic Ocean; NW Pacific; North Sea	(Xie *et al.* 2011a; Xie *et al.* 2011b; Zhong *et al.* 2012; Zhong *et al.* 2014)	Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research GmbH, Institute of Coastal Research
WOEG	Great Lakes	(Venier *et al.* 2014)	School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana 47405, USA

10.6. Annex 6: Excel spreadsheet with results from 129 peer reviewed articles published from 2011 to 2022

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