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D2.3. Data gaps: Workshop report

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ArcSolution

Arctic pollution in a One Health perspective
from complex challenges to sustainable solutions

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Executive summary

Deliverable 2.3 is a Workshop report on data gaps. D2.3 is based on task 2.3 “Data and information needs for a One Health approach” (responsible partners: **lead WP2 UOULU**, NORD, AU, NMBU, AKn, NRI, UGR, UiT, AMAP). This activity will seek and identify crucial gaps and provide a plan of how to fill these in close collaboration with WPs 3-5. This work is based on the outcomes of T2.1 (Integration of perspectives into a One Health approach) and T2.2 (Identification of priorities at the study locations) and their consequent deliverables D2.1 (1st One Health model) and D2.2 (Description of Citizen Science Projects). Additionally, some data gaps were identified before the project, in the ArcSolution project application phase. Furthermore, D2.3 is based on Data gaps workshops held in April and May 2025 for ArcSolution partners. Following the proposed strategy, some of the gaps will be closed in the specialized work packages throughout the project in the WPs: WP3 (Arctic pollution in a climate change context), WP4 (Impacts under different scenarios), and WP5 (Solutions: Resilience, adaptation, mitigation). All this work will feed back to developing the localized One Health framework created in WP2 in collaboration with other WPs. This deliverable represents the identified data gaps, and a plan to fill the gaps is provided.

1 Introduction

ArcSolution project produces a new locally anchored and integrated One Health framework, which is based on different knowledge sources that consider local concerns, priorities, and needs in the context of pollution at the ArcSolution study locations in Northern Finland, Northern Norway, Greenland, Svalbard, and Mackenzie delta area, Canada. In addition, the Faroe Islands have been added to the study locations in March 2025. ArcSolution is built on a community-based participatory framework, and knowledge is built together with local actors from the study locations. This means that various knowledge sources, including local, traditional, and Indigenous knowledge, and knowledge produced in citizen science (CS) projects, are included and incorporated into the scientific work. Through this co-creation process, the project will analyze the pollutant situation in a climate change context, study pollution impacts on ecosystems and human health, develop solutions, and synthesize the results for the ArcSolution One Health framework.

In Deliverable 2.3 with the lead of WP2 (ArcSolution One Health Framework), project partners will define crucial data gaps and a plan to fill in some of them in specialized work packages (WP3: Arctic pollution in a climate change context; WP4: Impacts under different scenarios; and WP5: Solutions: Resilience, adaptation, mitigation). D2.3. is based on task 2.3: Data and information needs for a One Health approach (responsible partners: **UOULU**, NORD, AU, NMBU, AKn, NRI, UGR, UiT, AMAP). Task 2.3 will focus on identifying gaps in data and knowledge based on the results of Tasks 2.1 (Integration of perspectives into a One Health approach) and 2.2 (Identification of priorities at the study locations), and their consequent deliverables D2.1 (1st One Health model) and D2.2 (Description of citizen science projects). Besides the work done for deliverables, data gaps have already been identified before the project in the ArcSolution project application. Furthermore, D2.3. is a report from the two gap analysis workshops conducted online on 25.4.2025 and 16.5.2025. In the workshops, WP leads presented gaps from the perspective of their work packages. Information specialists from the Oulu University Library made SciVal and VOSviewer analyses based on the existing research collected in D2.1. Also, AMAP summary reports have been utilized for this work.

2 Identification of data gaps

2.1 ArcSolution project application

ArcSolution started from a high level of a priori knowledge of pollution in the Arctic. Much of that knowledge, among others, was retrieved from AMAP summary reports on pollution impacts in the Arctic (see AMAP references from Appendix 1). AMAP process, through its international convention, include remarks on the data usage. AMAP process needs to be followed in ArcSolution with corresponding solution for data ownership. In the ArcSolution project application, the following research gaps were identified (Table 1).

Table 1 Identified research gaps in the ArcSolution project application and ongoing work in the project.

Topic	Gap	Work on-going (X)
One Health	One Health approach has mainly focused on Arctic communities with traditional lifestyles and dependence on traditional food. Gaps in other types of Arctic communities, such as **more urban areas, are missing**.	**X**
Human health	**Lack of human health data from Longyearbyen** and human **exposure data for microplastics and chemicals**.	**X**
Plastics, microplastics, plastic additives	Significant knowledge gaps in the **transport of plastic particles** and the potential leaching of **plastic additives**. Gap on effects of plastic and plastic additives on **Arctic wildlife.**	X (in planning)
Per- and polyfluoroalkyl substances (PFAS)	Persistent Organic Pollutants (POPs) and Polychlorinated Biphenyls (PCBs) have been studied widely, but the situation **regarding PFAS** is more complex and **less studied.**	X (in planning)
Chemicals of emerging Arctic concern (CEACs), microbial contaminants	CEACs have been identified, but their impacts on **ecosystems and health** are largely unknown. Chemical and **microbial contaminants** pass from the environment to animals and humans and back to the environment. These **interconnections are poorly** understood.	X (in planning)
Local emissions	Knowledge of the type and extent of **local emissions** is incomplete and limited. Waste disposal, wastewater discharge, infrastructures (airports, hospitals), and their emissions.	X (in planning)
Drinking water	**Not typically been studied** in the Arctic, but it is a potential exposure source to pollutants (PFAS, CEACs).	**X**
Key pathogens in the environment-wildlife-human health continuum	Potential transmission of **pathogenic and zoonotic bacteria** and their resistant genes between humans, animals, and the Arctic environment	X (in planning)

2.2. WP2 Deliverable 2.1. 1st One Health model

In D2.1. "1st One health model", already published scientific knowledge, traditional and Indigenous knowledge, and knowledge from first consultation meetings held in four study locations were collected and presented. Tables 2 and 3 show the volume of existing research and the areas lacking research, marked with pink colour.

Table 2 Existing published local, traditional, and Indigenous knowledge for study locations.

Location (Number of publications)	Environmental health - Pollution	Wildlife health – Pollution & Infectious diseases	Human health - Pollution	Drinking water and sewage water
Longyearbyen and Svalbard (N=25)[a]	+++[b] 11/25	++ 6/25	++ 9/25	++ 8/25

Consultation meeting, identified concerns	Wastewater, sewage, pollution, tourism, climate change	Visible plastics in wild-life, pollution, climate change, water safety, infectious diseases	Water and air quality, dump site, pollutants, microplastics	Wastewater
Nuuk and Eastern Greenland (N=11) [a]	+ 5/11	++ 7/11	+ 4/11	- 0/11
Consultation meeting in Nuuk, identified concerns	Sewage, solid waste management, contaminants, plastic on shore	Sewage, solid waste management, fishing nets	Food sovereignty, sewage, clean water, infectious diseases, plastics, solid waste management	Sewage
Tromsø and Skjervøy (N=10)[a]	+ 5/10	+ 3/10	- 0/10	+ 2/10
Consultation meeting, identified concerns	Drinking water, sewage, local contaminated sites and leakages from them, microplastics in wastewater	Landfill pollution, health of fish	-	Sewage
Inari (N=4) [a]	+ 3/4	+ 1/4	- 0/4	+ 1/4
Consultation meeting, identified concerns	Lakes and rivers, plastics, metals, radiation, emission and pollution from snowmobiles, air traffic, mining, wastewater	Health of fish, ticks, health of reindeer herds, huskies (waste and noise)	Noise and light pollution, poor water quality in one river, climate change (thinning ice)	Wastewater and environmental health
Mackenzie Delta area and Great Slave Lake area (N=10) [a]	++ 7/10	++ 9/10	++ 6/10	+ 5/10

[a] The detailed methodological description can be found in D2.1. Pink colour: showing lacking research areas based on our semi-quantitative analysis.
[b] Volume of existing information; - no information + little information ++ some information +++ lots of information ++++ studied extensively

Table 2 shows that most local and traditional knowledge from study locations was produced in Longyearbyen and Svalbard, with 25 identified studies from all One Health aspects. Eleven studies from Greenland (Nuuk, Eastern Greenland) were focused primarily on wildlife, but no studies on drinking water or sewage were found. Studies from Tromsø and Northern Norway (n=10) concerned environmental and wildlife health, with no detected studies related to the health of humans. Overall, there is a great research gap in the Inari area, with only four detected studies, none focusing on human health. Ten studies were mapped from Canada covering all One Health dimensions, but fewer studies were about drinking water and sewage issues.

Table 2 also summarizes the findings from consultation meetings held in four study locations. Longyearbyen's findings show that water issues were a cross-cutting concern for all One Health dimensions. Other concerns were pollution in general, climate change, (micro)plastics, and infectious diseases. In **Nuuk,** sewage was of concern in all One Health dimensions. Also, solid waste management, contaminants, plastic on shore, fishing nets, food sovereignty, and infectious diseases were brought up. Issues of concern in **Tromsø** were drinking water, sewage, local contaminated sites and leakages from them, microplastics in wastewater, landfill pollution, and fish health. Human health concerns did not come across from Tromsø or Longyearbyen meetings. Local people from **Inari** brought up worries about the health of lakes, rivers, and fish, (micro)plastics, heavy metals, radiation from Russia, emission and pollution from snowmobiles, air traffic, mining, wastewater, ticks, the health of reindeer, and huskies (waste and noise). Noise and light pollution come across as a human health issue. Climate change and thinning ice were a worry.

Table 3 Existing scientific knowledge from study sites.

Location (Number of publications)	Environmental health - Pollution	Wildlife health – Pollution & Infectious diseases	Human health - Pollution	Drinking water and sewage water
Longyearbyen and Svalbard (N=101)[a]	++++ [b]	++++	+	++
Nuuk and Eastern Greenland (N=30)[a]	++	++ (Nuuk) ++++ (East Greenland)	+++	-
Tromsø (N=28)[a]	+	++	+++	-
Inari (N=7)[a]	+	+	+	+
Mackenzie Delta area (N=74) and Great Slave Lake area (N=34)[a]	+++	+++	+++	-

[a] The detailed methodological description can be found in D2.1. Pink colour: showing lacking research areas based on our semi-quantitative analysis.
[b] Volume of existing information; - no information + little information ++ some information +++ lots of information ++++ studied extensively

Table 3 summarizes volumes of the existing scientific knowledge from the study sites and indicates the research and data gaps. Altogether, 274 studies were found using our search methods from the study sites (see more in D2.1). Table 3 shows the trends in data concerning publication volumes within each One Health dimension. Most studies (n=101) were from Longyearbyen and Svalbard. Environmental and wildlife health in relation to pollution was well studied. There were fewer studies on pollution's impact on human health.

Thirty studies from Nuuk and Eastern Greenland were included. Many studies from East Greenland on wildlife health exist, and human health has also been studied. No studies on drinking or sewage water were identified, showing a gap in research. Studies from the Tromsø area (n=28) were mostly about human health, while there is a lack of research on clean water and sewage water. Fewer studies were identified from Inari (n=7), showing knowledge gaps within all One Health dimensions. Mackenzie Delta area (n=74) and Great Slave Lake area (n=34) are extensively studied, but there were gaps in the scientific research on zoonoses and plastics, and on drinking water and sewage water.

2.3. WP2 Deliverable 2.2. Description of Citizen Science Projects

Deliverable 2.2. "Description of citizen science projects" presented the theoretical and methodological basis for citizen science (CS) as a research approach. The deliverable mapped and described previous and ongoing CS studies conducted in ArcSolution study locations. A detailed description of the methodology for mapping and the information about the studies can be found in D2.2. Based on that analysis, we showed the number of CS projects already done in our study locations, and the results also show where and in which topics CS was not conducted (Table 4)

Table 4 Citizen science (CS) projects published in study locations with identified gaps.

Study location	No. of past CS projects	Studied topics	Gaps
Svalbard / Longyearbyen	11	Beach litter, CS with tourists in cruises/vessels, wildlife monitoring.	Studies associated with human health. Sewage water. Projects at schools.
Greenland	10	CS with local hunters, fishers, and locals on wildlife and natural resources. Work on sea, ice, and permafrost.	Studies associated with human health. Sewage water. Projects at schools.
Tromsø and Northern Norway	9	Beach litter, water pollution, CS with cruise tourists, nature observations (floods, droughts, landslides, snow, ice, water sources, weather), wildlife monitoring.	Studies associated with human health. Projects at schools.
Inari, Finland	5	Microplastics in lake water (not labelled as CS).	Studies associated with human health. Wildlife health. Sewage water. Projects at schools.
Mackenzie Delta and Great Slave Lake, Canada	5	Aquatic ecosystems, permafrost.	Studies associated with human health. Projects at schools.

From five study locations, 40 CS studies/activities were detected. Most studies (n=11) were conducted in the **Svalbard area**, and pollution-related topics were beach litter, CS conducted with tourists in cruises/vessels on plastics and debris, and wildlife monitoring- There were no studies associated with human health aspects or sewage water. One CS project conducted at schools was identified, focusing on beach debris. In **Greenland**, CS was performed with local hunters, fishers, and locals on wildlife and natural resources. Also, CS was conducted on sea, ice, and permafrost. The school project was about beach litter source identification. There was a lack of studies associated with human health and sewage water.

Likewise, studies from the **Tromsø and Northern Norway** area were mostly about beach litter and water pollution, and CS was conducted with cruise tourists on debris. Also, nature observations (floods, droughts, landslides, snow, ice, water sources, weather) and wildlife monitoring studies were found. One school project was about air quality. Studies associated with human health and sewage were lacking.

Five studies from Inari / Northern Finland were identified, showing a lack of CS studies. One of the studies was about microplastics in lake water, but studies associated with human health, wildlife health, and sewage water were missing. One school project was about phenological phenomena in subarctic biomes. Five CS studies on pollution from **the Mackenzie Delta and Great Slave Lake area** were found, and they were about aquatic ecosystems and permafrost. Two of them were conducted with school pupils. Studies associated with human and wildlife health were missing.

D2.2. included also discussion about ethics in ArcSolution project, especially in the context of citizen science projects. Citizen science, like any research activities in ArcSolution, need throughout ethical considerations, including informed consent procedures, data quality and integrity issues, questions about data sharing, intellectual property, and conflicts of interest (Resnik et al., 2015). The ownership and re-use of the data needs to be discussed, and ethical statements needs to be requested and followed (see more D2.2). When working in the Arctic in ArcSolution, Indigenous research ethics needs to be considered along with the national ethical recommendations. According to the Indigenous ethical guidelines, Indigenous Peoples owns the research data they are involved in.

2.4. Gaps workshops

Two online workshops were held with the following agendas:

Workshop 25.4.2025. In this workshop, details of the content of D2.3 was introduced. The gaps identified by WP2 and ArcSolution partners for D2.1 and D2.2 were presented and discussed (see chapters 2.2 and 2.3 in this deliverable), and the outline for the second workshop was planned and agreed upon.

Workshop 16.5.2025. In the second workshop, WP leads were invited to present data gaps from the perspective of their work packages. WP2 introduced the gaps found based on D2.1. and D2.2., and SciVal and VOSviewer analysis. WPs 3-4 had prepared slides to show the identified gaps. All WP-leads provided text on the gaps. In the end, a discussion was held on a plan for filling the data gaps.

2.4.1. WP2 SciVal and VOSviewer analyses

With the help of an information specialist from UOULU Library, we conducted SciVal and VOSviewer analyses of the scientific knowledge articles, which were identified and mapped in the D2.1"1st One Health model". Of the scientific articles identified in D2.1., 217 were published in the Scopus database and used for SciVal and VOSviewer analyses. DOIs of the publications (n=217) were searched, and the following Figures were produced through the data analysis. Publication share by subject area (Fig 1) shows that most publications were from environmental sciences (67.0%), followed by Social Sciences (17.0%) and Earth and Planetary Sciences (12.8%).

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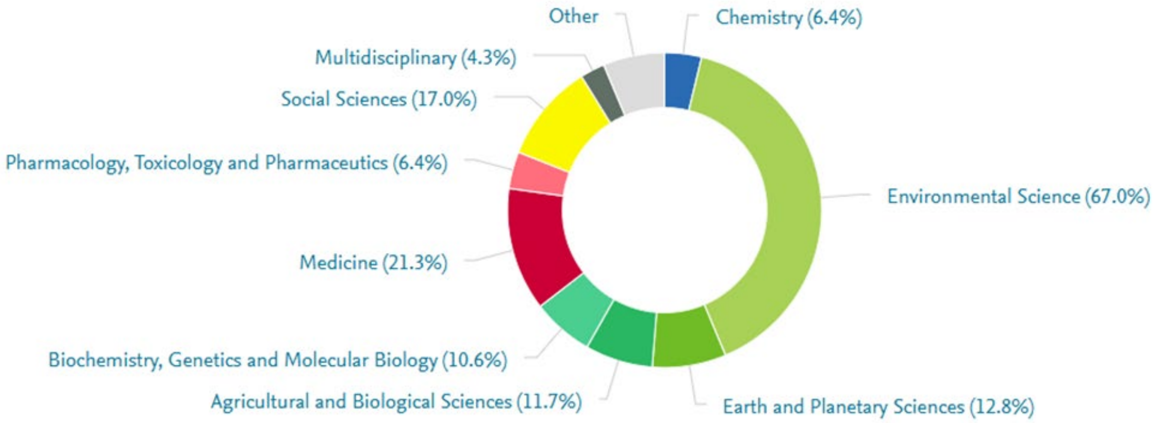

Figure 1 Publication share (%) by subject area in 2019-2025 (n=217).

Figure 2 includes the words that have an occurrence (frequency of a word) at least 5 times in the data corpus. There are loose terms on the map, and this is because the larger connections are described first. According to the Figure 2, there is a lot of research on environmental monitoring and pollution and water pollution. On the other hand, there is very little information about zoonotic and infectious diseases. The figure also shows a lack of research on (micro)plastics and collaboration with Indigenous peoples.

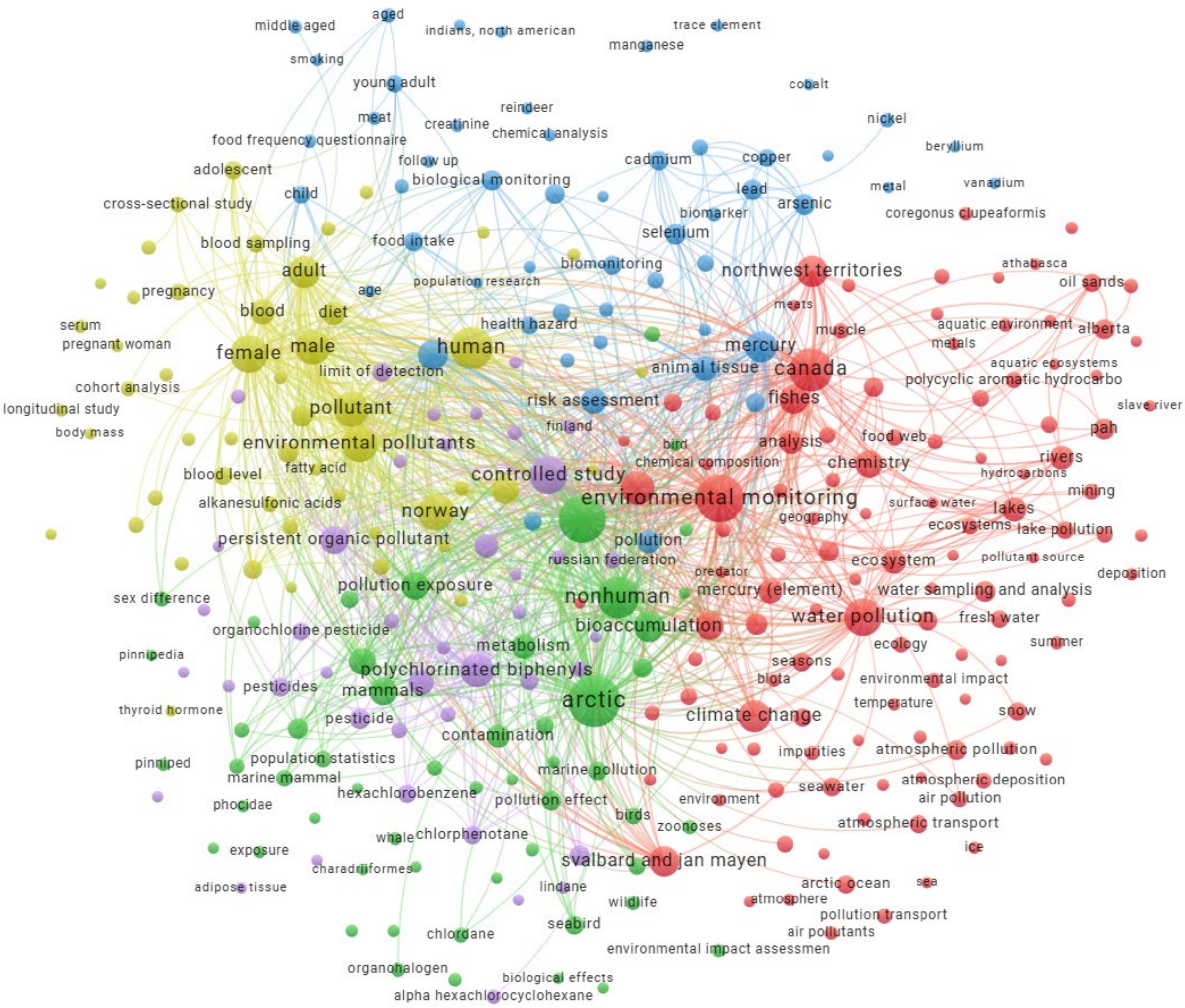

Figure 2 VOSviewer image of the index words of existing scientific publications from ArcSolution study locations (based on n=200 articles).

Colours describe the connections between terms. VOSviewer divides the terms into clusters. That is, words of the same colour appear together in the publications. Different coloured terms have connections with each other, but connections are stronger with those of the same colour.

2.4.2. WP3 data gaps

WP3 "Arctic pollution in a climate change context" identified several gaps from three different areas; Chemicals of Emerging Arctic Concern, Climate change, and local pollution.

(1) Chemicals of Emerging Arctic Concern (CEACs)

Contaminant monitoring in the Arctic has traditionally concentrated on POPs, regulated under the United Nations Stockholm Convention on POPs. In recent years, hundreds of new chemicals have been reported in Arctic samples using non-target screening techniques (e.g., Sørensen et al., 2023; Zhu et al., 2024). These detections warrant follow-up regarding confirmation, quantification, and more extended studies in other media than initially reported. AMAP report (AMAP, 2017) identified several general knowledge gaps. Despite the rapid developments in the field of CEAC identification, the knowledge gaps reported are still valid.

Gaps of CEACs:

- **Human exposure** data is scarce; very little on hazards. The limitations in chemical domains of non-target screening approaches (Hollender et al., 2023), new studies might report more CEACs. More identifications using non-target screening *in silico* approaches and other expanded screening approaches (AMAP 2017)
- **Spatial and temporal trends of CEACs**[1](AMAP 2017)
- **Effect data missing** (AMAP 2017)
- Connection with **human biomonitoring** studies (AMAP 2017)
- Impacts of **climate change**[2] (AMAP 2017)

(2) Effects of climate change

Climate change leads to complex changes in Arctic environments that affect the fate of contaminants in several ways, e.g., many processes are temperature dependent, such as the transformations of chemicals and their partitioning between media. Changes in the physical environment are likely to influence contaminant transport to the Arctic and intra-Arctic distribution patterns. The melting of the cryosphere leads to the release of previously stored POPs and CEACs. Changes in ecosystem structures affect contaminant accumulation and exposure in complex and highly dynamic ways. Finally, climate change might favor human activity in the Arctic, with potentially increased local use of chemicals. The state of knowledge was summarized in AMAP (2021a), which included an extensive list of knowledge gaps.

Gaps related to climate change (AMAP 2021a)

- Understanding **complexity**. Climate change affects contaminants in the physical environment and ecosystems.
- **Limited quantitative understanding**, e.g., higher temperatures will likely lead to more degradation and more volatilization – which process predominates?
- Observations of correlations without **knowledge of causality**
- Greater use of **local and Indigenous knowledge**
- **Local sources** of contaminants

(3) Local pollution and emissions

Human activities in the Arctic include the use of chemicals, which might lead to local emissions. As the focus on Arctic pollution has been on POPs, which are, by definition, transported over long distances, locally emitted POPs and CEACs have received little attention. Potential local pollution sources include, but are not limited to, industry/mining, shipping, waste handling, wastewater discharge, energy supply, infrastructure (such as airports), and the general use of consumer products. Airports have often been associated with the use of per-/polyfluoroalkyl substances (PFAS) in firefighting foams, also in the Arctic (Ahrens et al., 2023). The AMAP POP EG currently assesses the issue of local sources in a series of review papers in *Environmental Science: Advances*.

Preliminary identifications of knowledge gaps include (AMAP, forthcoming):

- The extent of contaminant releases with **thawing permafrost**
- The **role of riverine transport**, including contaminant inputs from settlements on rivers
- Data on POPs and CEACs in **wastewater discharges** for most parts of the Arctic

[1] Temporal trends of CEACs are included in a recently started AMAP assessment. However, it is limited by the data availability for CEACs.
[2] This was addressed in AMAP (2021a).

- **Airports** as sources of pollutants on the pan-Arctic scale
- Contamination from **landfills and other waste disposal sites**
- Projections of future developments on **local use and emissions** of POPs and CEACs

(4) Human health and pollution identified gaps for research

Table 5 Data gaps identified in AMAP 2021 report on Human Health in the Arctic 2021 (AMAP 2021c). Summary for Policy-makers.

Topic	Gap
Routes of exposure	Food security, co-production of knowledge with Indigenous communities, gender- and age-based differences in consumption, sources of exposure for PBDEs and PFASs
Biomonitoring	Pregnant women, time-trends for POPs, metals and chemicals of emerging concern, seasonality in sampling (traditional foods)
Health impacts	Cohort studies, links between exposures and health impacts, effects of contaminants on pregnant women, fetuses, and infants, mixtures of POPs and their impact on reproductive health and the immune system
Risk assessment	Better identification of the sources of contamination, improving the process of risk assessment
Interdisciplinary research	One Health, health impacts of contaminants and zoonotic infections on wildlife and humans, lifetime contaminant accumulation, lifetime exposure to zoonotic pathogens
Actions to reduce health risks	Communication strategies on health for different communities (social media, etc.), comparing health strategies across the Arctic to identify best practices

(5) Other gaps

- Since the main human exposure to POPs has occurred via animals that have accumulated POPs, there has been little attention **on other sources of exposure, such as drinking water, store-bought food, the indoor environment,** etc. These may be relevant exposure sources for some CEACs.
- Another consequence of the research and monitoring focus on biomagnifying POPs is a **lack of information on contaminants in lower trophic-level animals**. This can be important for ecosystem health.
- There is generally little knowledge on **the effects of contaminants**, especially CEACs, **for both humans and ecosystems.** Monitoring studies show a complex co-exposure situation with likely cases of mixture toxicity, which are not understood.
- **Plastic pollution** in the Arctic. Plastic particles can contain many chemical additives to ensure certain functions or properties (Fauser et al., 2022). We have little information on the leaching of these chemicals from plastic particles to the surrounding environment, including the stomachs of animals that have swallowed plastics.
- Pollution has been recognized as a significant contributor to ecosystem degradation, negatively impacting biodiversity. However, it has often been overlooked compared to other environmental factors. The United Nations Environmental Programme (UNEP) highlights this issue in their report: Pollution Action: The Missing Link in Biodiversity Protection. (UNEP 2023) Despite its importance, our understanding of the connections between pollution and biodiversity, particularly in Arctic ecosystems, remains limited.

2.4.3. WP4 data gaps

WP4 “Impacts under different scenarios” identified the following data gaps.

Specific data gaps and plan to fill those by WP4 in ArcSolution project:

- A need for a critical review of the **toxicity of PFAS, Hg, plastics (and additives),** including an *in silico* docking and read-across. This includes combining effect-directed analyses and non-target screening for new chemicals.
- A need for assessing **zoonoses and antibiotic resistance genes (ARGs) in wildlife and humans at all four study sites.** This includes whole-genome sequencing of bacteria, viruses, and gut microbiomes and quantification of the transfer between wildlife and humans. This also includes risks of health effects. This may include **sled dogs**, **cod,** and **reindeer** across study sites.
- Knowledge gaps in **certain marine and terrestrial species** regarding **biological effects on wildlife and fish, including necropsy, tissues and blood plasma, pathology,** and **immune markers about reproduction and endocrine effects**. These may be closed looking at cod, sled dogs, and reindeer, including owners and herders.
- A need to study the effects of **food webs' multiple stressors,** including climate change, pollution, and diseases.
- Knowledge gaps in the framework of the triple planetary crisis, including **habitat changes, exposure, and risks that need to be closed using various modeling tools of food web dynamics, species migrations, and toxicity of plastics**. These knowledge gaps may be closed using polar bear food webs, toothed whales (hunting statistics), and humans in East Greenland, the only study site from which such a time series is available.

Knowledge gaps in the Arctic on wildlife in general:

New information from effects studies on Arctic species has resulted in significant new insights into the risks of biological effects on Arctic wildlife from exposure to environmental contaminants. **Considerable knowledge gaps remain regarding the following:**

- Biological and toxicological effects of Organohalogenated Contaminants (OHCs), **Hg,** and, in particular, **CEACs** that are now being reported in Arctic biota. These knowledge gaps include **concentration thresholds for biologically relevant health effects and toxic threshold endpoints used to develop research questions**. **Integrating wildlife and human health assessments** can improve knowledge regarding the **combined effects of contaminant exposure and natural stressors** (e.g., infectious and zoonotic diseases) and how **multiple stressors** are **directly and indirectly influenced** in a changing Arctic, especially **in connection with climate change.**

There is a need for new methods and approaches, including:

- The expansion of *in vitro* experimental approaches
- Studies on the individual and combined effects of single compounds and chemical mixtures
- Increased use of *silico* modelling to better predict biological effects on the population and ecosystem levels

Specific knowledge gaps and information deficiencies in the Arctic:

- Certain Arctic regions, such as Russia, **Fennoscandia,** and Alaska, are not adequately represented in monitoring wildlife and fish exposure and effects. Greater attention needs to be given to access to data on hunting quotas and taking care of relevant species.
- **Invasive and migratory wildlife and fish species,** including killer whales and capelin (*Mallotus villosus*), are not represented or are under-represented in Arctic monitoring and research addressing biotic changes due to the changing Arctic climate.
- Further **pan-Arctic harmonization** is required concerning target species, sampling frequency and season, and methods for measuring contaminants, associated biomarkers, and biological endpoints applicable to effects assessment.
- **Need for increased communication and collaboration with local and Indigenous Peoples.**
- **A multi-stressor framework** is needed to assess the effects within a changing Arctic.
- **Data compilations on OHC and Hg exposure levels and trends on wildlife and fish populations**, and **observed climate change-related variables** (e.g., sea ice loss).
- A need to **establish and refine concentration thresholds for biologically relevant health effects in (Arctic) wildlife and fish**.
- **Physical-chemical and industrial production data** are required for newer chemicals of emerging Arctic concern.
- Effects need to be assessed in relation to spatial and temporal variation in **dietary pathways of exposure.** Determining the combined effects of contaminant exposure and natural stressors is also necessary.
- Need for **better identification of cumulative and interactive effects thresholds of contaminant exposure, including (i)** routine analysis of ancillary ecological metrics together with OHC and Hg studies, **(ii)** simultaneous consideration of the multiple mechanisms by which global climate change and contaminant interactions can occur, **(iii)** targeted research on species known to be sensitive to both global climate change and contaminants, and **(iv)** studies linking these changes to changes in major impact parameters such as immune and reproductive function and development, particularly at the population level. Environmental chemists studying contaminant levels in biotic and abiotic media, eco(toxico)logistics, and indigenous peoples of the Arctic could have a greater impact by working together to consider the combined impacts of these changes on contaminant exposures in Arctic marine and terrestrial biota.

Gaps on zoonosis

The ongoing change of the Arctic environment highlights current knowledge gaps and that we should prepare for **emerging zoonoses**. The warming Arctic climate influences long-range transport and biomagnification of industrial chemicals as well as pathogens to the Arctic, which has implications for human, animal and environmental health i. e., One Health. **Monitoring Arctic diseases has largely been neglected**, and knowledge of their **interactive effects with climate change and contaminant exposure** are much needed **to propel the One Health concept and its gains**. The lack of studies in the Arctic may be partly because of a much lower human density at northern latitudes. This should, however, not be a sole determinant for attention - particularly when taking into consideration fast and difficult-to-control global diseases and pandemic alertness/risk assessment. (See more detailed description of gaps related to zoonosis at Appendix 1).

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2.4.4. WP5 data gaps

WP5 "Solutions, resilience, adaptation and mitigation" identified several gaps. The Arctic is increasingly impacted by CEACs, including PFAS, Hg, and microplastics. These pollutants reach the region through long-range atmospheric and oceanic transport and local sources such as wastewater discharge, household products, and imported goods. The extreme climate, remoteness, and infrastructure limitations of Arctic communities pose unique challenges for pollution control. Knowledge gaps related to PFAS; HG and Microplastics, as well as cross-cutting challenges are next presented.

(1) PFAS (Per- and Polyfluoroalkyl Substances)

Knowledge Gaps

- **Environmental fate and transport**: Limited understanding of how PFAS behave in Arctic conditions, including their persistence in frozen soils and snowpack (Adlard et al., 2024; Hansen et al., 2024; Landrigan et al., 2020)
- **Remediation effectiveness**: Most PFAS remediation technologies (e.g., activated carbon, ion exchange) are untested in Arctic settings, where low temperatures may reduce efficiency (Langberg et al., 2022; Mukhopadhyay et al., 2021)
- **Indoor exposure**: High indoor PFAS levels from treated textiles and building materials are suspected, but data on exposure pathways and health outcomes in Arctic populations are scarce (Shoeib et al., 2004; MacNeil et al., 2022; Steeves et al., 2023).
- **Wastewater treatment**: Conventional Arctic wastewater systems are not designed to remove PFAS, and there is little research on cost-effective alternatives suitable for small, remote communities. (Skaar et al., 2019)

(2) Mercury (Hg)

Knowledge Gaps

- **Climate-driven mobilization**: Thawing permafrost may release previously sequestered mercury, but the scale and timing of this release are uncertain.
- **Transformation processes**: The microbial and photochemical processes that convert inorganic mercury to toxic methylmercury in Arctic environments are not fully understood (Bank et al., 2023; Fabre et al., 2024; Jermilova et al., 2025).
- **Indoor air exposure:** Mercury from Defect equipment like thermometers, fluorescent bulbs, and artisanal products may contribute to indoor air pollution, but monitoring information is limited (Baird et al., 2014; Eckelman et al., 2008; Alvarez-Chavez et al., 2014; Erfantalab et al., 2020).
- **Remediation feasibility**: Technologies for mercury removal from water and air are often energy-intensive and not adapted for Arctic deployment. New adjusted remediation strategies are required (Li et al., 2025; Wang et al., 2025).

(3) Microplastics

Knowledge Gaps

- **Indoor air pathways:** Arctic homes, often tightly sealed for energy efficiency, may have elevated microplastic concentrations in indoor air, but data are lacking although highly needed (Chandra et al., 2024; Fang et al., 2024; Peng et al., 2024).

- **Drinking water contamination**: The extent of microplastic contamination in Arctic drinking water sources is poorly documented (Chandra et al., 2024; Ahmad & Sheikh, 2024; Gani et al., 2023; Keerthana et al., 2022).
- **Wastewater treatment**: Existing systems are not designed to capture microplastics, and the effectiveness of potential upgrades in Arctic conditions is unknown (Ahmad et al., 2024; Kong et al., 2024; Surendran et al., 2023).
- **Ecological impacts:** The effects of microplastics on Arctic freshwater and terrestrial ecosystems are under-researched, particularly regarding ingestion by local fauna (De Lena et al., 2025; Liang et al., 2025; Zhuang et al., 2025).

(4) Cross-Cutting Challenges

- **Infrastructure limitations:** Many Arctic communities lack the technical and financial capacity to implement advanced treatment systems. A new low-tech but locally anchored solution needs to be found.
- **Monitoring and data gaps**: Sparse monitoring networks and limited laboratory capacity hinder the detection and quantification of emerging contaminants.
- **Cumulative exposure:** Residents are exposed to mixtures of contaminants through multiple pathways, but integrated risk assessments are rare, often even missing.
- **Policy and regulation:** Arctic-specific guidelines for acceptable levels of PFAS, mercury, and microplastics in water and air are lacking.

Future Research Priorities

- Develop low-energy, modular and locally anchored **treatment systems** tailored for Arctic use.
- Expand **community-based monitoring** using citizen science and Indigenous knowledge.
- Conduct **longitudinal health studies** to assess the impacts of chronic exposure.
- Promote international collaboration through **Arctic Council** working groups and global **pollutant treaties**.

3 A plan to fill the gaps in the Pan-Arctic and for each study area

Deliverable 2.3 is a report from the workshops on gap analyses, and besides identifying data gaps, it will provide a plan for how to fill in the data gaps. Next, the plan with three levels - Pan-Arctic, Local, and Practical Steps - is presented.

Pan-Arctic. The pollution-related data gaps in the Arctic are well presented in AMAP reports, which are continuously updated (see Appendix 1, AMAP reports). The reports present clear plans on how to proceed in research to fill the data gaps presented. Those gaps are also described in this deliverable and Appendix 1. Lots of research work is ongoing, and as this deliverable shows, ArcSolution will also respond to many of those gaps in their multidisciplinary and community-driven collaborative research.

Local. Based on our gaps workshops and this deliverable, **water systems** come across as a central topic needing more research. This includes studies focusing on sewage, wastewater, and drinking water. Another gap in research is the lack of **citizen science** as a way of doing research and monitoring the ArcSolution topics. One idea is to have more CS studies on water issues (tap water) and other pollution-related problems in the study locations. CS at schools would also be valuable in the study locations, and plans are underway to conduct CS on water and pollution-related topics in schools.

More local collaboration with local and Indigenous Peoples is generally called for, and ArcSolution works in a participatory way. Each year, meetings are arranged with local people, which include consultations, where local concerns are expressed. Also, each year, feedback meetings are held, where progress and results of the ArcSolution project are presented and discussed in the study locations. Feedback guides for further work on the project. Next, we highlight plans to fill in the information gaps in each study location.

- **Longyearbyen.** The women´s health study (18-44 years old) begins in June 2025 since no human health data exists from Longyearbyen. The study focuses on exposure to pollution. Importantly, it also includes women from Thai and Philippine communities living there for long periods. Other studies focusing primarily on the linked health of humans and animals have been planned (e.g., dog owners and dogs, microbiome)
- **Greenland.** Exposure to wildlife and humans is a special task in Greenland. WP7 "Human exposure to environmental contaminants" widens the scope of human population studies and immunological responses to exposure to marine mammals and hunters. In Greenland, sewage and drinking water are prominent issues and need research.
- **Tromsø** is an Arctic urban hub with the same type of problems with sewage and local emissions as many others in Arctic rural areas. Studies on those issues are called for.
- **Inari** has been studied less in relation to pollution issues compared to other locations. One of the reasons for the lack of existing research and knowledge is low POPs and heavy metals exposure levels identified in previous studies and pilot studies. However, new contaminants and plastics are impacting the Inari area and are interesting to the study.

Practical steps. Some practical steps for continuous work to fill in the data gaps were presented in the gap workshops. **Monthly meetings** with ArcSolution partners on gaps and the progress of filling them will be arranged. Many **cross-cutting activities** will be placed in collaboration with different work packages and local communities. **Yearly meetings** in study locations will ensure the project is in touch with the local needs and priorities.

The following figures, from 3 to 6, present the most common terms that occur in scientific research done in ArcSolution locations: Svalbard, Norway, Greenland, and Canada. Finland is not pictured here because the number of research conducted is so low.

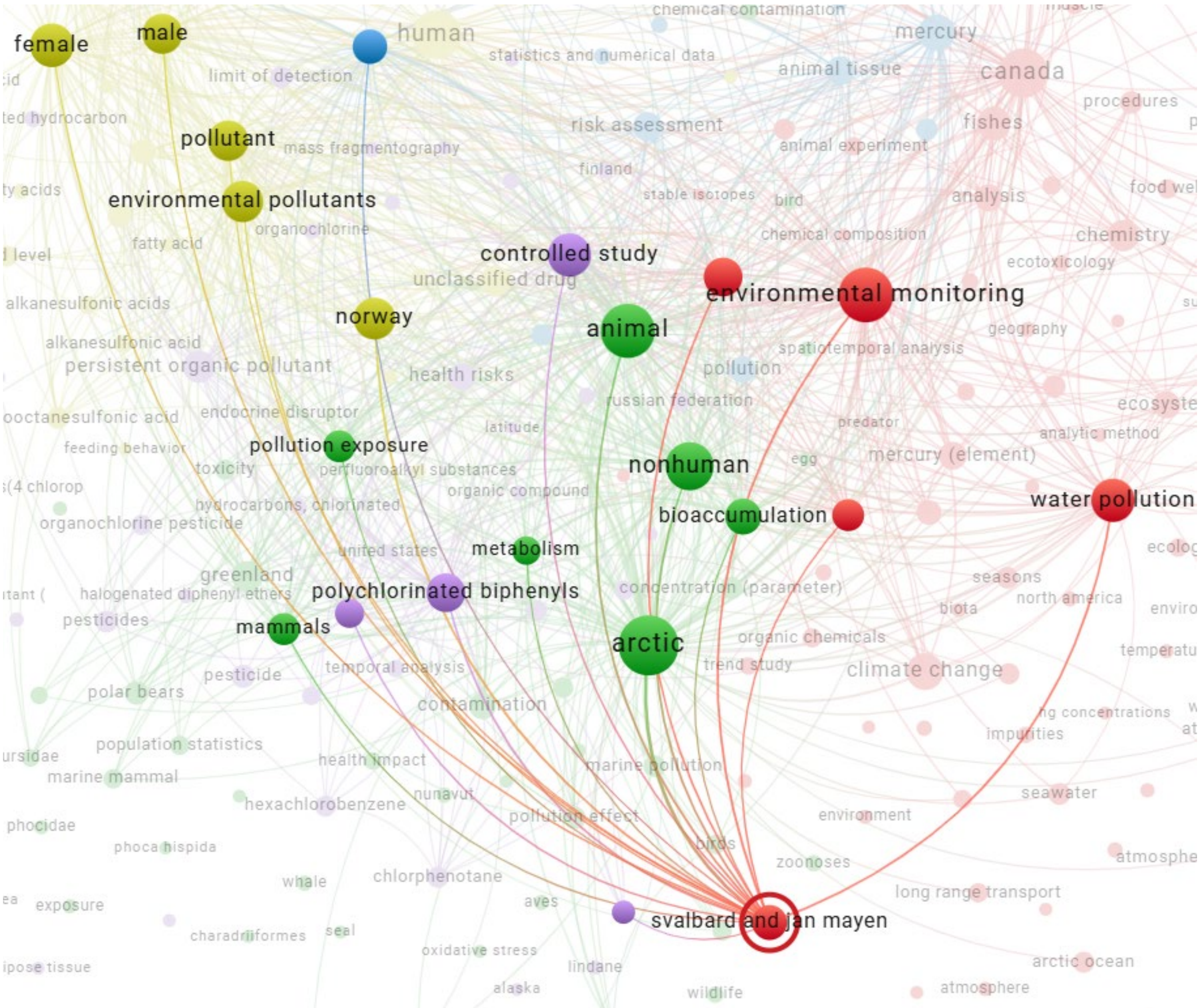

Figure 3. VOSviewer image of the index words of existing scientific publications from Svalbard.

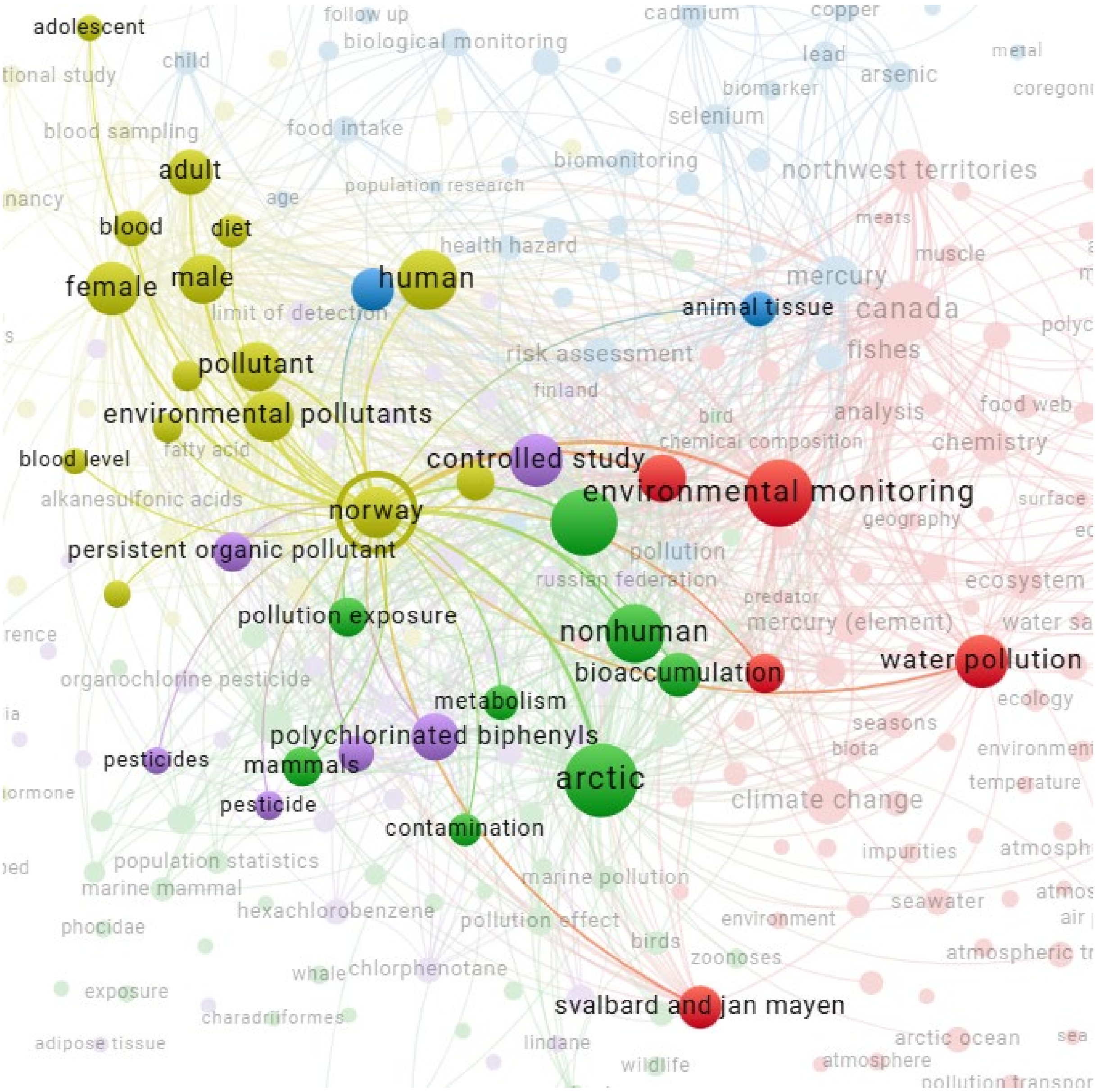

Figure 4. VOSviewer image of the index words of existing scientific publications from Norway.

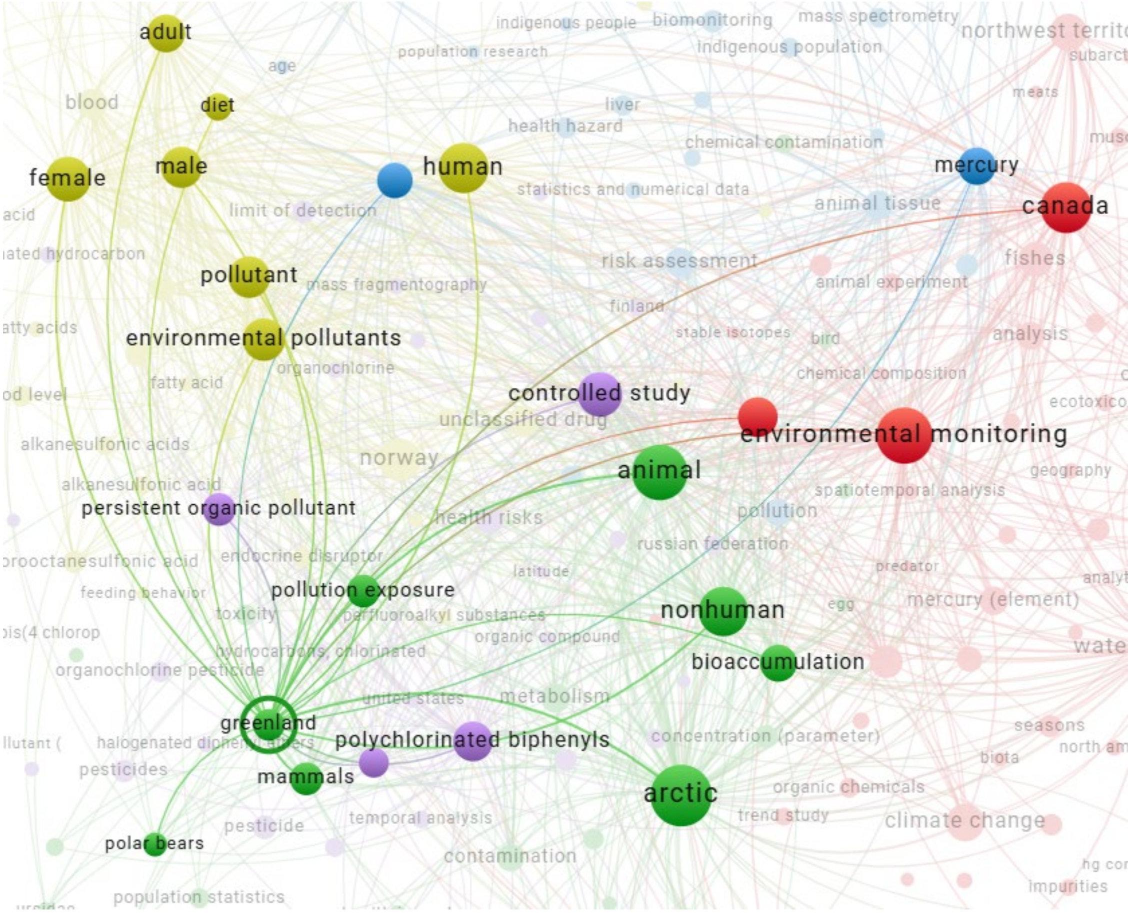

Figure 5. VOSviewer image of the index words of existing scientific publications from Greenland.

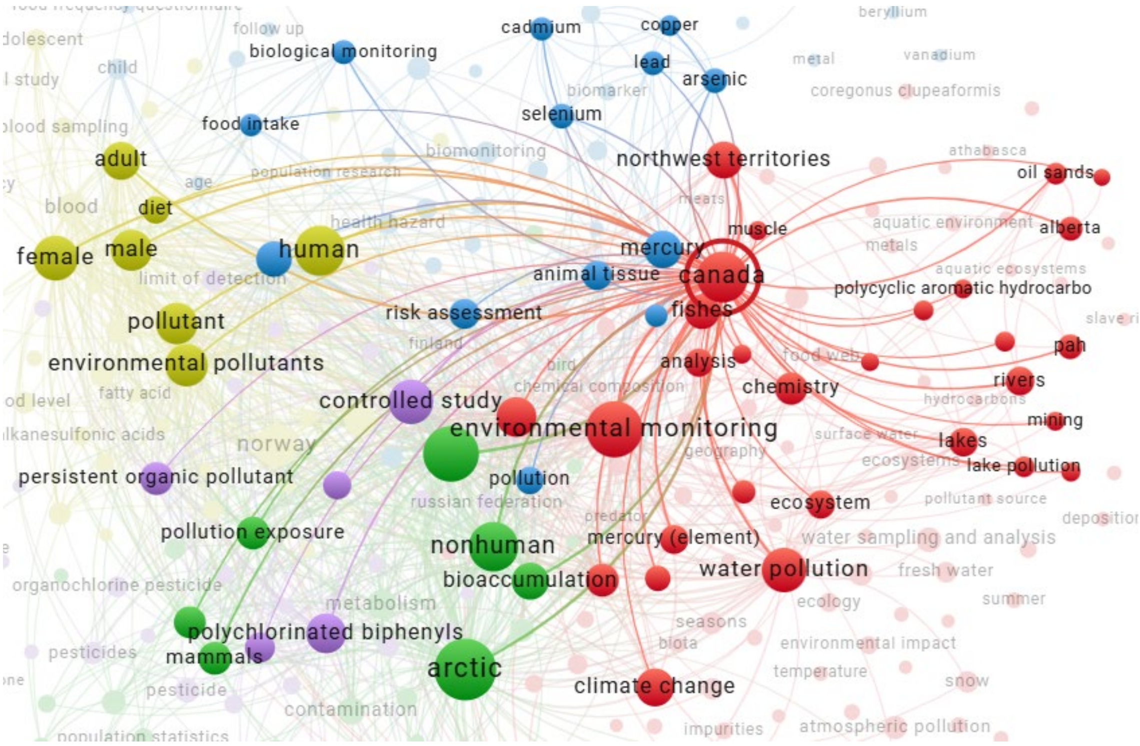

Figure 6. VOSviewer image of the index words of existing scientific publications from Canada.

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APPENDIX 1. ORIGINAL TEXTS FOR GAPS IDENTIFICATION

Appendix 1 presents complete texts provided by WP3, 4 and 5 leads on data gaps.

WP3 data gaps

WP3 “Arctic pollution in a climate change context” identified the following data gaps.

(1) Chemicals of Emerging Arctic Concern (CEACs)

Contaminant monitoring in the Arctic has traditionally concentrated on Persistent Organic Pollutants (POPs), those chemicals regulated under the United Nations Stockholm Convention on POPs, and toxic elements such as Hg, Pb, Zn, Cd and since 2005 especially PFAS. In recent years, hundreds of new chemicals have been reported in Arctic samples using non-target screening techniques (e.g., Sørensen et al., 2023; Zhu et al., 2024). These detections warrant follow-up regarding confirmation, quantification, and more extended studies in other media than initially reported. AMAP report (AMAP, 2017) identified several general knowledge gaps. Despite the rapid developments in CEAC identification, the reported knowledge gaps are still valid.

Gaps of CEACs:

- Human exposure data is particularly scarce; very little hazard information is typically available. Given the limitations in chemical domains of non-target screening approaches (Hollender et al., 2023), new studies will likely report additional CEACs.
- Spatial and temporal trends of CEACs[1] (AMAP 2017)
- More identifications using non-target screening and other expanded screening approaches (AMAP 2017)
- More identifications of potential CEACs using *in silico* approaches (AMAP 2017)
- Effect data (AMAP 2017)
- Connection with human biomonitoring studies (AMAP 2017)
- Impacts of climate change[2] (AMAP 2017)

(2) Effects of climate change

Climate change leads to complex changes in Arctic environments that affect the fate of contaminants in several ways. Many processes are temperature-dependent, such as the transformations of chemicals and their partitioning between media. Changes in the physical environment are likely to influence contaminant transport to the Arctic and intra-Arctic distribution patterns. The melting of the cryosphere leads to the release of previously stored POPs and CEACs. Changes in ecosystem structures including food web dynamics and thawing permafrost affect contaminant accumulation and exposure in complex and highly dynamic ways. Finally, climate change might favor human activity in the Arctic, with potentially increased local use of chemicals. AMAP (2021a) summarized the state of knowledge, which included an extensive list of knowledge gaps.

Gaps related to climate change (AMAP 2021a):

- Understanding complexity. Climate change affects contaminants in the physical environment and ecosystems.

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[1] Temporal trends of CEACs are included in a recently started AMAP assessment. However, it is limited by the data availability for CEACs.
[2] This was addressed in AMAP (2021).

- Limited quantitative understanding (e.g., higher temperatures) will likely lead to more degradation and more volatilization – which process predominates?
- Observations of correlations without knowledge of causality
- Greater use of local and Indigenous knowledge
- Local sources of contaminants

(3) Local pollution and emissions

All human activities in the Arctic include a certain use of chemicals, which might lead to local emissions. As the focus on Arctic pollution has been on POPs, which are, by definition, transported over long distances, locally emitted POPs and CEACs have received little attention. Potential local pollution sources include but are not limited to industry/mining, shipping, waste handling, wastewater discharge, energy supply, infrastructure (such as airports), and the general use of consumer products. Airports have often been associated with using per-/polyfluoroalkyl substances (PFAS) in firefighting foams, including airports in the Arctic (Ahrens et al., 2023). The AMAP POP EG currently assesses the issue of local sources in a series of review papers in Environmental Science: Advances.

Preliminary identifications of knowledge gaps include (AMAP, forthcoming):

- The extent of contaminant releases with thawing permafrost
- The role of riverine transport, including contaminant inputs from settlements on rivers
- Data on POPs and CEACs in wastewater discharges for most parts of the Arctic
- Airports as sources of pollutants on the pan-Arctic scale
- Contamination from landfills and other waste disposal sites
- Projections of future developments regarding local use and emissions of POPs and CEACs
- Increase in wildfire and thawing permafrost and release of GHGs and Hg

(4) AMAP 2021 summary report on human health in the Arctic identified the following gaps for research.

Table 1 Data gaps identified in AMAP 2021 summary report on Human Health in the Arctic 2021 (AMAP 2021e).

Topic	Gap
Routes of exposure	Food security, co-production of knowledge with Indigenous communities in dietary research, gender- and age-based differences in consumption, sources of exposure for PBDEs and PFASs
Biomonitoring	Pregnant women, time-trends for POPs, metals and chemicals of emerging concern, seasonality in sampling (traditional foods)
Health impacts	Cohort studies, links between exposures and health impacts, effects of contaminants on pregnant women, fetuses, and infants, mixtures of POPs and their impact on reproductive health and the immune system
Risk assessment	Better identification of the sources of contamination, improving the process of risk assessment
Interdisciplinary research	One Health, health impacts of contaminants and zoonotic infections on wildlife and humans, lifetime contaminant accumulation, lifetime exposure to zoonotic pathogens
Actions to reduce health risks	Communication strategies on health for different communities (social media, etc.), comparing health strategies across the Arctic to identify best practices

(5) Other gaps:

- Since the main human exposure to POPs has occurred from the consumption of animals that have accumulated POPs, there has been little attention **on other sources of exposure, such as drinking water, store-bought food, indoor environment,** etc. These may be relevant exposure sources for some CEACs.
- Another consequence of the research and monitoring focus on biomagnifying POPs is a l**ack of information on contaminants in lower trophic-level animals**. This can be important for ecosystem health.
- There is generally little knowledge on **the effects of contaminants**, especially CEACs, **for both humans and ecosystems.** Monitoring studies show a complex co-exposure situation with likely cases of mixture toxicity, which are not understood.
- **Plastic pollution** is also an issue in the Arctic. Plastic particles can contain many chemical additives to ensure certain functions or properties (Fauser et al., 2022). We have little information on the leaching of these chemicals from plastic particles to the surrounding environment, including the stomachs of animals that have swallowed plastics.
- Pollution has been recognized as a significant contributor to ecosystem degradation, negatively impacting biodiversity. However, it has often been overlooked compared to other environmental factors. The United Nations Environmental Programme (UNEP) highlights this issue in their report: https://www.unep.org/gef/news-and-stories/story/pollution-action-missing-link-biodiversity-protection Despite its importance, our understanding of the connections between pollution and biodiversity, particularly in Arctic ecosystems, remains limited.

WP4 data gaps

WP4 “Impacts under different scenarios” identified the following data gaps.

Specific data gaps for WP4:

- Need for a critical review of the **Toxicity of PFAS, Hg, plastics (and additives),** including *in silico* docking and read-across. This includes combining effect-directed analyses and non-target screening for new chemicals.
- Need for assessing **zoonoses and ARGs wildlife and humans at all 4 study sites.** This includes whole-genome sequencing of bacteria, viruses, and gut microbiomes and quantifying the transfer between wildlife and humans. This also includes risks of health effects. This may include sled dogs, cod, and reindeer across study sites.
- Knowledge gaps in **certain marine and terrestrial species** regarding **biological effects on wildlife and fish, including necropsy, tissues and blood plasma, pathology, and immune markers concerning reproduction and endocrine effects**. These may be closed looking at cod, sled dogs, and reindeer, including owners and herders.
- Need to study the effects of **food webs' multiple stressors,** including climate change, pollution, and diseases.
- Knowledge gaps in the framework of the triple planetary crisis, including **habitat changes, exposure, and risks that need to be closed using various modelling tools of food web dynamics, species migrations, and toxicity of plastic**s. These knowledge gaps may be closed using polar bear food webs, toothed whales (hunting statistics), and humans in East Greenland, which is the only study site from which such a time series is available.

Knowledge gaps in the Arctic on wildlife in general

New information from effects studies on Arctic species has resulted in significant new insights into the risks of biological effects on Arctic wildlife from exposure to environmental contaminants. **Significant knowledge gaps remain about the following:**

- Biological and toxicological effects of **OHCs, Hg,** and, in particular, **contaminants of emerging Arctic concern** that are now being reported in Arctic biota. These knowledge gaps include **concentration thresholds for biologically relevant health effects and toxic threshold endpoints used to develop RQs**. **Integrating wildlife and human health assessments** can improve knowledge regarding the **combined effects of contaminant exposure and natural stressors** (e.g., infectious and zoonotic diseases) and how multiple stressors are **directly and indirectly influenced** in a changing Arctic, especially **in connection with climate change.**

There is a need for new methods and approaches, including:

- The expansion of *in vitro* experimental approaches
- studies on the individual and combined effects of single compounds and chemical mixtures
- Increased use of *in silico* modelling to better predict biological effects at the population and ecosystem level.

Specific knowledge gaps and information deficiencies are as follows:

- Certain Arctic regions, such as Russia, **Fennoscandia,** and Alaska, are not adequately represented in monitoring wildlife and fish exposure and effects. Greater attention must be given to access to data on hunting quotas for relevant species.
- **Invasive and migratory wildlife and fish species,** including killer whales and capelin (*Mallotus villosus*), are not represented or are under-represented in Arctic monitoring and research addressing biotic changes due to the changing Arctic climate.
- Further **pan-Arctic harmonization** is required concerning target species, sampling frequency and season, and methods applied for the measurement of contaminants and associated biomarkers and biological endpoints applicable to effects assessment.
- **A need for increased communication and collaboration with local and Indigenous people.**
- A multi-stressor framework is needed to assess the effects within a changing Arctic.
- Data compilations on OHC and Hg exposure levels, trends on wildlife and fish populations, and in relation to observed climate change-related variables (e.g., sea ice loss).
- Need to **establish and refine concentration thresholds for biologically relevant health effects in (Arctic) wildlife and fish**.
- Physical-chemical and industrial production data are required for newer chemicals of emerging Arctic concern.
- Effects of spatial and temporal variation in dietary exposure pathways need to be assessed**.** There is also a need to determine the combined effects of contaminant exposure and natural stressors
- Need for **better identification of cumulative and interactive effects thresholds of contaminant exposure, including** (i) routine analysis of ancillary ecological metrics together with OHC and Hg studies, (ii) simultaneous consideration of the multiple mechanisms by which global climate change and contaminant interactions can occur, (iii) targeted research on species known to be sensitive to both global climate change and contaminants, and (iv) studies linking these changes to changes in major impact parameters such as immune and reproductive function and development, particularly at the population level. Environmental

chemists studying contaminant levels in biotic and abiotic media, eco(toxico) logistics, and Indigenous peoples of the Arctic could have a greater impact by working together to consider the combined impacts of these changes on contaminant exposures in Arctic marine and terrestrial biota.

Gaps related to zoonoses

The ongoing change of the Arctic environment highlights current knowledge gaps and that we should prepare for emerging zoonoses. The warming Arctic climate influences long-range transport and biomagnification of industrial chemicals as well as pathogens to the Arctic, which has implications for human, animal and environmental health i.e., One Health. Monitoring Arctic diseases has largely been neglected, and knowledge of their interactive effects with climate change and contaminant exposure are much needed to propel the One Health concept and its gains. This lack of studies in the Arctic may be partly because of a much lower human density at northern latitudes. This should, however, not be a sole determinant for attention - particularly when taking into consideration fast and difficult-to-control global diseases and pandemic alertness/risk assessment.

When more resources are allocated to areas with warmer climates or higher human population density there is an inherent risk of missing clues to an upcoming pandemic originating from a region where many people are in close contact with wildlife and (among other pandemic-promoting factors) a vast frozen library of historic and ancient microorganisms thawing. In addition, there are meat markets in the Arctic but not meat control and hardly any personal protection. That was reasonable until recently but given that the temperature increases there is an increasing demand for more food hygiene. There is a great need to invest in strategic One Health surveillance and research efforts in the circumpolar Arctic to concurrently address factors that affect both wildlife and public health. In many regions, such efforts need to draw on and honor traditional local and traditional knowledge and ways of knowing and should invest in participatory epidemiology methods for issue identification, early detection and ongoing monitoring. It is also crucial to assess additive, synergistic, or antagonistic effects between climate change and other stressors including anthropogenic pollutants, such as legacy- and emerging contaminants, especially in the marine ecosystem where the food chains are longer and contaminant levels of immune toxic substances hence are highest. Lessons learned in the Arctic are also likely to be relevant or applicable in a global context, not least because diseases arising in the north now have more potential to spread globally than ever before.

The COVID-19 pandemic illustrates how animal wet markets might have been ground zero for the introduction of a novel coronavirus to humans with globally devastating public health consequences and immense economic costs for society. Although the trade of wildlife meat in Asian markets is dramatically different from food sharing networks in Arctic communities, harvesting game in remote areas and consuming it raw and without authorized meat-control is typical in many indigenous cultures. Arctic inhabitants are often in close contact with, and dependent on, wildlife for sustenance. Traditional circumpolar food systems are therefore vulnerable to potential pathogens present in the hunted animals as well as to pathogen contamination during preparation or storage. This likely creates greater exposure risks for Indigenous circumpolar communities. In addition to this, many communities in the Arctic do not have year-round road access so health care is limited to health centers staffed by nurses and nurse practitioners with periodic visits by physicians. The nursing staff is often transient and may not be familiar with locally relevant diseases and have limited resources for diagnostic workups. This means zoonotic diseases may go undiagnosed. An example of this, is a case in the western Canadian Arctic where human cases of Giardia are disproportionately represented and were likely missed until the human strain was detected in muskoxen, and health care providers were thereby alerted of the occurrence of this disease in the area. Arctic inhabitants are moreover required to travel by plane to larger, typically more southern, cities or regional centers for specialized treatment (when the weather conditions allow flying). For example, Inuit in need of specialized health care in Greenland travel to either Nuuk or to Copenhagen, Denmark, which may take several days. In addition, these movements could be potential routes for the introduction of unexpected pathogens in more densely populated areas at southern latitudes.

The Arctic presents multiple challenges in terms of its vast geographical extent, hostile climate, and low density of animals (outside seasonal high-density aggregations) and diverse Indigenous people's cultures. Monitoring diseases and their dynamics, therefore, commands a high degree of international cooperation between Arctic nations and their respective scientific communities for example, to increase effort to educate the relevant groups of the public regarding safe handling of wildlife, including protective traditional practices and local knowledge not often known to tourists or transient medical or veterinary personnel. There is also a need for cross-disciplinary and international collaboration in a circumpolar framework to mitigate the current significant lack of scientific knowledge in the literature about zoonoses in the Arctic including their relation to current global changes. A rapidly transforming environment and growing human influence position the Arctic as a critical focal point for potential global health crises, primarily through the emergence of zoonotic diseases and thawing of permafrost, including ancient pathogens. The compounding pressures of environmental contaminants and shifting ecological dynamics not only endanger the unique wildlife but also amplify health risks for the Indigenous peoples who rely on healthy and stable wildlife populations. The region's deep-rooted cultural heritage and ecological systems, epitomized by traditional food sources, are being increasingly challenged, with episodes like the Siberian anthrax outbreak painting a grim picture of potential repercussions. Navigating this complex landscape, a multifaceted, global response is of paramount importance. This involves championing international research collaborations to bridge knowledge disparities, amplifying disease monitoring in the Arctic for proactive interventions, and engaging Indigenous communities to adapt to these evolving challenges. As the Arctic's global importance grows, effective guidelines on health and environmental mindfulness to respect biosecurity and protect the region's delicate balance are urgently needed. Investing more substantially in Arctic research and addressing the root environmental culprits, such as pollution and the overarching climate change, are also non-negotiable necessary actions. Ultimately, preserving the Arctic's future and averting global health crises requires a holistic One Health approach, rooted in rigorous scientific research, community-driven strategies, and unified international multidisciplinary efforts.

WP5 data gaps

WP5 “Solutions, resilience, adaptation and mitigation” identified the following data gaps.

The Arctic is increasingly impacted by chemicals of emerging concern (CECs), including PFAS, mercury, and microplastics. These pollutants reach the region through long-range atmospheric and oceanic transport and local sources such as wastewater discharge, household products, and imported goods. The extreme climate, remoteness, and infrastructure limitations of Arctic communities pose unique challenges for pollution control.

(1) PFAS (Per- and Polyfluoroalkyl Substances)

Sources: Consumer products, firefighting foams, wastewater effluent, and indoor materials like furniture and electronics

Knowledge Gaps:

- Environmental fate and transport: Limited understanding of how PFAS behave in Arctic conditions, including their persistence in frozen soils and snowpack (Adlard et al., 2024; Hansen et al., 2024; Landrigan et al., 2020).
- Remediation effectiveness: Most PFAS remediation technologies (e.g., activated carbon, ion exchange) are untested in Arctic settings, where low temperatures may reduce efficiency (Langberg et al., 2022; Mukhopadhyay et al., 2021).
- Indoor exposure: High indoor PFAS levels from treated textiles and building materials are suspected, but data on exposure pathways and health outcomes in Arctic populations are scarce (Shoeib et al., 2004; MacNeil et al., 2022; Steeves et al., 2023).
- Wastewater treatment: Conventional Arctic wastewater systems are not designed to remove PFAS, and there is little research on cost-effective alternatives suitable for small, remote communities. (Skaar et al., 2019).

(2) Mercury (Hg)

Sources: Long-range atmospheric deposition, legacy contamination, and combustion sources.

Knowledge Gaps:

- Climate-driven mobilization: Thawing permafrost may release previously sequestered mercury, but the scale and timing of this release are uncertain.
- Transformation processes: The microbial and photochemical processes that convert inorganic mercury to toxic methylmercury in Arctic environments are not fully understood (Bank et al., 2023; Fabre et al., 2024; Jermilova et al., 2025).
- Indoor air exposure: Mercury from Defect equipment like thermometers, fluorescent bulbs, and artisanal products may contribute to indoor air pollution, but monitoring information is limited. (Baird et al., 2014; Eckelman et al., 2008; Alvarez-Chavez et al., 2014; Erfantalab et al., 2020).
- Remediation feasibility: Technologies for mercury removal from water and air are often energy-intensive and not adapted for Arctic deployment. New adjusted remediation strategies are required (Li et al., 2025; Wang et al., 2025).

(3) Microplastics

Sources: Wastewater effluent, household dust, textiles, and imported goods.

Knowledge Gaps:

- Indoor air pathways: Arctic homes, often tightly sealed for energy efficiency, may have elevated microplastic concentrations in indoor air, but data are lacking although highly needed (Chandra et al., 2024; Fang et al., 2024; Peng et al., 2024).
- Drinking water contamination: The extent of microplastic contamination in Arctic drinking water sources is poorly documented (Chandra et al., 2024; Ahmad & Sheikh, 2024; Gani et al., 2023; Keerthana et al., 2022).
- Wastewater treatment: Existing systems are not designed to capture microplastics, and the effectiveness of potential upgrades in Arctic conditions is unknown (Ahmad et al., 2024; Kong et al., 2024; Surendran et al., 2023).
- Ecological impacts: The effects of microplastics on Arctic freshwater and terrestrial ecosystems are under-researched, particularly regarding ingestion by local fauna (De Lena et al., 2025; Liang et al., 2025; Zhuang et al., 2025).

(4) Cross-Cutting Challenges:

- Infrastructure limitations: Many Arctic communities lack the technical and financial capacity to implement advanced treatment systems. New low-tech but locally anchored solutions need to be found.
- Monitoring and data gaps: Sparse monitoring networks and limited laboratory capacity hinder the detection and quantification of emerging contaminants.
- Cumulative exposure: Residents are exposed to mixtures of contaminants through multiple pathways, but integrated risk assessments are rare, often even missing.
- Policy and regulation: Arctic-specific guidelines for acceptable levels of PFAS, mercury, and microplastics in water and air are lacking.

Future Research Priorities:

- Develop low-energy, modular, and locally anchored treatment systems tailored for Arctic use.
- Expand community-based monitoring using citizen science and Indigenous knowledge.
- Conduct longitudinal health studies to assess the impacts of chronic exposure.
- Promote international collaboration through Arctic Council working groups and global pollutant treaties.

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