URBAN WATER QUALITY MANAGEMENT

Emerging Pollutants in Water and Wastewater: UNESCO-HELCOM Case Study on Pharmaceuticals in the Aquatic and Marine Environment in the Baltic Sea Region[1]

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Introduction and Context

Good quality water is essential to sustain human health, livelihoods and a healthy environment. Polluted water supplies pose serious human health risks in addition to threats to the ecosystem sustainability. There is an urgent need to reverse the declining water quality globally and to improve wastewater management and safe reuse. The Sustainable Development Goals (SDGs) bring water quality issues to the forefront of international agenda. The SDG Target 6.3 calls on countries "*to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*", as well as Targets 6.1 and 6.2 urge action to ensure access to safe water, sanitation and hygiene for all. Improving water quality and wastewater management, including safe reuse, brings multiple benefits for poverty reduction, health improvement, food security, ecosystems integrity and biodiversity protection. The links of water quality with other sustainable development challenges are furthermore highlighted in a number of SDGs, calling for measures to reduce water pollution and its adverse impacts on human health, ecosystems and biodiversity, including: SDG 1 on poverty (Target 1.4); SDG 3 on health (Target 3.3); SDG 12 on responsible consumption and production (Target 12.4); and SDG 15 on ecosystems and biodiversity (Target 15.1). In particular, as emphasized in SDG Targets 3.3 and 12.4, emerging pollutants in water, wastewater and the aquatic environment present a new water quality challenge that must be addressed in view of their potential human health and environmental risks.

A wide variety of emerging pollutants (referred to also as 'contaminants of emerging concern') found in water resources and the aquatic environment poses a risk to human and environmental health. Emerging pollutants comprise synthetic or naturally-occurring hazardous chemicals used in our daily lives, including pharmaceuticals, personal care products, pesticides, industrial and household chemicals, metals, surfactants, industrial additives and solvents, as well as microorganisms that are not commonly monitored or regulated in the environment. These chemicals, which have not historically been considered as pollutants, are found today in varying concentrations in treated and untreated municipal wastewater,

[1] The information and data on the UNESCO-HELCOM case study on Pharmaceuticals in the Baltic Sea Region contained in the paper is an extract from a draft report prepared by a group of experts based on the analysis and evaluation of data provided by the HELCOM Working Group on Reduction of Pressures from the Baltic Sea Catchment Area and the HELCOM Working Group on the State of the Environment and Nature Conservation. The group of experts includes: Pär Hallgren, Sweco Environment AB; Petra Wallberg, Sweco Environment AB; Niina Vieno, ENVIENO; and Minna Puhala, Green Word. The draft report will be further reviewed by HELCOM working groups.

industrial effluents and agricultural run-off that seeps into rivers, lakes and coastal waters. Within these complex chemicals, a large group, known as endocrine disruptors, is a growing concern due to their human and environmental health risks as they interfere with the endocrine system in humans and animals. There is scientific evidence that many chemicals recognized as emerging pollutants may cause cancerous tumours, birth defects and developmental disorders, and affect fertility and reproductive health. Pharmaceuticals used both in humans and animals for therapeutic and diagnostic purposes are reported to be present in wastewater and rivers, even in very low concentrations.

Emerging pollutants are a source of concern due to their increasing discharge into freshwater systems and the environment even in very low quantities, with some capable of potentially causing endocrine disruption in humans and aquatic wildlife and the development of bacterial pathogen resistance. The current scientific understanding on the fate, transport and risk of emerging pollutants, individually and in combination, and their accumulation in the environment is limited. The effects of individual emerging pollutants on human and ecosystem health have been evaluated only marginally. Nor, have their cumulative effects in the aquatic environment and human body been studied at all. The concern is further complicated by the possibility that as-yet unknown chemicals may be present in the water. As most emerging pollutants are not regulated by wastewater discharge and water quality regulations and standards, monitoring data and information on their presence in water resources and wastewater are very scarce. More research is needed to evaluate their long-term effects on human health and the environment. Urban wastewater, industrial effluents and agricultural run-off are major sources of pharmaceuticals and endocrine-disrupting chemicals in surface waters and groundwater. The situation is most urgent particularly in developing countries, where large quantities of insufficiently treated or untreated municipal wastewater and industrial effluents are discharged into surface waters and coastal zones in every day.

These pollutants have also been detected in drinking water, as conventional water purification and wastewater treatment processes are not effective in removing these complex chemical compounds, although advanced technologies, such as membrane filtration, ultrafiltration, nanofiltration and reverse osmosis, can remove, at least partially, some endocrine-disrupting chemicals and pharmaceutically active compounds. Even if these technologies exist, their application is limited due to high costs. Consequently, humans and ecosystems are continuously exposed to these new and emerging pollutants via drinking water, as well as via agricultural products, as wastewater is widely used to irrigate crops in water-scarce areas. Potential human health risks of emerging pollutants through the exposure via drinking water, therefore, needs special attention and further scientific research. This new water quality challenge is faced by both developing countries and developed countries. Although there is increasing research focus on emerging pollutants in developed countries, effective tools and policies to monitor, regulate and control these pollutants in water resources have not been put in place even in developed countries.

Hence, there is an urgent need to strengthen scientific knowledge and adopt appropriate technological and policy approaches to monitor emerging pollutants in water resources and wastewater, assess their potential human health and environmental risks, and prevent and control their disposal to water resources and the environment. Better understanding of human health and environmental risks of emerging pollutants, as well as effective technological, regulatory and policy approaches to manage them in water resources and the aquatic environment are needed. International cooperation is key to mobilising and building capacities at technical and policy levels to support countries in addressing this global water quality challenge.

UNESCO Project on Emerging Pollutants in Water and Wastewater

The UNESCO Project entitled ‘Emerging Pollutants in Wastewater Reuse in Developing Countries’ responds to the urgent need to develop and improve scientific knowledge, understanding and information on emerging pollutants in water resources and wastewater.

The project, implemented under UNESCO-IHP International Initiative on Water Quality (IIWQ) and funded by the Swedish International and Development Cooperation Agency (Sida), aims to support countries to strengthen their scientific, technical and policy capacities to manage human health and environmental risks caused by emerging pollutants in water and wastewater, as well as to improve water quality and wastewater management, to promote safe reuse of wastewater and ultimately to enhance water and food security. Consequently, the project also aims to support the achievement of SDG targets related to water quality and in particular to emerging pollutants, as well as contributes to the goals on health, hunger, ecosystems and chemicals management.

Activities under three main components contribute to the achievement of this project's main objective:

- Strengthening scientific knowledge, understanding and policy on emerging pollutants in water and wastewater through a series technical and policy case-studies on emerging pollutants in water and wastewater in different regions and the development of technical and policy guidelines;

- Promoting and facilitating knowledge sharing, scientific collaboration and joint research on issues related to emerging pollutants and the implications for wastewater reuse;

- Capacity building and awareness-raising on emerging pollutants in water and wastewater.

Under the project, UNESCO has launched a series of IIWQ case studies on emerging pollutants to take stock of and disseminate the 'stat-of-the-art' knowledge and information on the needs and solutions to understand better and manage emerging pollutants in water and wastewater. These technical and policy case studies address a broad range of issues: the occurrence of emerging pollutants in water resources, wastewater and the aquatic environment; hydrological modelling of the fate of emerging pollutants; the potential and known risks of emerging pollutants to human health and the environment; effective technological and policy approaches to prevent, control and remove emerging pollutants in water resources and wastewater streams; and related socio-economic concerns. The case studies cover about 20 countries from all regions of the world, namely: Australia, Brazil, Canada, China, Ethiopia, India, Kenya, Kuwait, Mexico, Mongolia, Nigeria, Norway, Rwanda, Saint Lucia, Thailand, Tunisia, Ukraine and Vietnam. Some case studies have a global or international focus covering one or more regions, including the Africa, Asia, the Baltic Sea region, Caribbean islands, Europe, Latin America and North America.

UNESCO-HELCOM Case Study on Pharmaceuticals in the Aquatic and Marine Environment in the Baltic Sea Region

Pharmaceuticals are an important element of modern society and their beneficial effects on human and veterinary health are widely acknowledged. However, their undesired occurrence and potential effects on the environment are of global emerging concern. Residues of various types of pharmaceuticals (hormones, painkillers, antibiotics, etc.) have been detected in several environmental compartments in different regions, including the Baltic Sea.

Several national projects have been carried out in the Baltic Sea region with the purpose of obtaining data on the occurrence of medical substances in the environment, as well as on harmful effects of these substances on particular aquatic and marine species. Nonetheless, there was no compilation of information on the problem at the regional scale.

The UNESCO-HELCOM case study on 'Pharmaceuticals in the Aquatic and Marine Environment in the Baltic Sea Region' aims to compile a regional report with a comprehensive overview of the status and pressures of pharmaceuticals in the waters and environment in the Baltic Sea region. It is the first attempt to compile regional information on consumption of pharmaceuticals, to identify sources and pathways of

pharmaceuticals into the environment and to conduct a Baltic Sea regional level assessment of the occurrence and effects of pharmaceuticals in the aquatic and marine environment.

The case study is part of the UNESCO IIWQ Case Study Series and a contribution to the UNESCO Project on Emerging Pollutants in Water and Wastewater.

Policy setting

In the 2010 HELCOM Ministerial Declaration, the Contracting Parties of HELCOM agreed to '*further assess the environmentally negative impacts of pharmaceuticals and other substances that are not monitored regularly, with the aim as a first step to assess in a coordinated manner their occurrence in the Baltic Sea and evaluate their impacts on the Baltic biota'* (HELCOM, 2010). The commitment was followed up by the 2013 Ministerial Declaration, in which the Contracting Parties agreed '*to collect more information and assess the state of contamination with pharmaceuticals and their degradation products of the aquatic environment*' (HELCOM, 2013).

The EU Directive 2013/39/EU on priority substances in the field of water policy considers the contamination of water and soil with pharmaceutical residues an emerging environmental concern (European Commission, 2013). Several pharmaceuticals, such as Diclofenac, 17-beta-estradiol (E2), 17-alpha-ethinylestradiol (EE2) and estrone (E1), a breakdown product of E2, and three macrolide antibiotics erythromycin, clarithromycin and azithromycin, are included on the first 'watch list' of the EU Priority Substances, with the aim to gather monitoring data for the purpose of facilitating the determination of appropriate measures to address the risk posed by these substances (European Commission, 2015). The *Policy Area Hazards of the EU Strategy for the Baltic Sea Region* (EUSBSR, 2015) has decided to give increased attention to the topic of pharmaceuticals in the Baltic environment during the years 2015-2017.

Reporting and data collection

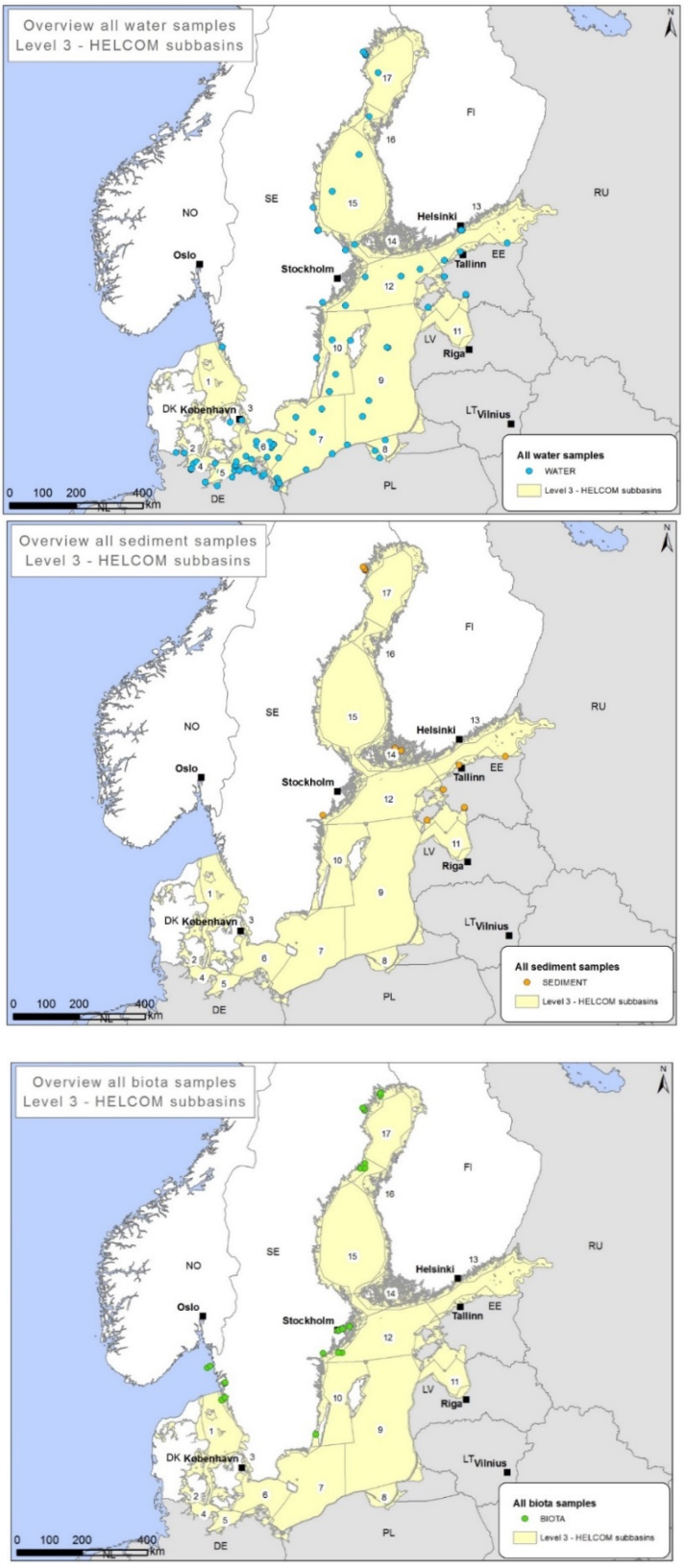
Two HELCOM Working Groups contributed to the gathering of data for the report: (1) the Working Group on the State of the Environment and Nature Conservation (State and Conservation) regarding the concentration of pharmaceuticals in the environment; and (2) the Working Group on Reduction of Pressures from the Baltic Sea Catchment Area (Pressure) regarding inputs and pathways of pharmaceuticals to the sea.

The data on regular monitoring and different kinds of screening campaigns carried out nationally were gathered. The reported data included:

- Measurements in influents and effluents to wastewater treatment plants, as well as in sludge;
- Concentrations observed in rivers and other inland water bodies; and
- Concentrations of pharmaceuticals observed in compartments of the marine environment such as water, sediments and biota.

In total, 45,000 observations from the period 2003-2014 were included in the dataset on sources and pathways of pharmaceuticals (i.e., monitoring of wastewater influents and effluents, sludge and river water) and 4,600 observations from the same period on concentrations of pharmaceuticals in the marine environment (Figure 1). The data were evaluated by external experts.

Figure 1 Overview of samples from water, sediments and biota (data submitted by Denmark, Estonia, Finland, Germany, Poland, and Sweden).

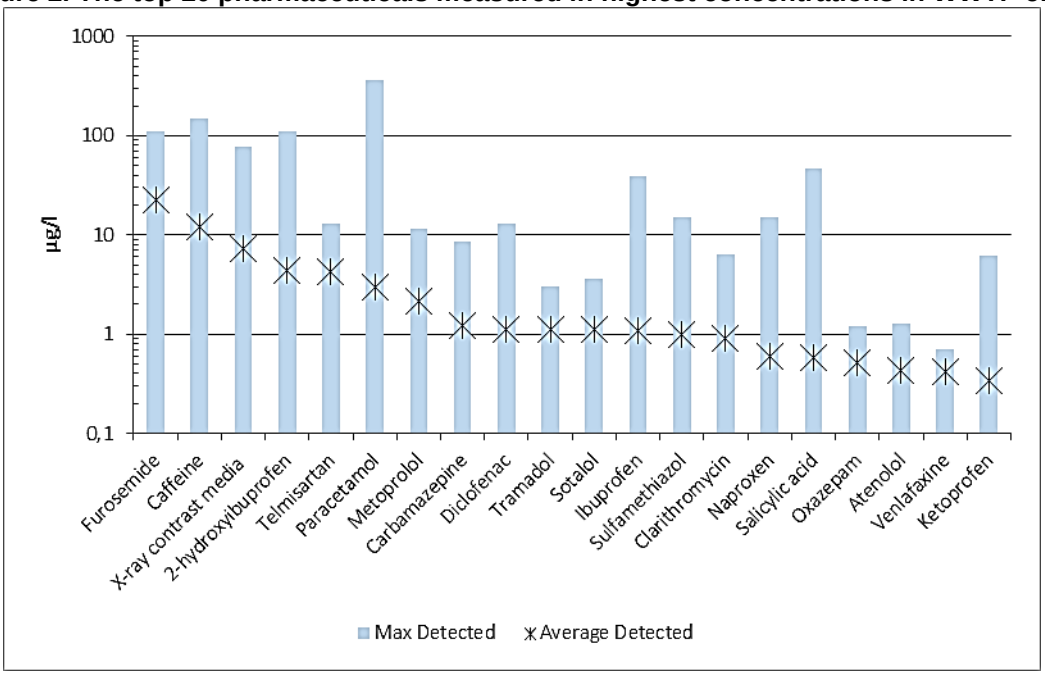


Main results

A rough estimate suggests that 2,200 tonnes of pharmaceuticals enter the environment in the Baltic Sea region each year via wastewater treatment plants (WWTPs).

By therapeutic groups, the highest discharge loads were estimated to be for cardiovascular agents, followed by central nervous system agents and anti-inflammatories and analgesics (Figure 2).

Figure 2. The top 20 pharmaceuticals measured in highest concentrations in WWTP effluents.

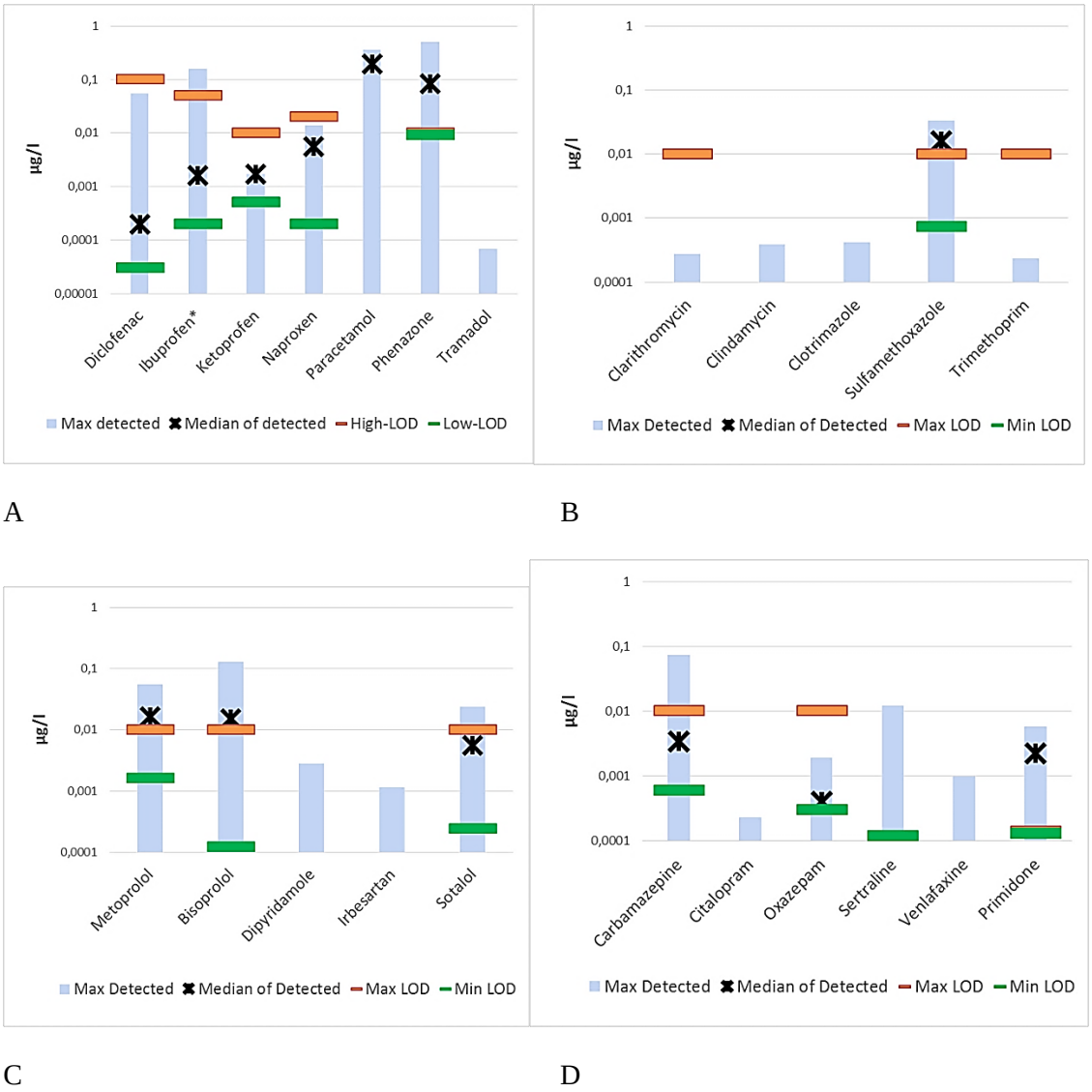


'X' indicates the average concentration of the measurements and the bar indicates the maximum measured concentration

According to the data collected on concentrations of pharmaceuticals in the Baltic Sea environment, the most frequently detected substances belong to the therapeutic groups of anti-inflammatory and analgesics, cardiovascular and central nervous system agents and some of antimicrobial substances (Figure 3). The most frequently detected anti-inflammatory agents are diclofenac, ibuprofen and paracetamol which were detected in almost all compartments of the Baltic Sea environment. Sulfamethoxazole was the most frequently detected antimicrobial substance and it was detected in all matrices. Cardiovascular agents metoprolol, bisoprolol and sotalol were detected mainly in water samples. The central nervous system agents carbamazepine and primidone were frequently detected in water, where the latter was detected in all samples where it was measured. The largest number of pharmaceuticals and the highest concentrations were found in blue mussels.

Based on available data on consumption, concentrations and detection rates in WWTP influents, effluents and in river waters, the substances of the greatest priority and concern for the Baltic Sea are the anti-inflammatory and analgesic drugs codeine, diclofenac, ibuprofen, irbesartan, ketoprofen, naxoproxen, paracetamol, and tramadol; the antimicrobial drugs ciprofloxacin, clarithromycin, fluconazole, sulfamethoxazole; cardiovascular agents atenolol, eprosartan, furosemide, metoprolol, sotalol; and the antiepileptic drug carbamazepine.

Figure 3 Concentrations of pharmaceuticals in Baltic Sea water



A - anti-inflammatory agents, B - antimicrobial substances, C - cardiovascular agents, D - central nervous system agents.

Data gaps

The reported data do not cover all countries of the Baltic Sea drainage area and the assessment of input of, and concentrations of, pharmaceuticals in the aquatic environment is not complete. No data were received on the occurrence of veterinary pharmaceuticals in manure or in the environment. Thus, the contribution of agriculture and aquaculture into the total inputs of pharmaceuticals was not assessed.

No data were received on occurrence of pharmaceuticals in the groundwater, or in the soil, thus the assessment of the role of these compartments as a source and pathway of pharmaceuticals into the Baltic Sea is incomplete.

Reported detection limits for some of the pharmaceutical substances were in some cases higher than the requirements; for example, the minimum acceptable detection limit and the Environmental Quality Standards (EQS) for hormones (estrogens) and anti-inflammatory substances (diclofenac), according to EU 'watch list'. Thus, the occurrence of these substances in the environment was not properly assessed.

Recommendations

The UNESCO-HELCOM case study is a significant contribution to the improvement of the current state of knowledge on emerging pollutants in water, wastewater and the aquatic environment and the identification of measures for their effective management and control, given the lack of data and information on the presence of these pollutants in water resources and wastewater globally and the scientific uncertainties about their effects on human health and the environment.

The following key recommendations can be drawn from the findings of this study on the occurrence and sources of pharmaceuticals in the aquatic and marine environment in the Baltic Sea region, which is the first of its kind not only in Europe, but also in other regions. The complete set of conclusions and recommendations of the study will be presented in the final report after its review by HELCOM Working Groups for adoption by HELCOM Heads of Delegations in 2016 and for deciding on further steps based on the outcomes of the study.

Recommendations for improving scientific knowledge and data

Monitoring data are needed from every Baltic Sea country, as well in from other regions globally. The study revealed a number of pharmaceuticals with high consumption levels which have not been included into national monitoring programmes or screening campaigns. Furthermore, analytical methods with lower detection limits are required for measuring concentrations of some pharmaceuticals for which Environmental Quality Standards have been proposed.

There is a need of further research to investigate the occurrence of pharmaceuticals in the environment. The occurrence and fate of metabolites require more thorough consideration and research. More studies are needed on the pharmaceuticals occurrence in groundwater and soil, in particular for substances with a high level of consumption in veterinary.

Studies on potential impacts of pharmaceuticals on ecosystems are needed in order to identify and assess potential adverse effects of these substances and, consequently, to set the boundaries and thresholds for good environmental status. Pharmaceuticals in biota and their appearance in the food chain need further investigations.

Recommended and potential measures for reducing inputs of pharmaceuticals to the aquatic environment

Measures to reduce the inputs of pharmaceuticals to water bodies and the aquatic environment should address all stages of the product lifecycle from manufacturing to consumption to waste management. Such measures should include both technical solutions and policy tools for the prevention of discharge of pharmaceuticals and their metabolites into wastewater.

Technical solutions can be applied in wastewater treatment plants, mainly as tertiary advanced wastewater treatment methods. The tertiary treatment methods that could be used to enhance the removal of pharmaceuticals are ozonation and other advanced oxidation processes, adsorptive methods (e.g., activated carbon), membrane and nano-filtration, and reverse osmosis. Oxidation, adsorption and filtration methods could also be used for the pre-treatment of hospital wastewater and industrial effluents prior to discharging to the sewer system.

Emphasis needs to be placed on policy approaches based on the precautionary principle rather than end-of-the-pipe techniques, as the latter is less effective than preventive measures because of the high costs involved in removing pollutants once they are discharged into sewerage. This involves that policies and regulations need to go beyond the water sector to tackle the source of pollution pathways, as well as measures to ensure sustainable production, use and disposal of pharmaceutical products and hazardous chemicals.

Pollution prevention measures such as take-back of unused medicines by pharmacies should be applied in countries where such systems are not yet in place, in order to reduce the disposal of unused medicines via solid waste or wastewater. Furthermore, educational campaigns should be carried out to increase the awareness of the public on correct disposal of pharmaceutical waste. Eco-labelling of pharmaceutical products can help doctors, pharmacists and consumers to consider environmental perspectives when choosing medication. Decreasing the total consumption of pharmaceuticals also reduces their discharge with treated or untreated wastewater. This can be done by educating people on proper use of medicines.

References and Data Sources

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Data are provided by:

- HELCOM Working Group on Reduction of Pressures from the Baltic Sea Catchment Area
- HELCOM Working Group on the State of the Environment and Nature Conservation

Data compilation and evaluation:

- Pär Hallgren, Sweco Environment AB
- Petra Wallberg, Sweco Environment AB
- Niina Vieno, ENVIENO
- Minna Puhala, Green Word