Role of Environmental Science in Solving the Plastic Pollution Issue

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Contents

Abstract The first volume of the book "Plastics in the Aquatic Environment" – "Part I: Current Status and Challenges" – gives insights into the role of environmental science and a global perspective. The volume includes 15 chapters dealing with different methods for sampling, sample preparation and analyses of these methods as well as monitoring studies and risks for organisms. Moreover, case studies about the plastic pollution problem from Asia, Latin America, and Europe are presented which gives the reader an integrated overview of the global scope of this issue.

Keywords Global problem aquatic environment, Monitoring, Plastic, Pollution, Risks, Science

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1 Introduction

Plastics are emerging contaminants and found in all environments of the world (including the Arctic [1] and remote mountain regions [2]). Plastics in the environment have been investigated since several decades. Researchers all around the world focus on monitoring in different compartments [3–5]. In the last decades, the focus was set on larger plastics (macroplastics) in the world oceans and on beaches as well as impacts on biota, while small plastic particles (<5 mm, the so-called microplastics [6]) in coastal waters were mentioned for the first time in the 1970s [7, 8] and were then discarded for a long time. In the last decade, researchers started to investigate microplastics in detail in marine and freshwaters, biota, sediments, and soil [9–13]. Moreover, many studies have been published about plastic pollution in different countries worldwide.

Some researchers include plastics as part of the "Anthropocene", a new stratigraphically epoch. Humans are a geological factor and strongly influence the environment. Waters et al. [14] argument that the Anthropocene is another stratigraphically epoch which has to be differentiated from the Holocene. Different definitions and starting points are discussed, one among them the Industrial Revolution [15, 16]. The impacts of the Anthropocene can be investigated in different geo-bio-archives such as floodplains, colluvial deposits, beaches, lakes, deltas, soils or ice caps [17].

Besides research on plastics, waste management is one of the main aspects to find solutions to the plastic pollution. Several directives, national frameworks, and bans on certain products have been established in order to deal with the plastic problematic.

The first volume of the book "Plastics in the Aquatic Environment" – "Part I: Current Status and Challenges" – is composed of 15 chapters about environmental science and the state-of-the-art of research on plastic pollution conducted all over the world. The idea to publish a book about science and stakeholders and their role in preventing, reducing, and eliminating plastic pollution emerged at the International Summer School about plastics in marine and freshwater environments which was organized by the German Federal Institute of Hydrology and the International Centre for Water Resources and Global Change (ICWRGC) in July 2017 in Koblenz, Germany. The international researchers and stakeholders discussed the state-of-the-art of research and also presented the diverse efforts and monitoring techniques which are conducted in the countries all over the world [18].

2 Overview of This Volume

The book "Plastics in the Aquatic Environment" consists of two parts: "Part I: Current Status and Challenges" and "Part II: Stakeholders' Role against Pollution" with a total of 27 chapters. The goal of this book is to introduce the current state-of-the-art in science and to show efforts of industry, commerce, and governments to

tackle the plastic pollution. Such efforts are manifold and include many directions of action, including but not limited to: formal and informal education, various activities performed by NGOs, development of alternative industrial products, voluntary trade reduction measures, and governmental regulatory actions.

The problem of plastic pollution needs immediate attention. While the existing scientific knowledge is still incomplete and the problem is very complex, there is a pressing demand from the public and policymakers to take prompt measures, including regulatory. This two-volume book aims to provide answers as to how the society, scientists, and policymakers can contribute to solving this problem, what is required of them. Moreover, the book also discusses what data are needed from which stakeholders in order to take the more efficient actions.

Whereas Part II of the book, "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution" deals with the society and policy perspectives, Part I gives an overview about the role of environmental science with detailed chapters about sampling, sample preparation and analyses. Moreover, impacts and risks (exposition, hazard, aquatic organisms) for organisms are mentioned and monitoring studies about sources and sinks, transport and fate in the environment for macro- and microplastics are presented. The book also displays case studies from Asia, Latin America, and Europe which gives the reader an overview of the global scope of this issue. Moreover, the last chapters highlight the perception of the plastic issue from the perspective of different countries worldwide.

Stock et al. [19] study pitfalls and limitations in microplastic analyses. The chapter gives an overview about sampling, sample preparation, and analytical methods for analyzing microplastics and discusses the related limitations and challenges of these methods. Although many research papers have been published in the last years about this topic, a comparability of data is still not given. Therefore, the authors describe in detail local and temporal variations and sampling devices in different environmental compartments such as water (plankton and neuston nets, manta trawls, pump-based filter cascades), sediment/soil (shovels, spoons, grabber, corer), or biota. Due to the small size of microplastics (<5 mm) and the complexity of matrices, a thoroughly sample preparation is crucial (size fractionation, density separation, sample purification). Moreover, the authors describe sample loss (adhesion and static forces) and contamination verification via blank samples. The analytical approach covers visual identification and different spectroscopical, spectrometrical, and thermoanalytical methods.

Analytical methods are crucial for detecting microplastics from environmental samples. In their chapter, Dierkes et al. [20] present different spectroscopic and thermoanalytical methods. While spectroscopic methods are, on the one hand, more time-consuming regarding sample preparation, they reveal information about particle numbers, size distribution, color and are non-destructive. Thermoanalytical methods, on the other hand, require less pretreatment of samples and mass concentrations are given. The authors describe the two vibrational spectroscopic methods: Fourier-transform infrared spectroscopy (FT-IR) and Raman spectroscopy which enable reliable microplastic detection when coupled with a particle finding software or a focal plane array (FPA) detector. Identification of particles is conducted with a

comparison of recorded spectra to spectra in a library. These methods are widely used by researchers. Different thermoanalytical techniques (pyrolysis, thermogravimetry, and differential scanning calorimetry) have been used for microplastic analyses in the last years. They may serve as an alternative to spectroscopical methods but also complement the existing methods. However, the authors underline that harmonization of these different methods is still missing.

In the "European Strategy for Plastics in a Circular Economy" the European Commission, inter alia, touches the issue of biodegradable plastics. The Commission recognizes the need to establish a clear regulatory framework for plastics with biodegradable properties as some alternative materials claiming biodegradability properties, such as "oxo-degradable plastics," have been found to offer no proven environmental advantage over conventional plastics. In view of this, the chapter by Endres provides insights into the issue of biodegradable plastics from a technical as well as historical perspective [21]. He defines properly the terminology that is used in the whole context, i.e. "biopolymer", "bioplastic", and "biodegradable plastic". In order to better assess the complex issue, Endres focuses on different degradation mechanisms, gives an overview of different standards to characterize degradability, and describes the physico-chemical environmental conditions and main environmental and microbiological parameters for biodegradability.

Biological and ecological impacts of plastic debris (including bioplastics) in aquatic ecosystems are described by Green [22]. Hereby individual organisms as well as biodiversity and ecosystem functioning are considered. Individual organisms suffer, e.g., from entanglement and ingestion. With regard to ingestion, physical (like shape and size), chemical (like polymer type, additives, and persistent organic pollutants), and biological (associated microbes) characteristics of plastics play a decisive role and were intensively looked at. Furthermore, Green also discusses potential spreading of antimicrobial resistance and present research about effects of plastics on ecosystems including changes of benthic assemblages, nutrient cycling, and primary productivity. Moreover, floating debris has always been important for spreading of organisms (e.g., sessile and mobile ones, without pelagic larval stage) all over the world. Man-made litter such as micro- or macroplastics plays an important role for a further dispersal. Depending on the density of polymers, they either float on the water or sink. Biofilms may cover the low-density plastic particles so that these particles with attached organisms sink onto the sea floor and may change the structure and composition.

Anastasopoulou and Fortibuoni [23] describe the impact of marine litter, which is mainly composed of plastic, on life in the Mediterranean Sea. They focus on the such impact categories as ingestion, entanglement, and effects like colonization and rafting. They detail which species have been reported in literature and online sources to ingest plastics and microplastics, while plastic ingestion is the most studied impact in the Mediterranean area. Furthermore, they describe possible consequences of the different impact categories at the individual and population level. Finally, Anastasopoulou and Fortibuoni assess the gaps in the current scientific knowledge in order to evaluate effects at the individual and population level.

Sapozhnikov et al. [24] investigate interactions of plastics with microorganisms. The first part of this chapter gives an overview about many research papers which have been published in the last years. The chapter describes in detail the results of these articles. The authors evaluate the papers by forms of interactions of different polymers and microorganisms and by biofilm communities and biodegradation of polymers. In the second part of this chapter the authors provide in-depth information concerning their own research. For several years, they studied species composition of microorganisms which colonize plastic litter in natural reservoirs and conducted experiments with regard to colonization pattern of synthetic polymers which they put in the natural environment under defined conditions.

An overview of the state of knowledge and research of freshwater microplastic pollution is given by Zandaryaa [25] from the UNESCO Division of Water Sciences. In the UN 2030 Agenda for Sustainable Development, microplastics and their reduction can be associated with several Sustainable Development Goals (SDGs), mainly for reaching a better water quality and for better protecting the water. In her chapter, Zandaryaa presents and discusses the manifold results from scientific publications about sources, pathways, and occurrences of microplastics in different freshwater environments showing that microplastics have been detected in freshwater environments all over the world in lakes, rivers, groundwater, or drinking water. Health and ecological risks of microplastics with special regard to ecotoxicology, human health risks, and microplastics as carriers and sources of other pollutants are also mentioned. Moreover, measures to reduce microplastics such as sustainable consumption, public awareness, responsible production and manufacturing (e.g., reduction, recycling, and reuse), improving wastewater treatment and solid waste collection are discussed in the chapter.

Cieplic from the BKV company in Germany describes the model "From Land to Sea – Model for the documentation of land-sourced plastic litter" [26]. The BKV company provides industry with data and fact base to serve as an aid for decision-making and discussion on topics of resource efficiency and plastics recycling. Cieplic's model systematically records discharges of improperly disposed-of land-sourced plastic litter, with regard to all of its discharge pathways and discharge sources into the North Sea, the Baltic Sea, and the Black Sea. The goal of this project is systematic recording, structuring, and quantification of the principal discharge sources and pathways for plastics. The model uses several categories of discharge sources and pathways for land-sourced litter, namely: "Coastal regions," "Rivers," "Ports," "Landfills," and "River shipping." According to Cieplic, efforts to prevent further litter in the seas can only be effective if discharge sources and pathways along with the corresponding mass flows of plastics into the water are detected and analyzed.

Horodytska et al. [27] have a critical look at plastic waste management and describe the current status and its weaknesses. Global plastic production is still rising and with it the plastic pollution of the natural environment due to the weaknesses of existing plastic waste management strategies. Although approx. 75% of the plastic litter come from developing countries, still 25% remain from western countries owing to the limited efficiency of collection systems and low

recycling rates. The authors give an extensive overview of current waste management routes and existing recycling and recovery options with focus on rigid and flexible materials, respectively. These two different types of plastic materials differ regarding their behavior and are therefore usually treated separately. Sources of plastic waste also vary and are mainly grouped into post-industrial (generated during the converting operations, e.g. rejects and offcuts, and this type is usually clean and homogeneous) and post-consumer (mixture of products at the end of their service lives) plastics, whereby post-consumer plastics, not only due to its higher amount, pose a substantial challenge when treating. The post-consumer waste can again be further subdivided into the so-called commercial waste (mainly secondary and tertiary packaging from retail industry areas) and the domestic post-consumer waste (from kerbside collection). Commercial waste is generally homogenous, its composition mostly known, and the amount of physical impurities as well as chemical contaminants is usually low. Domestic post-consumer waste, however, is mostly dirty, often highly contaminated and generally heterogeneous. Waste treatment methods can be divided into mechanical recycling, chemical recycling, and energy recovery. Prior to waste treatment, however, a lot of actions are necessary for managing human produced waste. These include collection, transportation, sorting, and disposal or treatment. The European Waste Framework Directive clearly states that operations for managing waste should not cause any damage to the environment and human health, respectively. For this reason, a waste hierarchy has been implemented for specifying precedence in waste treatment processes: (1) prevention or minimization, (2) preparing for reuse, (3) recycling, (4) recovery as energy, and (5) disposal. The present economy model, which based on extraction, use as well as disposal, is not sustainable from an environmental perspective, particularly with regard to fossil-based non-biodegradable plastics. For this reason, the idea of a new economy model, the Circular Economy, has been developed. The main principles are zero waste, diversity, use of renewable energy, and interaction between systems. After the product's service life the following steps should be addressed: (1) maintenance, (2) reuse, (3) refurbishment, and (4) recycling. But a successful waste management has to start with effective collection and sorting operations. Environmental pollution and waste accumulation can often be traced back to the lack and inefficiency of municipal collection strategies, respectively, especially in developing countries. Inexistent waste collection services as well as limited capacities of landfills play an important role so that inhabitants and authorities feel compelled to throw the waste directly into the environment.

The chapter by Kalčikova and Gotvajn [28] deals with plastic pollution in Slovenia. In the first part the practice of waste management and plastic waste is summarized. Slovenia significantly increased the recycling rate of plastic and packaging waste to one of the highest in Europe (62–69% in 2016) and decreased landfilling in the last years. Social aspects, fines, education, and NGOs considerably contribute to this transition. The second part of the chapter presents research about plastics and microplastics in Slovenia in the last years. In order to prevent plastic waste, researchers studied other materials and investigated biodegradable plastics based on natural products. At the same time, researchers conduct conduct monitoring

and impact studies on macro-and microplastics in aquatic environments and biota. The results show that the Slovenian coast is significantly polluted by microplastics although a good waste management in the country exists.

Kolitari and Gjyli [29] studied marine litter and its abundance, composition, and sources along the south-eastern coastline of Albania. The four beaches differed significantly. Two beaches were characterized as semi-urban, one as urban and one as rural. During one winter, the authors monitored 12 cross sections with 12,000 m^2 and an extension of more than 1,000 m. The results revealed a mean litter density of 219 items/100 m and 0.219 items/m^2. The litter was dominated by plastics and other polymer materials (58%) and 37.5% of the items collected mostly originated from tourism and recreational activities. Moreover, poor waste management also contributes to marine litter. At the end of their report they provide options to manage the litter of Albanian beaches as well as mitigation actions that may substantially help to address the problem.

An overview about plastic pollution as a regional problem in East Asia is presented by Walther et al. [30]. The detailed chapter gives insights into the state-of-the-art of macro- and microplastic research in the four countries China, Japan, South Korea, and Taiwan. The authors also summarize the efforts which are made by government policies, society, and the industry/inventors to reduce plastic pollution, to increase recycling, and to create alternative products. The authors used their own research results and conducted a literature review by searching in Web of Science and Google Scholar using specific keywords and their combinations. The results show that intensive research has been conducted in the four abovementioned countries in the last 10 years and that all countries are characterized by high pollution with plastics. However, due to the different socio-economic-political systems, a large difference occurs between the countries regarding mitigation efforts to decrease plastic pollution. The government started to ban some single products and some regional frameworks and collaborations exist between the countries.

The case study of Tanchuling and Osorio [31] deals with monitoring of microplastics in rivers within Metro Manila, Philippines, from 2018 until 2020. The authors studied this area as the Philippines was one of the largest contributors of plastics in the ocean in 2010. The results reveal that up to 60,000 particles/m^3 were detected in the rivers of Metro Manila which is higher than in many studies worldwide. The microplastics mostly degraded from larger plastic pieces and originated from solid waste. The second part of the chapter deals with solid waste management and the regulatory framework. Although a solid waste management infrastructure exists within the country, the waste is disposed on landfills. Moreover, the collection coverage is not very high. The recycling rate has increased up to 33% in 2010; however, many more efforts are still needed to better tackle plastic pollution.

One chapter deals with plastic contamination in Brazilian freshwater and coastal environments. Lima et al. [32] reviewed 37 articles on the basis of Scopus and Web of Science. Although literature about plastics in Brazil exists, a detailed research on plastic pollution in freshwater environments has not been conducted yet. A study of interaction with freshwater fish revealed the source of ingested microplastics from

discarded trash. Most of the articles deal with estuarine environments showing that biota ingested microplastics. The results reveal that plastics of all sizes are present in the different compartments (water and sediment). The level of pollution has been described in most of the studies; however, information about transport and pathways are mostly missing. Sources of plastics found in the environment were mostly related to fisheries, urbanization, or improper disposal. On beaches, domestic waste, sewage, and fisheries were mentioned as possible sources. Lima et al. suggest using the source-to-sea approach in order to better understand the plastic problems along the Brazilian coast.

Ershova et al. [33] describe the results of a monitoring study of marine litter on regularly cleaned and wild isolated beaches in the Russian part of the Gulf of Finland (Neva Bay) and the south-eastern Baltic Sea. The authors used different methods (OSPAR, NOAA, IOW beach litter) for monitoring micro- to macrolitter (2 mm to >25 mm) during a four-year period from 2016 to 2020. The monitoring included the wave wrack-line zone and the entire width of the beach from the water line to the first vegetation. The results reveal that no difference can be made between both kind of beaches (wild and regularly cleaned ones) as they are all polluted with marine litter and plastics (domination of microplastics). However, a clear distinction can be made of findings in the Gulf of Finland and the south-eastern Baltic Sea. In the south-eastern Baltic Sea, the beaches are relatively clean and no obvious distinction can be made between high and low populated and visited areas. In the inner part of the estuary of the Neva Bay, the authors detected the largest amount of marine litter. In the region of the Gulf of Finland, plastic pellets, glass, cigarette butts, metal and building plaster, synthetic napkins, and cotton-buds dominate on the beaches. The monitoring results show that different methods complement each other and that they partly depend on the composition of the beaches. The results will be integrated in a database for estuaries and lagoons of the Baltic Sea and will be used for recommendations for the national program of marine litter monitoring along the Russian coasts of the eastern part of the Gulf of Finland.

3 Discussion

World publishing houses pay great attention to the topic of plastic pollution. In Springer, several books have been published about the plastic problem in marine and freshwater environments, especially in the most recent years. These books mainly dealt with research which has been conducted lately.

Looking at the contents of the books published in Springer in the past 5 years, it becomes obvious that the interest towards this problem has been growing significantly. The topics covered have now become more specific, detailed; new aspects of microplastic pollution emerge as subjects for scientific research. For example, in 2015, the book “Marine Anthropogenic Litter” (eds. Melanie Bergmann, Lars Gutow, Michael Klages) [34] analyzed the problem of marine litter, mainly plastics and microplastics, starting from the history of marine litter research, its composition

and distribution, moving to discussing effects of marine litter on marine life, sources, pathways, and consequences of the presence of microplastics in the marine environment, as well as methodologies for their detection and identification. The book also reviewed the economics, regulation, and management of marine litter and the role of citizen science in monitoring of marine litter. It is seen both from the title of the book and the titles of the chapters that they tackled the main aspects of the problem. Further books started to focus directly on plastics or microplastics. For instance, in 2018, the book "Freshwater Microplastics. Emerging Environmental Contaminants?" (eds. Martin Wagner, Scott Lambert) [35] discussed the specific problem of microplastics in freshwater systems. In analyzing whether freshwater microplastics were new environmental contaminants, the book reviewed research on microplastics in lakes and rivers, including sources, transport, fate, interactions with biota. Acknowledging the complexity of this problem, the book also examined risk perception of plastic pollution and the role of citizen science and stakeholder involvement, discussed the social-ecological risk perspective, challenges for management and regulation, and the potential solutions.

In 2019, the book "Hazardous Chemicals Associated with Plastics in the Marine Environment" (eds. Hideshige Takada, Hrissi K. Karapanagioti) [36] dug deeper and covered chemicals and additives in plastics, their environmental risks, sorption and desorption of hydrophobic organic compounds. The book also examined ingestion of plastics by marine organisms, factors affecting the amount of plastic in digestive tracts of such organisms, and following on this, transfer of hazardous chemicals from ingested plastics to organisms of the higher trophic level. The book also discussed in detail consequences of the fact that plastics have several chemicals within them. In the same year another book was published, "Bioremediation Technology for Plastic Waste" (eds. Mohd Shahnawaz, Manisha Sangale, Avinash Ade) [37], which focused on bioremediation technologies for plastic degradation, as well as covered other aspects of plastic waste degradation and plastic waste in general, including legislation and social awareness.

The books published in 2020 covered yet even more specific research questions. The book "Microplastics in Terrestrial Environments – Emerging Contaminants and Major Challenges" (2020) (eds. Defu He, Yongming Luo) [38] focuses on microplastics in terrestrial environments, discussing sources, distribution, and environmental fate of microplastics, impacts on ecosystems, health risks, as well as the effect of biodegradable polymers on the environment, and management and legal systems for the control of plastic and microplastic pollution. The book "Mare Plasticum – The Plastic Sea. Combatting Plastic Pollution Through Science and Art" (2020) (eds. Marilena Streit-Bianchi, Margarita Cimadevila, Wolfgang Trettnak) [39] describes the impacts of plastics and microplastics; the "plastisphere", or the new marine ecosystem, the current situation of plastic pollution in various parts of the world. The book provides a brief history of plastics, discusses existing effective and innovative solutions, including the use of circular economy methodologies; outlines the causes of plastic problem in China and Asia and the measures being taken. It further depicts the role of rivers and streams in moving plastic debris from land to the ocean and illustrates the problems associated with small plastic

wastes in soils. The book "Proceedings of the 2nd International Conference on Microplastic Pollution in the Mediterranean Sea" (2020) (eds. Maria Cristina Cocca, Emilia Di Pace, Maria Emanuela Errico, Gennaro Gentile, Alessio Montarsolo, Raffaella Mossotti, Maurizio Avella) [40] covers a wide range of topics related to microplastics pollution, which confirms both the complexity and the strong interest towards this research area. It deals with such issues as the sources, fate and impacts of microplastics, methods for their analysis, microfiber pollution, biodegradable plastics, inhalable microplastics, occurrence of nanoplastics in drinking water, innovative solutions to the microplastic problem, transport of pollutants in and on microplastics, and many more other specific issues covering various aspects of microplastic pollution.

We are thankful to Springer for their continuous interest towards the problem of plastic and microplastic pollution and are positive that such books contain comprehensive information on the problem and should be used by various stakeholders, such as scientists, decision- and policymakers, national and international institutions, educational establishments, NGOs, in order to better understand the problem and develop effective solutions. We are also certain that such books can be used by the general public thus raising the awareness of this issue, which will assuredly contribute to the behaviour change.

In this book volume, "Plastics in the Aquatic Environment – Part I: Current Status and Challenges," the chapters provide valuable information on current research areas and challenges that scientists deal with now. We believe that this volume will be useful for scientists in various career stages as well as policymakers to inform themselves of the latest developments in this field and case studies in various countries. We hope that this information will be beneficial and will help solve this problem worldwide in the nearest future.

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