MICROPLASTICS IN FRESHWATER WATER ENVIRONMENTS

A SCOPING STUDY

Report
to the Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

The world is continually faced with increased complexities of water pollution and its effects. Current legacy water pollution issues are addressed through a number of global conventions and agreements, such as the Stockholm Convention which deals with persistent organic pollutants (POPs), the Minamata Convention dealing with Mercury, etc. However, there are emerging and new pollutant issues, currently not covered where there is a clear concern, but the science has not caught up yet to convince and assist in policy and practical interventions. Plastic and microplastic pollution, along with related nanoparticles (Hernandez et al., 2017), is one such 'emerging' concern. Plastic pollution in the marine environment is well documented, however, there are few studies on the extent of pollution in freshwater and treated water sources. This project addresses microplastics in South African freshwaters, noting that almost all existing knowledge is derived from the large volume of literature from marine studies. Given the low dilution potential of South African freshwaters, coupled with waste management deficiencies (notably the obvious large amounts of plastics in our environment), microplastic pollution is an unknown component of possible impact and injury to our freshwaters and freshwater-dependent biological processes. This scoping study is an attempt to characterise the presence, levels, and potential implications of microplastics in freshwaters, as well as provide recommendations on areas of concern, as well as research gaps and future priorities for South Africa.

METHOD

As part of the literature survey, a scan on existing definitions of microplastics and particles was conducted. The literature survey done included grey literature such as reports, on microplastics and microparticles in the aquatic environment. Findings made from literature were categorised into common themes such as sources, pathways, threats, possible accumulation of extraneous pollutants, long range transport, breakdown, uptake by organisms, and any other issues. In addition, an annotated compendium of relevant sampling and analytical methods was made, with specific attention as to the situation and conditions in South Africa, accepted methods and recommendations made by the National Oceanic and Atmospheric Administration. Sampling and analysis for microplastics was done in a variety of freshwaters, including drinking and ground water in selected locations in North West, Gauteng and the Free State, mainly in commercially important river systems such as the Vaal River, Mooi River and Wasgoedspruit River. Municipal water samples were collected from the greater metropolitan municipalities such as City of Johannesburg and Tshwane. A synthesis was made from each of the work packages above and translated to the situation in South African freshwaters and water cycles, including potential threats to human health and biota. From this potential hot-spots or areas of concern, and potential mitigating actions, as well as research gaps and future priorities were identified.

RESULTS

Microplastics in surface water sources

Based on the sites used for this project, freshwater sources were found to contain microplastics between 56 and 0.33 particles per litre. Two sites had very high concentrations of plastic particles; 56 and 39 particles per litre, respectively. The geographic distributions are also insightful as very high fragment concentrations at was observed at 2 Sites. The heavily used Crocodile River that drains most parts of Johannesburg recorded the highest the total particle, fragment and fibre counts. At the Vaal Dam and towards the north, larger particles were observed and make up greater proportions. Fragments and fibres are also prominent to the west near Potchefstroom, while northern and eastern parts have noticeably lower concentrations. As has already been shown, small particles dominate at all sites. The fibre size classes were more homogenously distributed. Fragments had a very clear pattern when compared against size classes, with the smallest size class (20-300 µm) having four times more particles than the other fragment particle size classes combined. This pattern could be due to a significant release of small manufactured fragments in excess of larger particles, the resultant effect of the breakdown from larger to smaller fragments, or a combination of both. For fibres, there was no size-class pattern discernible although the Kruskal-Wallis analyses did indicate some size-class differences.

Due to the amount of literature available on freshwater microplastics, as well as the varied differences in the sampling methods used in other studies, there is very narrow scope for comparison with other global studies. Based on the available data, low to average levels were observed. Higher microplastic levels have been reported in developed countries, such as China, US and in some European states (see Table below).

Location	Microplastics per litre of water	Reference
Austrian Danube, Austria	Mean: 3.2 $\times 10^{-4}$ Maximum: 5.0 $\times 10^{-3}$	Lechner *et al*., 2014
Goiana Estuary: Brazi	Maximum: 1.5 $\times 10^{-4}$	Lima *et al*., 2014
WWTP effluent: Paris, France.	Untreated waste water: 260-320 Effluent: 14-50	Dris *et al*., 2015
Italy: Lake Bolsena and Lake Chiusi	0.0027 0.0034	Fischer *et al*., 2016
Dutch river delta and Amsterdam canals	Mean: 100 Max: 187	Leslie *et al.,* 2017
USA general	Mean waste water treatment effluent: 0.5 ± 0.024	Mason *et al.*, 2016
North America: 29 Great Lakes tributaries	Mean: 0.0042 Maximum: 0.032	Baldwin *et al.,* 2016
Los Angeles river, San Gabriel river, Coyote Creek	13	Moore *et al.,* 2011
China: Lake Taihu (developed area)	3.4–26	Su *et al.*, 2016
China: Three Gorges Dam	Mean: 4.1 Maximum: 12.6	Di & Wang, 2017
Yangtze Estuary	Mean: 4.1 Maximum: 10.2	Zhao *et al*., 2014
China: Lakes, Wuhan	8.9	Wang *et al.,* 2017
Gauteng and North West Province	**Mean: 1.9** **Maximum: 5.12**	**This study**

Microplastics in groundwater sources

This study is one of the few studies to evaluate microplastic pollution in groundwater. The size class profiles seem similar between soils and water, albeit with much lower numbers of both. The fragment proportion is also much lower in soils compared to surface water (mean of 0.17 particles per litre). Only fragments in the two lowest size classes were found in soil water, but fibres occurred in all size classes. However, in many places, people get their prime household consumption water from groundwater. Therefore, more studies would be needed to determine the factors involved, as well as the possible health implications it may have.

Microplastics in tap (drinking) water

Tap water samples were collected from selected tap in City of Johannesburg and Tshwane regions. Generally, much lower particles were observed in treated water compared to the raw water. Tap water samples collected from the Tshwane region seemed to have fewer fragments compared with Johannesburg. In Johannesburg tap water, particles seem to be distributed homogenously between different size classes, while in the Tshwane region tap water only had particles in the two smallest size classes.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this scoping study and a host of other reports and publications, we present the following recommendations.

Research priorities

Having scanned the literature, the following research questions and themes, as well as our own insights, seems appropriate for South Africa.

- Factors that affect release, transformation, persistence, and transportation in surface and ground waters
- Baselines and time trends
- Polymer compositions of microplastics
- POPS (including DDT and PFAS), metals, and other chemicals in plastics and microplastics
- Leaching of chemicals from plastics under South African conditions (high temperatures, dry periods, and UV).
- Biological effects studies in laboratory and field
- Sinks and sources
- Runoff and waste sites
- Accumulation in humans, animals, plants, and other biota
- Microplastics in ground- and tap waters
- Aerial deposition
- Investigate the interaction of microplastics, bacteria, and antimicrobial resistance

Policy recommendations

- Following the actions taken in other parts of the world, eg USA, Sweden, UK and elsewhere, South Africa needs to consider the immediate ban on the import, manufacture, use, formulation, sale, and export of microbeads in products.
- As an example – in September 2002, the South African government, representatives of labour and of industry, signed a memorandum of agreement concerning use of disposable polythene shopping bags. Research conducted in 2010 showed a continued increase in carrier-bag consumption will continue over time, despite the price increases. Thus, it may be imperative to review and tighten South Africa's responses to plastic pollution. Implementation of the Waste RDI roadmap needs to be strengthened in order to provide much needed guidance on waste management in the South African environment.
- Although plastic does not seem to feature much as one of the water quality concerns in South Africa, increasing awareness raising, most likely will reduce the consumption of single use plastics, and increase the use of value added plastics, thereby reducing environmental plastic pollution.
- Plastic packaging seems to be the most obvious and visible component of inland plastics pollution. Given market forces and few regulations, meaningful voluntary reduction of the plastic components of packaging, or promoting the use of recyclable or re-usable plastics (which are more expensive), seems remote. However, even 'remote' opportunities can be advanced, and these opportunities should be investigated. There is an opportunity to harness the circular economy concept for redefine products and services to design waste out, while minimising negative impacts.

Education

The inclusion of waste management into the education curricula is important. Currently training is only offered at higher education level at CSIR and NWU in partnership offers a B.Sc. Hons course in Environmental Sciences (specialization in waste management) and Master's degree in waste management, as implementing agency of the Department of Science and Technology.

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ACRONYMS & ABBREVIATIONS

AMWN	African marine Waste Network
AOP	Adverse outcome pathway
DDT	Dichlorodiphenyltrichloroethane
FT-IR	Fourier-transform infrared spectroscopy
HDPE	High-density polyethylene
MP	Microplastics
NOAA	National Oceanic and Atmospheric Administration
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyls
POP	Persistent organic pollutant
PP	Polypropylene
PVA	Polyvinyl alcohol
ROS	Reactive oxygen species
SANPRO	South African Plastics Recycling Organisation
SEM	Scanning electron microscope
UV	Ultraviolet
WPO	Wet peroxide
WWTP	Waste water treatment plant

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

The world is facing and increasing complexity of water pollution and its effects. The causes of water pollution are often inter-related, such pollution as a result of mining, industrialisation, and expansion of residential areas leading to increased environmental pollution (STAP, 2012) or water quality deterioration due to as climate variabilities and change. Although the global community has come together to address current legacy pollutant issues, such as persistent organic pollutants (POPs) through the Stockholm Convention, Mercury pollution through the Minamata Convention, new and emerging issues have to overcome a lag period whereby the concern is obvious, but the science has not caught up yet to convince and assist in policy and practical interventions. Plastic and microplastic pollution, along with related nanoparticles (Hernandez *et al*., 2017), is one such 'emerging' concern. However, 'emerging concern' in this context also reflects that some of the legacy contaminants might become 'emerging' as new sources develops. Plastics and microplastics are a class of pollutants generally labelled as 'contaminants of emerging concern' (STAP, 2012) as opposed to legacy classes such as POPs (e.g. DDT, PCB, and dioxins), polycyclic aromatic hydrocarbons, solid waste, and heavy metals, because legacy issues have largely been or are being addressed.

Microplastic particles have been found in aquatic, terrestrial, and atmospheric systems (Wagner and Lambert, 2018). It is dispersed throughout water, soil, and air and is often found in biota. The presence and fate of plastic debris in our oceans is well documented. Oceans act as a sink for plastics, as great volumes of terrestrial plastic make its way into aquatic systems and deposited into the oceans. Billions of tons of plastics are produced annually and applied in a multitude of industrial, household, agricultural, and medical sectors. The wide spread use of plastics is due to their high durability and malleable characteristics. Unfortunately, due to the general incorrect manner in which plastics products are discarded of, and poor management of waste facilities, plastic debris ends up in the aquatic environment. Microplastic particles have been found to occur in parts of the ocean. Studies have found microplastic particles in deep-sea regions (Woodall *et al*., 2014). Plastic is also present in remote deep sediments and water layers that hold large volumes of plastic that have not been reckoned into estimations of the oceanic plastic volume (Van Cauwenberghe *et al*., 2013).

Microplastics (arbitrarily understood to be <5 mm in its largest dimension) have two main sources: primary sources which are the manufactured microplastics and secondary microplastics, which are the fragments that result from the degradation of larger plastic pieces. Manufactured microplastics (primary sources), include industrial pellets, scrubbers (as used in cosmetics), and abrasives in synthetic sand-blasting. Microplastic beads, which are used in cosmetic exfoliates, and end up in rivers because the current clean-up methods of sewage treatment plants are insufficient in removing such small particles (Fendall and Sewell, 2009). These particles often consist of polyethylene, polypropylene, polystyrene, poly (ethylene terephthalate), and poly (vinyl chloride) (Andrady, 2011). Secondary microplastic fragments are derived from the degradation of larger plastic pieces. Most plastics are very durable, taking a long time to breakdown completely, depending on types of plastic and conditions. When exposed to oxidative conditions, UV radiation, and physical stress, they become brittle, fragmenting into smaller and smaller fragments (Andrady, 2011). Fibres from washing fabrics have also recently been recognised as an important contributor to the microplastic component of pollution but it is less well understood. A general schematic of how plastics enter the aquatic environments in shown in Figure 1-1.

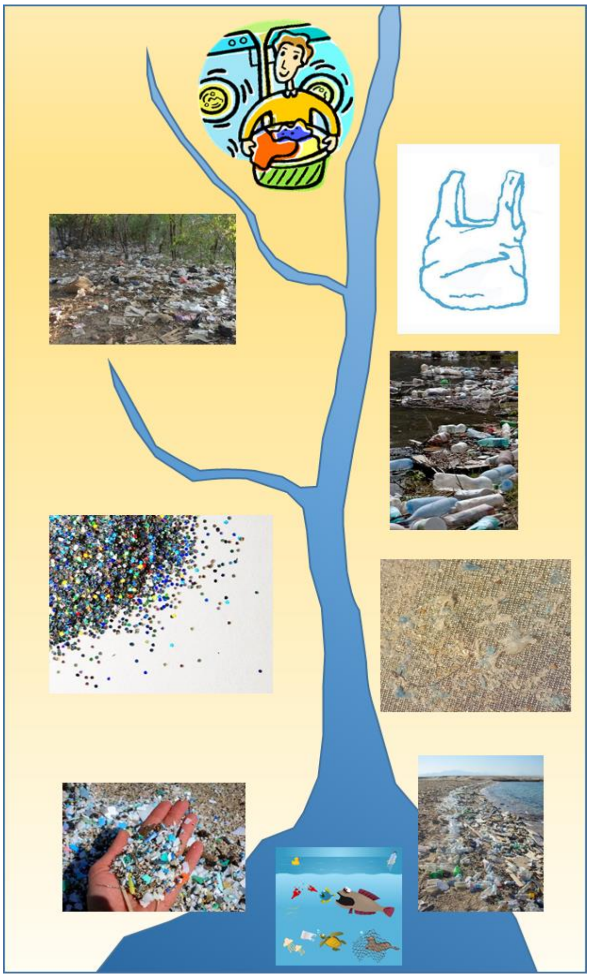


Figure 1-1: General representation of how land-based consumption and use of plastics and microbeads end up in rivers and oceans, breaking down along the way into smaller and smaller pieces.

While there is an overwhelming number of published studies on plastics and microplastics pollution in the marine environment, there is a dearth of information on microplastics in freshwater systems. In the light of the rapid recent developments in microplastic research, countries with developing economies such as South Africa have initiated a number of studies in order to improve understanding on microplastic quantities and distribution in freshwater and treated water sources (Verster *et al*., 2016). The interest in microplastics in the environment is motivated by the large amounts likely to be involved due to the known ubiquity of plastic debris and microplastics in the marine environment. Interpretation of a growing knowledge base of plastic debris in aquatic systems consistently indicates the real and potential risk of microplastics at many levels (Cole *et al*., 2011; Depledge *et al*., 2013; Do Sul and Costa, 2014; Wright *et al*., 2013). A recent assessment by UNEP concluded that the damage to marine ecosystems equates to about $13 billion, every year, and probably an underestimate (UNEP, 2014). As freshwater serves as one of the pillar resources of an economy and a primary human need it is necessary to assess the threats to this resource. This scoping study is an attempt to characterise the presence, levels, and potential implications of microplastics in freshwaters, as well as provide recommendations on potential hot-spots or areas of concern, as well as research gaps and future priorities for South Africa.

1.2 PROJECT AIMS

The following were the aims of the project:

1. To conduct a review of literature on existing definitions of microplastics and particles, their occurrence in the aquatic environment and compile a list of research entities working on microplastics in South Africa.
2. To develop and test sampling and analytical methods with specific attention as to the situation and conditions in South Africa.
3. To sample and analyse microplastics and microparticles in a variety of freshwaters, including river water, drinking and groundwater.
4. To construct a synthesis of the above, translated to the situation in South African fresh-estuarine and coastal waters and water cycles, including potential threats to human health and biota. Priority plans of action will be identified, as well as possible and potential mitigating actions.

1.3 SCOPE AND LIMITATIONS

Data presented in this report is part of an initial baseline study and as such the findings are inconclusive. Due to the amount of literature available on freshwater microplastics, as well as the varied differences in the sampling methods used in other studies, there is very narrow scope for comparison with other global studies. Based on the available data, low to average levels were observed.

CHAPTER 2: THE GLOBAL PLASTIC POLLUTION PROBLEM

2.1 WHAT ARE PLASTICS?

Plastic as a material is generally understood to include synthetic (fossil fuel derived) and or natural organic (biomass derived) polymers that can be formed into desired shapes and forms (Wagner & Lambert, 2018). Plastic material is generally of low cost and great utility, such as packaging, medical applications, piping, construction, and a wide variety of other applications such as manufacture of protective clothing, safety equipment, applications in medical, electronic, and scientific equipment, making of vehicle parts, toys, electronics, etc. Plastics have many benefits, with many applications in packaging, as it protects foods and other products from getting spoiled, soiled, or contaminated. Packaging is also used as marketing and product recognition tools. Other benefits include: plastics being light-weight thereby reducing transport costs. Plastic piping and storage containers can reduce the chances of water pollution (Hahladakis et al., 2018). Common types of plastics and their uses are shown in Table 2-1.

Table 2-1: Common types of plastics and their densities[1]

Type of polymer	Typical use	Density (g/cm^{-3})
Distilled water		1.00
Brackish water		1.005 – 1.012
Sea water		1.025 – 1.027
Natural rubber	Vehicle tyres	0.29
Polyethylene* - low density	Plastic bags, outdoor furniture	0.91 - 0.93
Polyethylene* - high density	Bottles, pipes	0.94 - 0.97
Polypropylene	Rope, bottle caps, gear, strapping	0.85 - 0.94
Polystyrene (expanded)	Cool boxes, floats, cups	0.016 - 0.36
Polystyrene	Utensils, containers, microbeads	0.96 - 1.05
Polystyrene (high impact)	Shelves, printed graphics	1.04
Polyamide (Nylon)	Fishing nets, rope	1.12 - 1.14
Polycarbonate (bisphenol-A)	CDs, glass alternative, lenses	1.2
Polyurethane	Foams	1.2
Metacrylate (acrylic)	Alternative for plate glass	1.19
Cellulose acetate	Cigarette filters, fabric fibre	1.28
Cellulose nitrate	printing inks, nail polish, foil	1.35
Polyvinyl chloride	Film, pipe, containers	1.38
Polylactic acid (biodegradable)	Packaging, cups	1.21 - 1.43
Polyethylene terephtelate	Bottles, strapping	1.34 - 1.39
Melamine	Flooring, dinnerware, dry boards	1.57

*Can be manufactured to required densities

The density of the various plastics becomes important as it indicates their buoyancy relative to water. There are many types of polymers that can form plastics, and many different ways to classify them, including chemical and crystalline structures, production process, hardness, design, density, capacity to absorb water, conductivity, and degradability (Table 2-1). The vast majority of monomers used to make plastics

[1] Sources: GESAMP (2015), https://www.engineeringtoolbox.com/polymer-properties-d_1222.html and http://scientificpolymer.com/density-of-polymers-by-density/

are derived from fossil hydrocarbons and thus, most are not biodegradable. Given the challenges of fossil fuel-based plastics, biomass derived or biodegradable plastics are slowly gaining momentum, and are normally made from one or a combination of substances such as lignin, chitin, wool, starch, protein, DNA, etc. Virgin plastics are pure polymers made from their constituent monomers and contain no additives to change its properties or appearance, polyethylene and polypropylene are such examples. Plastics are also being manufactured in very small sizes, typically referred to as microplastics, microbeads, or nanoplastics. This report will mostly focus on these types of plastics. A generalised representation of plastic production is shown in Figure 2-1.

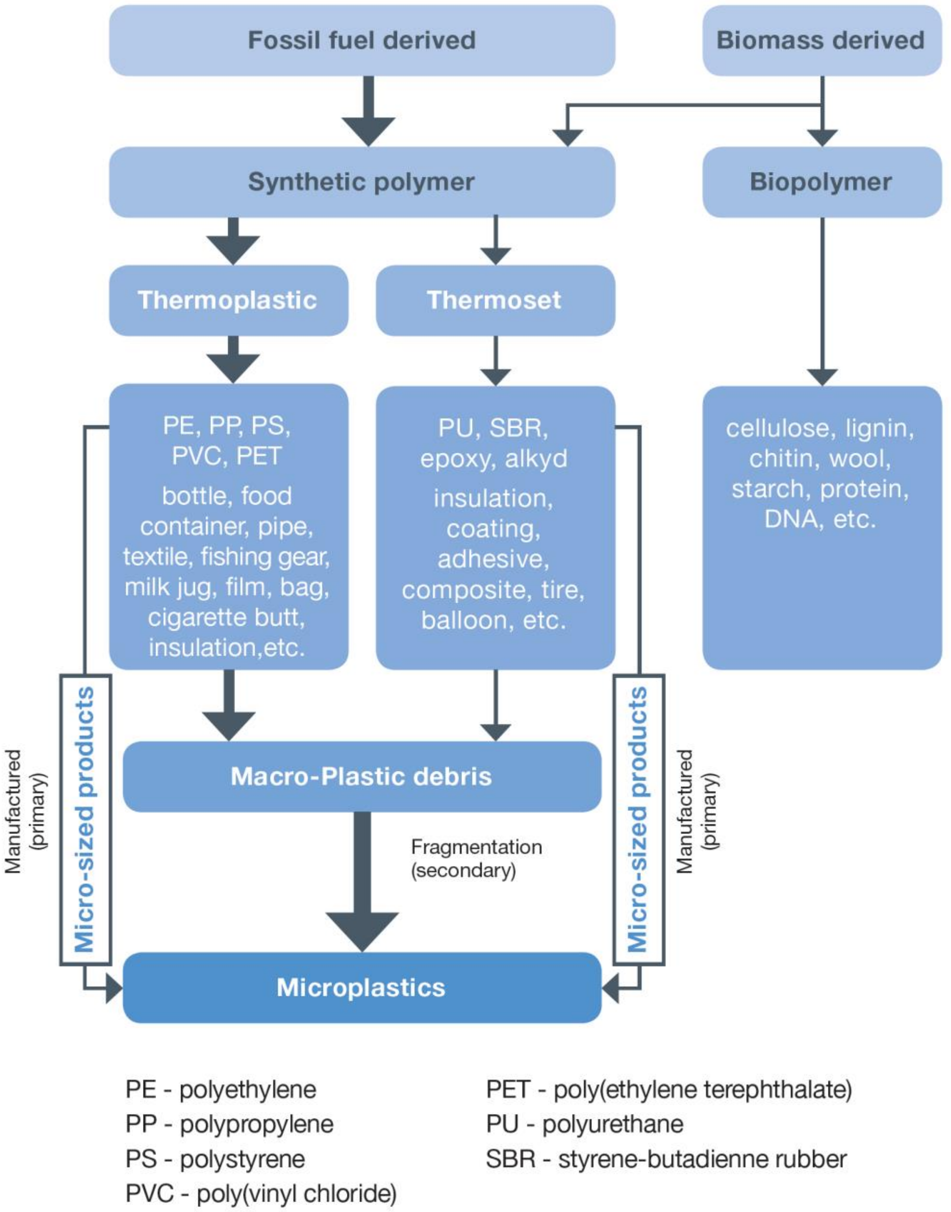


Figure 2-1: A generalised schematic of plastics production (GESAMP 2015. Reproduced with permission).

2.2 EXTENT OF GLOBAL PLASTIC POLLUTION

Plastics have been around since the 1950s, and it is estimated that by the year 2015, a total volume of 8.3 billion tonnes of plastic had been produced. With the current annual production of plastics estimated about 300 million metric tons, it is expected that their presence in the environment is much higher than earlier predicted (Andrady, 2017). Biomass-based plastics currently have a low global production capacity, currently estimated at only 4 million tonnes, since they are biodegradable their presence in the environment is expected to be insignificant (Geyer *et al.,* 2017). Geyer and colleagues (2017) have also suggested that as of 2015, about 6.3 billion tonnes plastic waste has been generated, of which about 567 million tonnes (9%) has been recycled, 756 million tonnes (12%) has been incinerated and a bulk of it, about 4.98 billion tonnes (79%), has been accumulated in landfills or the natural environment. Based on the current production and waste management trends, it is projected that about 12 billion tonnes of plastic waste will be end up in landfills or in the natural environment by 2050. These projections have been well depicted in a recent graphic which appeared on the 10 December 2017 issue of the BBC's Science and Environment section (http://www.bbc.com/news/science-environment-42264788). A study by Jambeck *et al.* (2015), estimates that in a worst-case scenario, there may be a total of about 250 million metric tons of plastics would be present in the marine environment by the year 2025 (Figure 2-2).

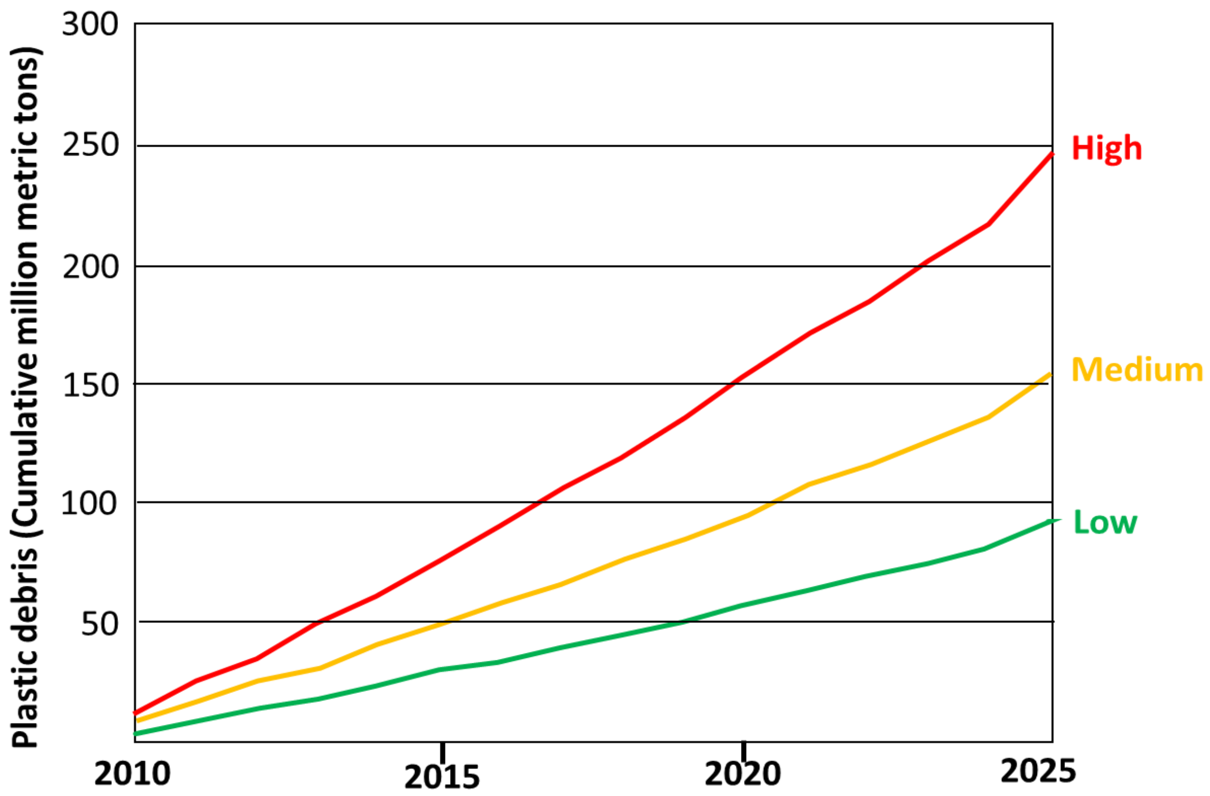


Figure 2-2: Estimated cumulative releases into the global marine environment from mismanaged plastic wastes for three different release scenarios (Redrawn from Jambeck *et al*., 2015).

2.3 THE PLASTICS INDUSTRY IN SOUTH AFRICA

2.3.1 Market size

Plastic is a vital part of the South African economy, with the plastic manufacturing industry contributing 1.6% to the GDP and 14.2% to the manufacturing sector in 2014. The industry is also growing (Figure 2-3 and 2-4). About 60 000 people are employed, formally and informally, by about 1 800 companies across the plastics supply chain. Total turnover was an estimated $3.6 billion in 2014, with exports of $1.25 billion, and further imports of $2 billion (the DTI 2016). The South African government has identified the plastics industry as a priority sector to promote economic growth through the IPAP (Industrial Policy Action Plan 2016-17 – 2018/19) by stimulating aspects such as export, trade policy measures, innovation, and recycling (the DTI 2016).

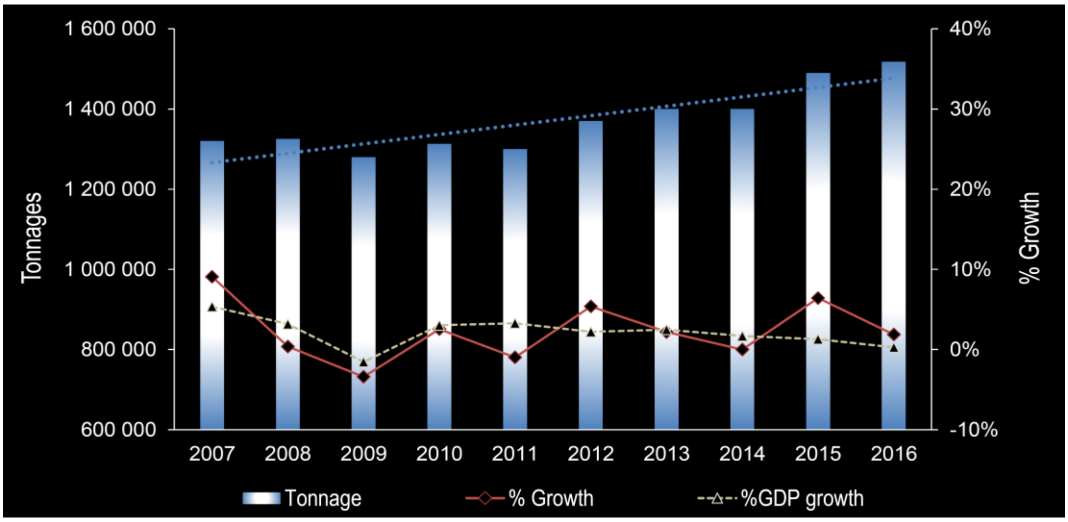


Figure 2-3: The growth in the use of plastics by the South African industry between 2007 and 2016. (Reproduced, courtesy of Me. Annabel Pretorius, SANPRO.)

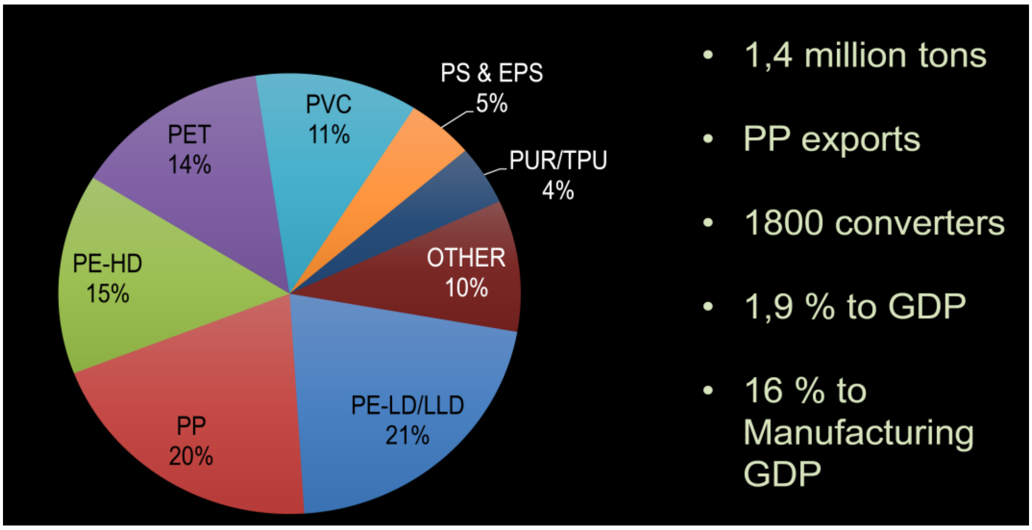


Figure 2-4: The composition of the different polymers used in the South African plastics industry. (Reproduced, courtesy of Me. Annabel Pretorius, SANPRO.)

2.3.2 **Typical uses of plastics in South Africa**

The greatest portion of this used for packaging (hard and flexible packaging), incorporating the plastics industry into almost every part of the South African economy (Verster *et al*., 2017). About 1 490 000 tonnes of virgin plastic and 310 600 tonnes of recycled plastic was used across all industries in the country in 2015 (Plastics SA 2016; and http://www.plasticsinfo.co.za/). Packaging uses about 55% of the plastics and building and construction materials about 15% (Figure 2-5). Sectors using 6% or less each include electronics and electrics, automotive and transport, engineering, agriculture, and domestic products (Plastics SA 2016). South Africa's own polymer production presented 0.47% of the global production, yet the consumption of plastics far outweighed the consumption in Europe. This resulted in a trade deficit of approximately R 15 000 000 000 in 2015. The largest consumer of polymers is the packaging industry, using up to 53% of all plastics converted. The two most common types of converted plastics in South Africa are PE-LD (Low-density Polyethylene) and PP (Polypropylene). Together, the production of PE-LD and PP plastics consumed more than 600 000 tonnes of the 1.5 million tonnes polymer raw materials used in 2015. One of the biggest markets for PE-LD is plastic carrier bags. A study published in 2010 reported the use of 8 billion plastic carrier bags per annum in South Africa alone, of which most end up on open dumping landfill site where the bags can easily be blown away.

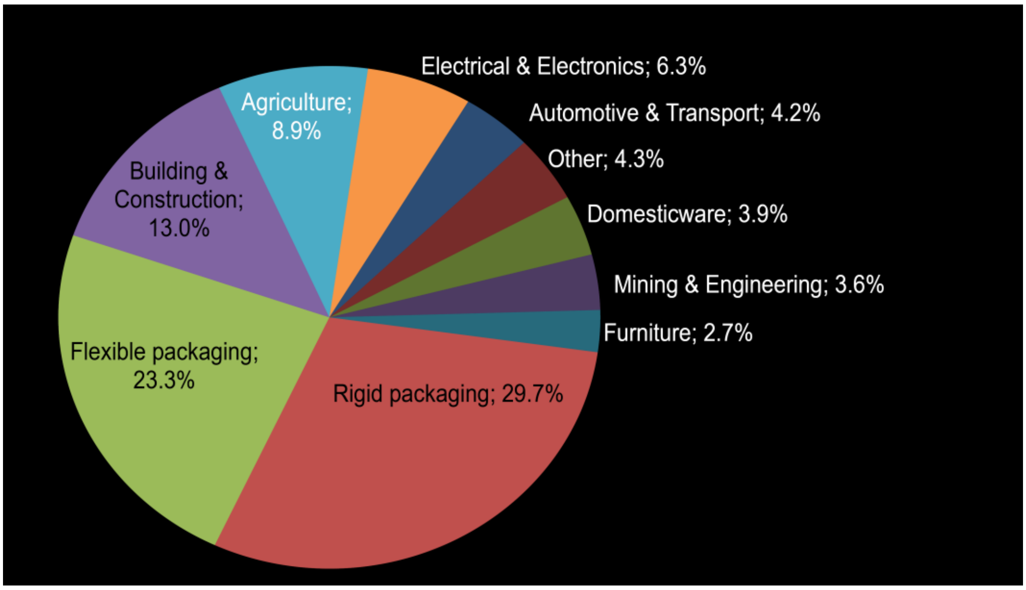


Figure 2-5: Different uses of plastics in South Africa. (Reproduced, courtesy of Me. Annabel Pretorius, SANPRO.)

2.3.3 **Regulatory environment**

The high mass of plastics generated resulted in a worldwide waste pandemic driven by increased industrialisation, increasing the need for disposable and cheap products. South Africa is at an impasse where discarding of plastic waste on landfills have become too difficult, and too costly. Embedded in the South African National Environmental Management: Waste Act (Act No.58, 2008) is the right to an environment that is not harmful to a person's health, and to have the environment protected for this generation and generations to come. This Act aims to prevent pollution and ecological degradation; to promote environmental conservation by industry and the public; and secure the sustainable use of natural resources within ecological, economic and social development.

2.3.4 **Research, development and innovation**

In 2012, the Department of Science and Technology (DST) and the Council for Scientific and Industrial Research (CSIR) embarked on a process to develop a Waste Research, Development and Innovation (RD&I) Roadmap (published in 2015) to provide national guidance priority areas, as well as the required public and private sector investment in waste RD&I over the next 10 years. According to this roadmap, a total investment of about R3.9 billion over the next 10 years is what is needed to prevent a significant portion of waste from reaching landfills and the environment. This investment is targeted towards value-adding alternatives, through more effective decision-making, faster insertion of context-appropriate technology, strengthened RD&I capability and capacity and the transfer of know-how and technology. The following institutions are known to have active or past research programmes or projects on microplastics:

- University of Kwa-Zulu Natal
- Rhodes University
- Nelson Mandela University
- University of Cape Town
- North-West University
- CSIR

2.3.5 **Management of plastic waste in the environment**

2.3.5.1 The Waste Management plan

The tight environmental regulations in this Act also brought about the development and implementation of a Waste Management Plan, as proposed by PackagingSA, to increase recycling in South Africa from 1.5 million tonnes in 2009 to 2.1 million tonnes by 2018. In this plan, PlasticsSA has set an ambitious target of eliminating all plastic waste from South Africa’s landfill sites by 2030. Although legislation is in place to promote recycling and sustainable use of natural resources, the recycling of plastic-based materials, with reference to packaging materials, had been implemented predominantly through corporate initiatives (Nahman, 2010). In 2014, 315 600 metric tons of plastics were recycled by about 1 800 convertors, which are mainly small businesses (Plastics SA 2016); these efforts are increasing. 41.8% of locally manufactured plastic was diverted from landfill for recycling in 2016, seeing an increase of 35% since 2011 and anticipating growth of up to 6% in 2017 (AMWM, 2017). 75% of all recycling in South Africa is done post-consumer (AMWM, 2017) (Figure 2-6).

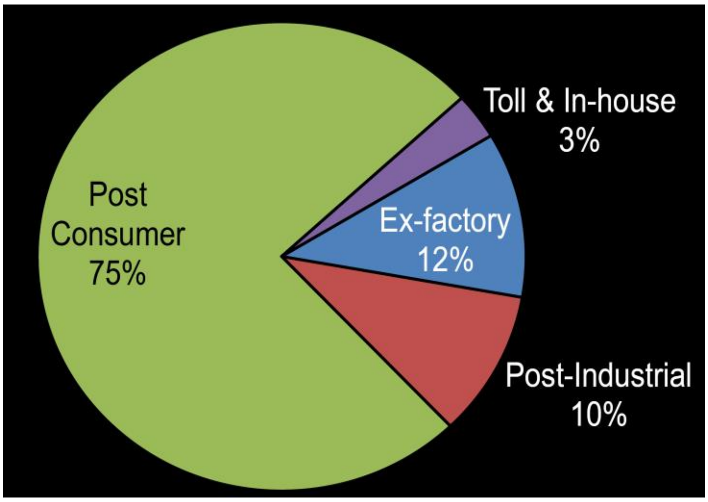


Figure 2-6: Sources of recyclables in South Africa. (Reproduced, courtesy of Me. Annabel Pretorius, SANPRO.)

Figure 2-7 shows the quantities of polymer-based plastics recycled between the year 2014 and 2016. The amount and effect of imported plastics is harder to determine, and the total amount of plastics recycled will be substantially lower than that of which is locally manufactured. Inadequate waste disposal protocols and infrastructure are likely to cause much of this unrecycled plastic ending up in water supply systems (Verster *et al*., 2017).

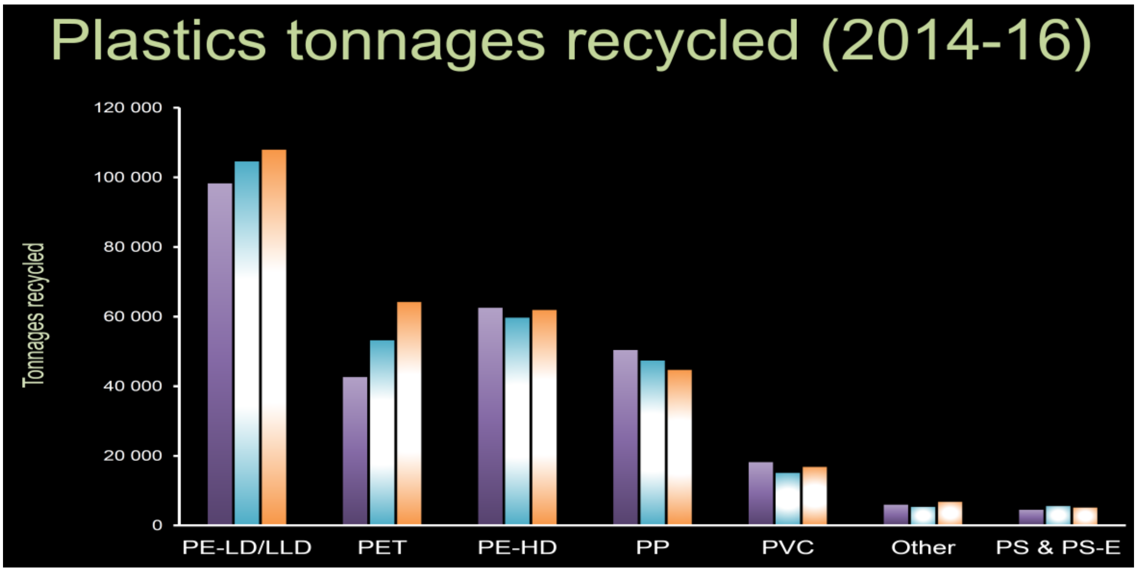


Figure 2-7: Tonnages of different polymers recycled in South Africa: 2014 - 2016. (Reproduced, courtesy of Me. Annabel Pretorius, SANPRO)

2.3.5.2 PlasticsSA

There are numerous actions taken by Plastics SA (the voluntary industry association of South Africa) (http://www.plasticsinfo.co.za/). Plastics SA has and is funding research at universities and is making big efforts to reduce pollution through strengthening recycling and improving stewardship. We strongly recommend including Plastics SA and associates into future actions. Although membership is voluntary (not all companies belong to this association), PlasticsSA is making a difference (including supporting other associations in Africa) and should be seen as a partner. They list the following activities and key points on their website, under sustainability:

- Partnerships
- Zero plastics to landfill by 2030
- Resource efficiency
- Education and training (including recycling training of municipal managers)
- Global action on marine litter.

PlasticsSA also has extensive awareness, educational, and beach clean-up campaigns.
http://www.plasticsinfo.co.za/pressroom/

2.3.5.4 Woolworths

The promotion of more responsible plastic use by retailers such as Woolworths seems limited to the high-end sector of the market, as there is a premium associated with such interventions. Ways and means should be explored to expand and support responsible use. More about waste management at Woolworths can be found at:

http://www.woolworths.co.za/store/fragments/corporate/corporate-index.jsp?content=../article/article&contentId=cmp205998

2.3.5.5 The South African Plastics Recycling Organisation (SAPRO)

SAPRO "represents the plastics re-processors in South Africa. Its members procure sorted, baled end-of-life plastics and re-process it into raw material. The recycled material can be used to manufacture new plastics products. Recyclate can be used as a percentage of the final material mix and, in some cases, can even solely be used to produce new products. South Africa is amongst the top recycling countries in the world." Their website contains updated information on this plastics recycling (http://www.plasticrecyclingsa.co.za/). SAPRO would be a useful partner in further studies.

2.3.5.6 The Two Oceans Aquarium initiatives

Although there are many more, we would like to highlight two community-based efforts dealing with plastic pollution. The Two Oceans Aquarium has had programmes on awareness raising about plastic waste for a number of years, with particular inspiration from the impacts of plastics and turtles and penguins. For a number of years now, The Two Oceans Aquarium in Cape Town are driving multiple programmes related to plastic, three of which we like to highlight below.

- **'Rethink the bag'**. We quote: "Most plastic shopping bags end up in landfill or in the sea where they are often swallowed by animals. These animals suffer a terrible and slow death, after which the plastic bag still remains in the environment. Choose a beautiful reusable fabric shopper and say "no thanks!" next time the cashier asks if you would like to buy a plastic bag."

- **'Straws sucks'**. We quote: "Straws are one of the most common rubbish items found on our beaches. Much like plastic bags, straws are often swallowed by marine creatures, resulting in blockages which ultimately cause death. Refuse this luxury item next time you buy a cold drink or milkshake, you'll be surprised by how unnecessary it is."

- **'Cut a loop".** We quote: "Box bands, and other loops formed by rubbish, can end up entangling land and sea animals to the point where they are slowly strangled to death. Make sure all looped refuse is cut before disposal (and recycled where possible) otherwise you are essentially throwing a noose into the environment!"

2.3.5.7 The African Marine Waste Network.

"The network is the first to unite a growing community of researchers, educators, industry, media and governments to find solutions to Africa's marine waste issues." https://africanwastenetwork.org.za/

- The network provides a platform for (copied from their website):
  - The development of a knowledge base for informed decision making though resource and expertise sharing.
  - Dissemination of opportunities and sharing of best practices for capacity building, empowerment, education and public awareness.
  - Sharing ideas and garnering support, collaboration opportunities and financial backing.
  - Broadcasting latest news and events.
  - Building towards greater prosperity through the promotion of green economic enterprises and the circular economy.

- An important and highly successful conference was held in Port Elizabeth, June 2017 (AMWN, 2017). It was attended by 200 delegates from nine African countries, with delegates from 10 other countries also attending. The outcome report can be found at https://africanwastenetwork.org.za/images/conference2017/documents/Workshop%20Outcomes%20Report%20-%20The%20African%20Marine%20Waste%20Conference%202017.pdf
- A paper emanated from this conference and is available as open source at: https: //www.sciencedirect.com/science/article/pii/S0308597X17305286

2.3.5.8 The circular economy

The Ellen MacArthur Foundation released a far-reaching and hugely important report in 2015 on the circular economy. This model "is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out, while minimising negative impacts. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural and social capital." A schematic representation is provided in Figure 2-8 (permission to reproduce is pending). More information can be found at their website. https://www.ellenmacarthurfoundation.org/circular-economy

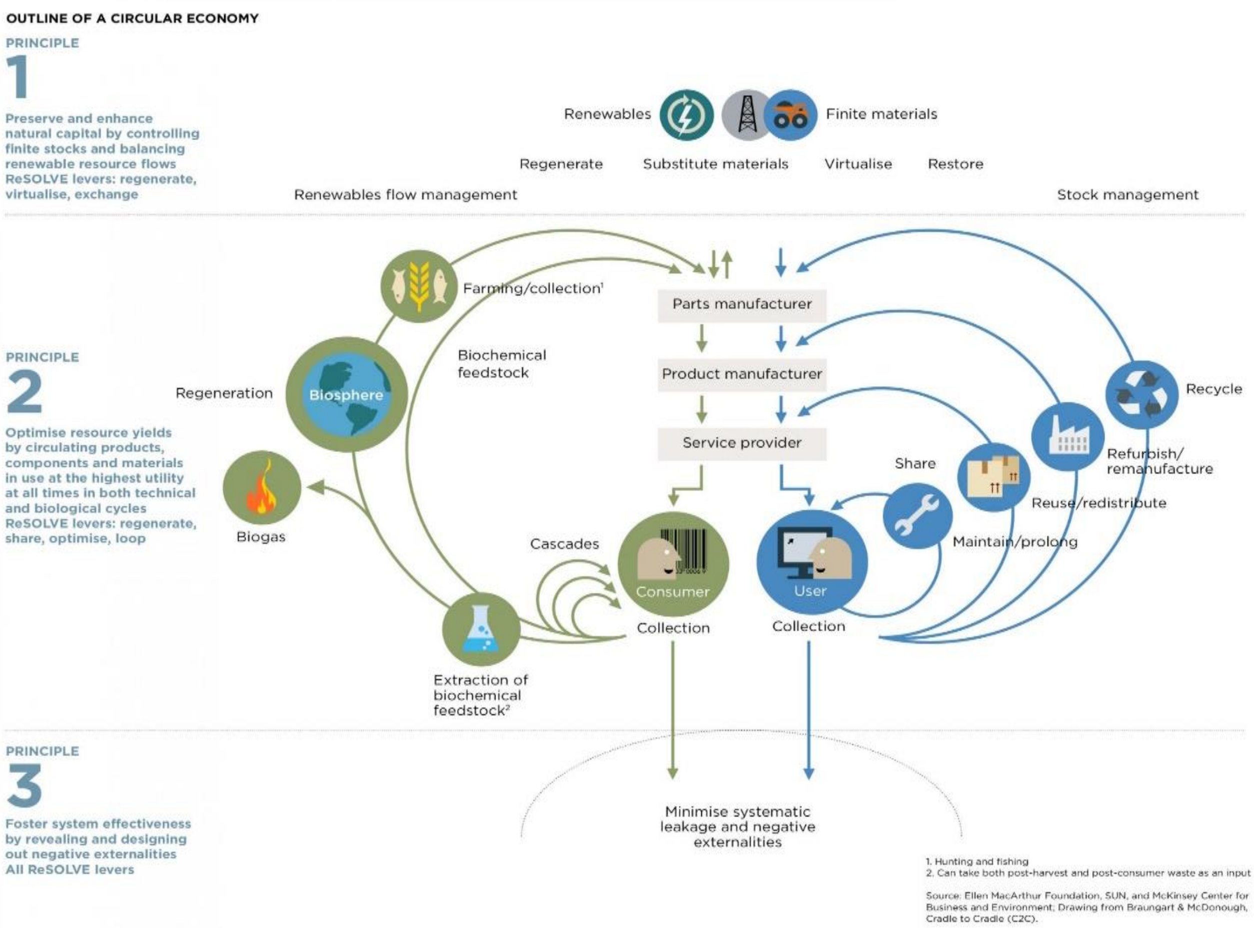


Figure 2-8: Outline of the model of the circular economy. Within this scheme, materials stay in circulation, reducing and ultimately eliminating waste to the environment.

2.3.6 **Capacity building**

Training is of course very important. We here, highlight two activities that relates to plastics.

- The CSIR and NWU in partnership offer a Master's degree in waste management, as implementing agency of the Department of Science and Technology. The first six students have completed the course. The B.Sc. Hons course in Environmental Sciences (specialization in waste management) at the NWU graduated 10 fulltime students in 2016, while 12 will complete the next class. http://natural-sciences.nwu.ac.za/sites/natural-sciences.nwu.ac.za/files/files/uesm/nuus/Engels/WASTE%20-%2050.pdf

https://www.csir.co.za/postgraduate-degrees-waste-management-now-offered-south-africa

- PlasticsSA also conducts training in plastic recycling for municipal managers, details can be found here: http://www.plasticsinfo.co.za/sustainability/

2.3.7 **Risk perceptions and communication in South Africa**

Risk perception has a complex and important impact on how society reacts to threats (Syberg *et a*l., 2018). Under- and over reactions are common and disproportional (both large and small) interventions often happens. Plastic pollution has a strong visible, tangible, and consumer responsibility component, and is difficult to ignore. Otherwise, plastic pollution has all the components of other types of environmental pollution or threats, such as pesticides, industrial chemicals, mercury, and genetically modified organisms that have less visual impact. Plastic pollution also has a social responsibility component, as consumers can make choices and take actions to reduce plastic pollution, thereby also driving markets (Syberg *et al*., 2018). The strong awareness raising efforts by Sky News in the UK has already lead to major changes in how producers, retailers, and consumers interact with plastic, in a positive and more responsible way. Visible plastics also has a link with 'invisible' plastic as common experience makes an easy acceptance of the process of breakdown from large to increasingly smaller pieces, and the use of microbeads in personal care products. The risk perception of plastic pollution therefore, offers some additional perception drivers, but public awareness and care should be in place.

In an effort to determine the South African public awareness of microplastic pollution, we used Google Trends application, which searches the internet for keywords that can be entered. Trending Stories searches Google Search, Google News, and YouTube and ranks stories based on the relative spike in volume and the absolute volume of searches. Each weekly data point is divided by the number of searches of the selected region over the period selected and expressed as relative popularity. Limited to South Africa only, we searched the last five years for the following keywords: Plastic, pollution, plastic pollution, water pollution, microplastic, marine debris, and marine pollution, downloaded the data file, and prepared the graph (Figure 2-9). The search terms 'microplastic' and 'marine debris' did not lift above the baseline and were excluded. Plastic as a search term featured consistently over the five years, and much more than the other terms. It seems as if the social awareness of these two topics are still lacking. Remarkably, 'pollution' and 'water pollution' showed spikes in all five years at exactly during the same four periods: March, May, August, and October. We have no explanation for this periodicity. It may have to do with dry and rainy periods where pollution may play a role, but this will need closer inspection. It seems however, that based on social media, pollution does feature in South Africa, but plastic as a component does not.

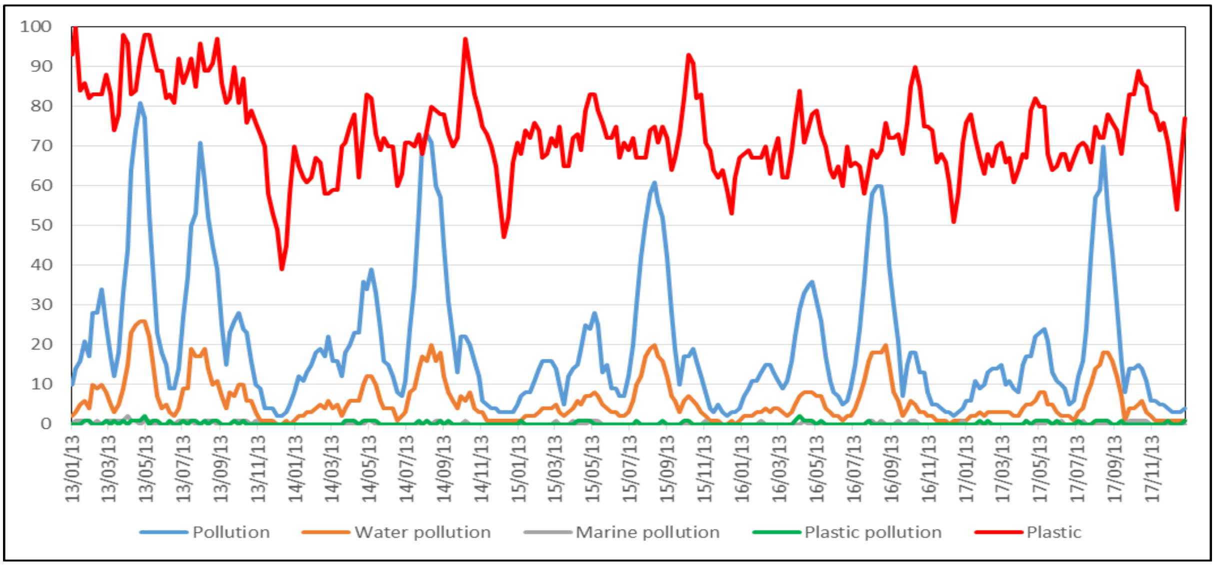


Figure 2-9: Relative popularity of the colour-coded search terms indicated below the graph, as on 13 January 2018 for the past five years.

2.4 WHY IS PLASTIC IN THE ENVIRONMENT PROBLEMATIC?

Plastic is a ubiquitous contaminant in all environments. Plastic is such a commonly found material that it has been proposed could be used as the stratigraphic indicator for the Anthropocene (Zalasiewicz *et al*., 2016), also called the Plastisphere (Pietrelli *et al*., 2017). The issue of plastics in the marine environment has first been documented decades ago (Ryan, 1987), but recognition was slow, initially. Already though, a search on Google Scholar returned 1 290 publications for the key words “plastic debris”, and 185 for “microplastic” with 2018 as the most recent publication date (as of 14 January 2018). In a certain sense, plastic as a pollutant has now ‘re-emerged’ as a major concern. One of the characteristics of plastics is that larger pieces are visible and obvious when contrasted with ‘invisible’ pollutants such as POPs molecules. This makes it easier and obvious to recognise plastics as a pollutant by all parties concerned, including manufacturers, retailers, and consumers. Plastic made from synthetic polymers are designed to last for a very long time, and thus are mostly non-biodegradable. Consequently, they accumulate, rather than decompose, in landfills or the natural environment. And nearly all the plastic ever created still exists in some form today. The global demand for pure polymer plastics, is spread s follows; polypropylene, 21%, polytethylene, 18%, polyvynil chrloride, 17%, high-density polyethylene, 15%, polystyrene, 8%, and polyethylene terephthalate, 7% (Hahladakis et al., 2018). However, additives are often added during production to obtain products of desired properties, some of these functions are listed in Table 2-2. The additives in plastic problems pose their own pollution problems, eg plasticisers and flame retardants can compose 3-70% of the mass the product, depending on the intended use. Therefore, its fate during and after use may become a major problem. During use, it may be mobilised to the product itself, air, water, food, saliva, sweat, and taken up by humans and other organisms from there. Heat, time, and fat content of the food are some of the factors that promote migration of additives into food and leaching into the environment (Hahladakis et al., 2018). Plastics that float in the oceans are known to travel long distances (Barnes *et al*., 2009; Collignon *et al*., 2014; Desforges *et al*., 2014; Ryan, 2014), and it may therefore be assumed that this will also be the case for freshwater systems. Facilitated by this long-range transport are the chemicals that are inherent in the plastics (added during manufacture such as plasticisers, UV-protectors, pigments, etc.), as well as those absorbed from the water itself (Ashton *et al*., 2010; Bakir *et al*., 2014; Farrington and Takada, 2014a; Fries and Zarfl, 2012; Lee *et al*., 2014; Ogata *et al*., 2009; Rios *et al*., 2007).

Table 2-2: Examples of plastic additives (Hahladakis et al., 2018 and Lambert & Wagner, 2018)[2]

Additive	Function	Example
Plasticisers	Making the material more pliable	Bis(2-Ethylhexyl) terephthalate
Accelerants	Speeds up curing of polymers	Ethylene thiourea
Cross-linking additives	Links the polymer chains	2-Mercaptobenzothiazole
Flame retardants	Reduces flamability	Tetradecachloro-p-terphenyl
Antidegradents	Reduces the rate of degradation due to oxygen, heat, and light	N,N'-bis(1,4-Dimethylpentyl)-p-phenylenediamine
Antioxidants	Slow down the oxidation cycle during processing	2-2-Hydroxy-5-tert-octyphenyl benzotriazole
UV stabilizers	Protects plastic against UV or sunlight damage	2-(2-Hydroxy-5-methylphenyl) benzotriazole
Antizonants	Slows degradation due to ozone	Nickel dibutyl dithiocarbamate
Biocides	Reduces biodegradation	Arsenicals, organotin, triclosan, Sn, Hg, Hg
Photosensitizers	Absorbs radiation of a particular wavelength	Benzophenones
Surfactants	Modifies surface properties	Polysiloxanes
Inorganic fillers	Improves impact resistance	Mica and clays
Pigments	Colours	Titanium dioxide

Plastics can also act as a sink for contaminants present in the environment, POPs such as DDT and PCB have been commonly reported (Eriksson et al., 2013; Hartmann et al., 2017; Ryan et al., 2012; Wagner & lambert 2018). In addition, mercury and other metals have also been found (Graca et al., 2013; Holmes et al., 2014). This presents the potential of facilitated long-range transport of both the traditional persistent organic pollutants (POPs), heavy metals, and the (assumed) less persistent chemicals incorporated within the plastics themselves from polluted areas to less polluted areas. Accumulated pollutants have been found in plastic debris from remote oceanic locations, (Doyle *et al*., 2011; Farrington and Takada, 2014b; Heskett *et al*., 2012; Ogata *et al*., 2009). What is not quite clear is whether the pollutants in plastics are actually available or released to the immediate environment or to animals that ingest them once the debris has beached. Plastics have been found in the stomachs of birds, turtles, mammals, turtles, crabs, fish, mussels, and many more marine organisms (Auta *et al*., 2017; Pazos *et al.*, 2017; STAP, 2015; Watts *et al*., 2014, to list but a few). The possibility that these chemicals may subsequently leach into animals once ingested is the subject of intense study and topicality. Formulated plastic products and plastics that end up in the environment are therefore a highly diverse and complex set of products that will be difficult to characterise in terms of risk, management, and intervention. The onus of providing generally acceptable evidence of impacts is therefore less compared with other types of pollutants, resulting in the need and willingness to implement mitigation. The only way to reduce the volume of plastic waste is by destructive thermal treatment, such as combustion or pyrolysis, which merely converts the contaminant from one form to another. Thus, the persistence of plastics and their near-permanent contamination in the natural environment is a growing concern. This recognition has already resulted in many actions around the world, including South Africa, to reduce the release of plastics to the environment, including restrictions or complete bans on plastic bags. (Erikson, *et al*., 2014; Geyer *et al.*, Jambeck *et al*., 2015; 2017; Verster & Bouwman, 2017; Wagner, 2018; Xanthos & Walker 2017).

[2] See also: https://www.chromspec.com/pdf/e/a12.pdf

CHAPTER 3: MICROPLASTICS POLLUTION IN THE AQUATIC ENVIRONMENT – A REVIEW

3.1 DEFINITIONS OF MICROPLASTICS

Microplastics can be described and characterised from different parameters (Wagner *et al*., 2014). These include:

- Classification according to source, location, use, and release patterns
- Size
- Shape (e.g. fragment or fibre)
- Polymer composition

In most cases, knowledge (as well as the gaps) and estimations on all of these parameters are needed when researching microplastics. However, the field is still developing and some assumptions and knowledge gaps may need to be acknowledged and or assumed. Based on the size, microplastics are a size group of plastic between macroplastics and nanoplastics. The exact size parameters defined as microplastics has not been officially defined. Macroplastics is generally understood to be easily visible objects such as bottles, bags, and food containers. Smaller, less easily seen particles (usually needing a microscope) are either manufactured as such, or fragments of larger pieces, or fibres derived from fabric.

The following are some of the other definitions of microplastics found in literature:

- The initial use of the term 'microplastics' was in reference to particles in the range of 20 µm (Thompson *et al*., 2004).
- Arthur *et al*. (2009) widened the range to describe all particles smaller than 5 mm.
- There is, however, now a notion in recent literature to restrict the upper limit of 'microplastics' to 1 mm (1000 µm) (Van Cauwenberghe *et al*., 2015).
- Microbeads, that are manufactured to be small, generally fall in the range of 5 µm to 1 mm (Hernandez et al., 2017). These small particles are difficult to detect and quantify, so little is known.

Practically, in most studies the smallest size is determined by the size of the net or mesh sieve used for sampling (Blair *et al*., 2017). In this scoping report, for practical reasons, we will use 5 mm – 20 µm, with the understanding that smaller particles will be missed. However, given that technology is catching up fast, it would not be advisable to have a limit on the smallest sizes. Microplastics eventually become nanoplastics. This transitional parameter is purely based on the SI system, and only represents a gradual change in behaviours and characteristics from larger to smaller. Therefore, a clear indication must be given in any report or study of the upper and lower size classes that is used.

GESAMP (2015) devised a scheme for easy reference (Figure 3-1). In this report, the experts distinguished between mega- (larger than 1 m), macro- (2.5 cm – 1 mm), meso- (1 mm – 2.5 cm), micro- (1 µm – 1 mm), and nanoplastics (smaller than 1 µm).

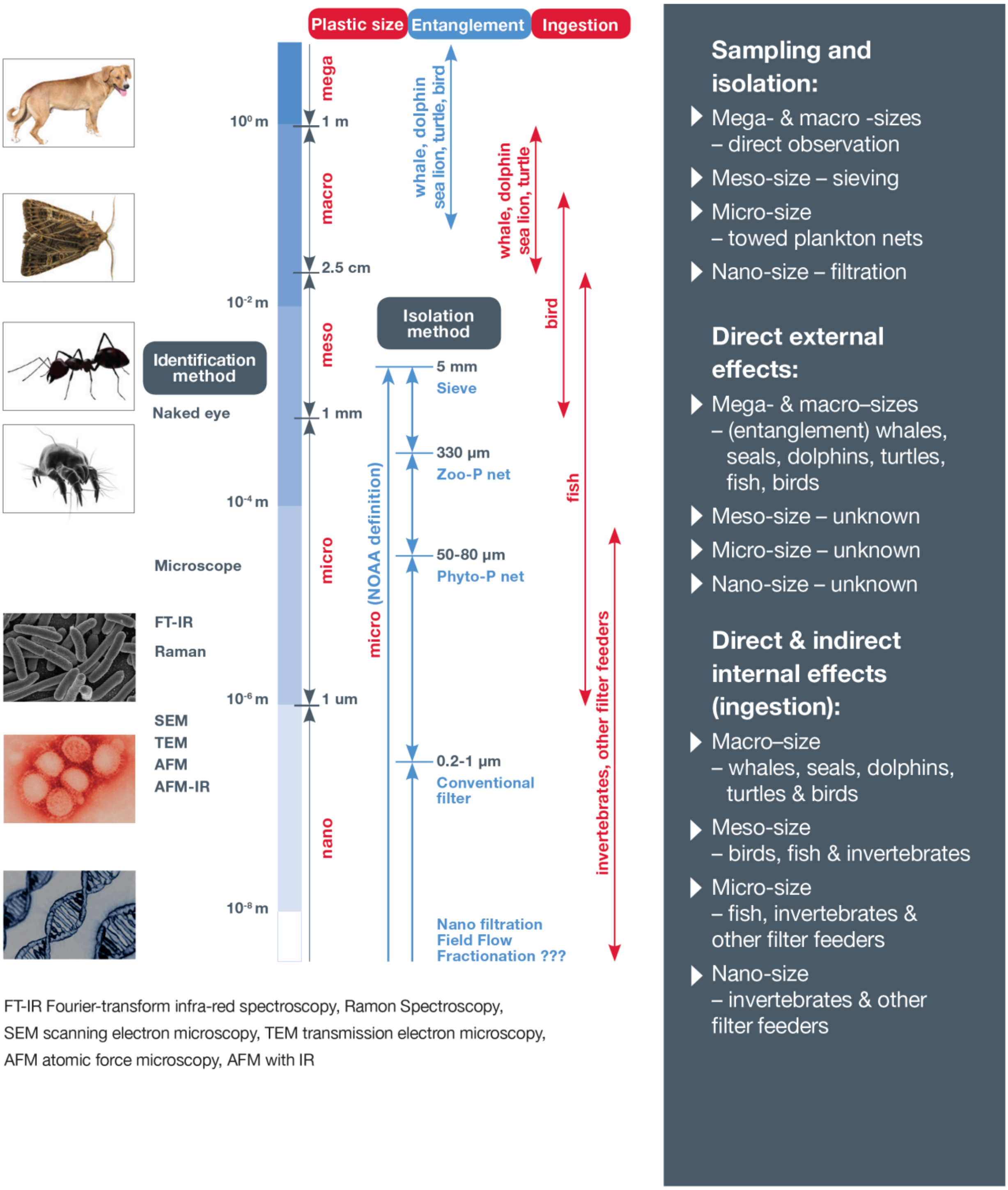


Figure 3-1: Proposed classification, comparisons, properties, impacts, and examples of various size ranges of plastics (GESAMP 2015. Reproduced with permission).

3.2 SOURCES OF MICROPLASTICS

The sources of microplastics are varied, their environmental behaviour and exposure scenarios differs in various media, and the properties of plastics also change in the environment. The origin and purpose of plastics in this size range varies greatly. The major groups of microplastics based on origin and shape are primary particles, secondary fragments and fibres. Primary particles are those pieces of plastic included in the microplastic size range that is manufactured to be this size (Cauwenberghe *et al*., 2015). These include plastic pellets used as raw plastic in industry, or cosmetic plastic particles used in body scrubs and exfoliators and end up in water systems using municipal waste water as a carrier (Arthur *et al*., 2009). Secondary microplastics are degraded by mechanical and biological action, and sunlight from larger plastic pieces. Fibres as a microplastic have become a recent field of interest in the microplastic community as it originates from the washing of clothes. This releases microplastics in even the remotest of streams as rural communities wash clothes in rivers or washing effluent ends up in rivers.

The actual and potential activities that result the release of microplastics into the environment have been summarised by Wagner and Lambert (2018). Based on the survey conducted in this study the list has been extended to cover South African conditions. Such activities include;

- Breakdown from larger pieces of plastic
- Fibres and microplastics from personal care products and fabrics via WWTP
- Application of biosolids from WWTPs to land
- Storm water and runoff
- Release from industrial processes
- Atmospheric deposition
- Spillages and accidents
- Plastic film from agricultural processes
- Sandblasting using polymer particles
- Weathering from construction sites
- Automotive tyre wear
- Rural washing
- Runoff from landfills and unmanaged waste dumps

3.3 OCCURRENCE AND PERSISTENCE OF MICROPLASTICS IN THE AQUATIC ENVIRONMENT – A GLOBAL PERSPECTIVE

3.3.1 Overview

The persistence of plastic particles in the environment is difficult to predict and little is known (Wagner and lambert, 2018). Properties such as tensile strength and changes in molecular and crystalline structure occur, together with microbiological action. There are a number of factors that affect breakdown: temperature, sunlight, mechanical action, biofilm formation, influence of additives (including anti-microbiological agents), hydration, to name a few (Wagner and Lambert, 2018). Knowledge of persistence in freshwater environments is important as the continuous addition of new particles probably outstrips the decay of particles already in the environment. Accumulation is therefore a very likely scenario.

Measurement and monitoring however, is difficult, as advective transport, aerial deposition, suspension, resuspension, settling, burial, biofouling, aggregate formation, ingestion and excretion, and diffusion, interacts differently with plastic properties such as density, size, shape, electric charge, and porosity (Bagaev *et a*l., 2017; Wagner and Lambert, 2018). Added to this are environmental variables such as water density, temperature, oxygen, flow velocity, turbulence, water depth, salinity, suspended particles, river flow diversion, dams and weirs, sediment types, etc. that will affect environmental behaviour. In South Africa, dried up river beds and droughts may redistribute plastic particles towards terrestrial environments, a process that has been described for landfills (Barnes *et al*., 2009). Many plastics are composed of multiple polymers and/or are layered with foil, paper, or carton – therefore, studies and predictions based on single polymer characteristics will only cover a certain, unknown, amount of plastics in freshwaters. Since all these conditions, as well as use and release patterns, vary seasonally and per region, prediction of persistence and environmental fate remains difficult. Although modelling has been attempted and is ongoing, for the near future, we anticipate that sampling, quantification, and identification will remain the best way to describe microplastic behaviour in the environment. This knowledge will then feed-back into exposure studies, model development, as well as risk assessments.

3.3.2 **Pollution level influencers**

3.3.2.1 Freshwater systems

The type of river, that is whether it is a tributary river or a main river channel, and the area through which the river flows has a great effect on the quality of the water. Urban river systems tend to be more polluted than non-urban systems. Phillips & Bonner (2015) found that in urban rivers, the most common type of microplastic was film. In non-urban rivers, filaments or fibres are more common. Water bodies close to densely populated or industrialised areas contain more microplastic. Main river channels seem to accumulate plastic pollution and sees higher concentrations of microplastics than their tributary rivers. Rainfall or weather system influences on microplastic concentration

3.3.2.2 Wastewater effluents

Since repeated use and treatment of freshwater in South Africa is the norm, attention should be given whether water after waste water treatment contains microplastics that may be taken up further downstream for drinking water treatment. It is well established by now that WWTPs, even those in developed countries, emit a small proportion of microplastics to receiving waters (Peng *et al*., 2017; Talvitie, *et al*., 2015). WWTPs removed 95-99% of microplastics, but substantial amounts do get emitted (4.9 to 8.6 particles per Litre in effluent, 1770 particles per hour, or 65 million per day) from different plants in Europe and the USA (Peng *et al*., 2017). Microplastics, mostly fibres, are also by wind from landfills (Peng et al., 2017), which can then be deposited in water. Studies on United States and Canadian waste water effluent indicated that municipal waste water treatment plants were not completely effective at removing plastic (Leslie *et al*., 2013). The plastic found in the effluent is mainly by microbeads. Parisian waste water was examined before and after purification and microplastics decreased by a factor of 10 after purification, however contamination levels were still found to be high after purification (Gasprei *et al.*, 2015).

Since plastics are very durable (Barnes et al., 2009), continued accumulation of plastics in natural waters can be expected. This means that drinking water treatment plants may expect increasing loads of microplastics entering the treatment systems. We could find no research on effectiveness of microplastic removal from raw water by drinking water treatment plants. No mention of this aspect could be found in literature, nor was it mentioned in the 2018 review of microplastics in freshwaters (Wagner and Lambert, 2018), using ‘drink’ and ‘potable’ as search terms.

3.3.3 **Summary of findings from selected studies**

3.3.3.1 *A global perspective*

Globally, very few studies have been published on microplastics in freshwater, compared to the marine environment. Recently, there has been a renewed interest in microplastic pollution in freshwaters, therefore, the numbers of publications are expected to increase exponentially. Studies on freshwater microplastics have been done in all continents (except Antarctica). The greatest part of this body of work pertains to North America, Europe and Asia. Studies in North America tend to focus more on riverine microplastics and pollution by waste water effluent. A study by Eriksen *et al.* (2013) on the North American Great lakes using a continuous sampling method did however shed some light on the distribution of plastics in larger inland water bodies. Plastic concentrations were found to increase by a magnitude of 10, closer to major cities when compared to pelagic zones. Microplastic was found in al rivers and drainage basins examined. Much of the knowledge on European fresh water microplastics is of concentrations in rivers. Concentrations range from 14 to 50 particles per litre in the Seine River (Dris *et al.*, 2015) and Leslie *et al.* (2013) found a mean of 52 particles per litre in Dutch water bodies. Microplastic was present in all samples taken from the Thames River (Horton *et al.*, 2015). In a study by Fischer *et al.* (2016), low concentrations (<1 particle per litre) of microplastics were found in two central Italian lakes. Studies on microplastics in Asian freshwater systems increased over the past decade, catching up with the rest of the developed world. Most of this work is done on surface water and sediment of lakes in China, with isolated studies done in India and Hong Kong. Concentrations of up to 4100 particles per litre of water were found in Chinese estuaries (Zhao *et al*., 2015). Table 3-1 and Table 3-2 provide summarises of selected published studies conducted in different parts of the world.

3.3.3.2 Microplastics in the South African aquatic environment

South Africa is a country rich in natural resources. Although a water scares country, its rivers house an incredible diversity of biota, of which much is endemic. These resources are however, insufficiently protected. Much of our natural heritage, which is also contributing to research and ecotourism, becomes polluted because of insufficient infrastructure such as waste removal and effective waste water treatment. Microplastic is one of the most recent additions to the list of pollutants that need to be quantified to determine the reach of the damage to freshwater systems. This data will subsequently be used to advocate legislation ensuring the protection of natural heritage. The scope of microplastic research in South Africa is largely limited to the marine and estuarine environment. Many studies have been done to quantify microplastics in oceanic surface water, estuarine systems and beach sand. Microplastic as a research topic has exponentially grown in popularity over the last five years (GESAMP, 2015). Naidoo *et al*. (2015) states that South African research on marine debris started in the mid 1980’s and focused largely on the impact thereof on seabirds. The increase in plastic debris on South African beaches also started to attract the research attention of Peter Ryan around this time (Naidoo e*t al.*, 2015). Almost all the literature found on microplastics in a South African context is from research done on the marine environment. Some parallels can be found between the marine environment and aquatic systems, which are of interest in this study and these include quantitative data, plastic structure and composition, and the distribution and movement of microplastics. Table 3-4 presents a summary of the work that has been published.

Table 3-1: Annotated summary of selected research on microplastics (MPs) in freshwaters around the world.

Topic	**Summary**	**Article**
Europe	Paris area – Seine River: MP found in atmospheric fallout (mostly fibres). Average MP in wastewater: 260-320 x10^3 particles/m^3. Treated effluent: 14-50 x10^3 particles/m^3.	Microplastic contamination in an urban area: a case study in Greater Paris. (Dris *et al.*, 2015)
	No microplastics found in many of the freshwater bodies and when found, it is mostly in sediment samples. MP of varying concentrations found in WWTP effluent. MP concentrations decreased during waste water treatment.	Microplastics in Irish freshwaters: a preliminary study. (Credo & Cleary, 2015)
	MP is present in Rhine River, Germany: 1g/kg sediment or 4000 particles. Rivers are vectors for MP transport to oceans.	Occurrence and spatial distribution of microplastics in the river shore sediments if the Rhine-Main area in Germany. (Kleine *et al.* 2015)
	Two lakes in central Italy (Lake Bolsena, Lake Chiusi): surface waters 2.68 to 3.36 particles/m^3 (Lake Chiusi) and 0.82 to 4.42 particles/m^3 (Lake Bolsena). Sediments (dry weight): 112 (Lake Bolsena) to 234 particles/kg (Lake Chiusi). MP concentration increased after moderate rains and heavy wind.	Microplastic pollution in lakes and lake shoreline sediments – A case study on Lake Bolsena and Lake Chiusi (central Italy). (Fischer *et al.*, 2016)
	Plastic (all) is between 0.8% and 5.1% of the total debris collected. 2.3 g floating plastic per Parisian inhabitant per year is estimated.	Assessment of floating plastic debris in surface water along the Seine River. (Gasprei *et al.*, 2014)
	WWTP: 3 samples yield great variation in MP concentration. Mean = 52 particles/L. This study suggests that treated and non-treated waste water have similar MP concentrations.	Microplastic survey of the Dutch environment. (Leslie *et al.*, 2013)
	MP found in all sites sampled in the Thames River.	Presence and abundance of microplastics in the Thames River basin, UK. (Horton *et al.*, 2015)
	Thames River, UK: (large 'microplastic' particles in sediment) all samples contained MP. Average = 66 particles per 100g. One site with significantly higher MP levels is downstream from a storm drain outfall. Paint used on roads is identified as another source of microplastics. In some places, direct runoff from land is a greater source of MP than sewerage. Rivers are important sources of oceanic MP and sinks for higher density MPs.	Large microplastic particles in sediments of tributaries of the River Thames, UK – Abundance, sources and methods for effective quantification. (Horton *et al.*, 2017)
	Paris: Microplastic observed in atmospheric fallout. 29 – 280 particles per day (collected with funnel in glass bottle), with 90% of these fibres. Seine-Center WWTP: raw wastewater – 260-320 x 10^3 particles/m^3; final effluent – 14-50 x 10^3 particles/m^3. The WWTP MP is all fibres. Surface water: 0.28-0.47 particles/m^3.	Microplastics in the continental area: an emerging challenge. (Gasprei *et al.*, 2015)

	MP found in all 11 samples taken along 820km of the Rhine River with average concentrations of 292 777 particles/km^2. MP sources identified are WWTPs, tributaries and weirs. Population density correlates with MP concentration. Seasonal and weather chances influence MP concentrations.	Microplastics profile along the Rhine River (Mani *et al.*, 2015)
North America	Sediments of the St. Lawrence River (Lake St. Francis in Quebec City): Concentrations: mean=13832 ($\pm$ 13677) parts/m^2, median = 52 parts/m^2, max. = 1.2 x 10^5 parts/m^2. Sites receiving municipal effluent were dominated by smaller microbeads.	Microplastic pollution in St. Lawrence River sediments. (Castaneda *et al.*, 2014)
	River is a pathway for MP to lake. Mineral-polyethylene and -polypropylene sink to the bottom of the lake and associate with minerals (filters and adsorption) ant might become part of future rock material. Offshore MP in sediments can be buried and preserved (degradation period prolonged). Higher rainfall increased MP concentrations because of high runoff. Ave concertation: 21.2 pellets, 4.5 fragments and 1.7g polystyrene/m^2	Hidden plastics of Lake Ontario, Canada and their potential preservation in the sediment record. (Corcoran *et al.*, 2015)
	0.5 ± 0.024 average MP/L in municipal waste water effluent throughout the US. Average across 17 waste water treatment facilities: 4 million MP particles released per site per day. Fibres and fragments were found to be the most common type of MP. An average of 14 million cosmetic microbeads is released every day in the US. Tertiary floatation would not be effective in eliminating MP from waste water.	Microplastic pollution in widely detected in US municipal wastewater treatment plant effluent. (Mason *et al.*, 2016)
	North Shore Canal, Chicago: Main source of MP is waste water. Concentrations in this river were found to be higher than in the Great Lakes and the open ocean (from literature).	Microplastic is an abundant and distinct microbial habitat in an urban river. (McCormick *et al*., 2014)
	Plattsburgh Waste water effluent: Fibres are most common MP type, especially in the larger MP range. Water flow rate correlates with MP abundance, but not type.	Microplastic pollution: A survey of waste water effluent in Plattsburgh, NY. (Buksa & Niekrewicz, 2016)
	Great Lakes of North America. Average: 46 000 MP/km^2. Max (Near 2 major cities): 466 000 MP/km^2.	Microplastic pollution in the surface waters of the Laurentian Great Lakes. (Eriksen *et al.*, 2013)
	Average of 8% of fish (6.3% invertivore-carnivore, 21% herbivore-omnivore guild) examined from rivers draining into the Gulf of Mexico had MP in their digestive tracts. In urban rivers, the most common MP type was found to be film, and in non-urban rivers filaments. MP ubiquitous among habitats and taxa.	Occurrence and amount of microplastics ingested by fishes in watershed of the Gulf of Mexico. (Phillips & Bonner, 2015)
	Snake River and Palisades Reservoir, Montana: 72.7% of samples contained probable MP.	The presence of microplastic in freshwater systems: Snake river and Palisades Reservoir. (McDevitt *et al.* 2016)
	Brazos River Basin, between Lake Whitney and Marlin: Internal MP – Sunfish 45%. Sunfish living in urban areas had greater internal MP concentrations. MP ingested while feeding (correlation with other debris found).	Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA. (Peters & Bratton, 2016)

South America	Goiana Estuary (North-eastern Brazil): Microplastic concentrations are comparable with that of fish eggs in the water. At places, more microplastics were found than Ichthyoplankton. MP concentrations were at its highest in the late rainy season. MP is readily available to planktonic organisms, which serves as an entry point in the food chain, moving to next trophic levels.	Distribution patterns of microplastics within the plankton of a tropical estuary. (Lima *et al*., 2014)
	The seasonally moving salt wedge in the Goiana estuary determined the migration of Ichthyoplankton and MP. Both are ubiquitous. Highest MP concentration observed (late rainy season) is 14 items per 100 m^3 when MP is washed towards the ocean. Some MPs shape and size are similar to zooplankton and ingestion by fish is highly likely.	Seasonal distribution and interaction between plankton and microplastics in a tropical estuary. (Lima *et al*., 2015)
Africa	Preliminary study, which detected microplastics in the African Great Lakes (Lake Victoria) by examining the gastrointestinal tracts of two local fish species. Plastic was found in 20% of fish examined.	First evidence of microplastics in the African Great Lakes: Recovery from Lake Victoria Nile perch and Nile tilapia (Biginagwa *et al*., 2016)
	Detailed study on abundance, size and type of microplastic pollution in five estuaries on the eastern coast of South Africa (Durban area). Most particles <5mm. Estuaries has high fibre load. Highest concentration found was 745.4 $\pm$ 129.7 particles per 500ml sediment.	Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa (Naidoo *et al.*, 2015)
Asia	Preliminary study to quantify microplastics in the Venbanad Lake in southern India. This is the first study on microplastics conducted in India. Similar conditions to this study: rivers flowing through a densely-populated area. River runoff is influenced by a 4 to 6-month monsoon period. 60 650 particles per km^2, mostly polyethylene.	Microplastics: An emerging contaminant – with potential threat to aquatic systems – less studied in India (Ramasamy, 2016)
	Remote lakes in Tibet Plateau: very low human population, high altitude. Average abundance up to 563 items/m^2. Mechanical and oxidative weathering. Source is suspected to be riverine input.	Microplastic pollution of lakeshore sediments from remote lakes in Tibet plateau, China. (Zhang *et al.*, 2016)
	Lake Hovsgol (Mongolia) – Remote lake. Very little work done on freshwater MP. Ave. = 20 264 particles per km^2, mostly fragments and film. No microbeads and few pellets. More polluted than Lithuanian Great lakes. Low populations can heavily pollute a water system without proper waste management.	High levels of microplastic pollution in a large, remote mountain lake. (Free *et al.*, 2014)
	Microplastics were found in salt collected from lake, rock and sea salt. Microplastic concentrations were found to be much higher in sea salt (550 – 681 particles per kg salt, mostly fragments and fibres) than in lake salt (43 – 364 particles per kg salt, mostly cellophane) and rock salt (7 – 204 particles/kg salt, mostly cellophane).	Microplastic pollution in table salts from China. (Yang *et al.*, 2015)
	Average microplastic density for Hong Kong is 5595 articles per m^2 (collected in sand – mostly expanded polystyrene). Microplastic concentrations are higher on the east coast than on the west coast of the island, and this is attributed to the Pearl river carrying inland plastic to the ocean.	Hong Kong at the Pearl River Estuary: A hotspot of microplastic pollution. (Fok & Cheung, 2015)
	Jiaojiang, Oujiang and Minjiang Estuaries – Typhoon had no meaningful effect on MP concentrations. 100.0 n/m3 to 4100.0 n/m3.	Microplastic in three urban estuaries, China (Zhao *et al.*, 2015)

	From 3407.7×10^3 to $13{,}617.5 \times 10^3$ items per square kilometre in the main stream of the Yangtze River and from 192.5×10^3 to $11{,}889.7 \times 10^3$ items per square kilometre in the estuarine areas of four tributaries.	Accumulation of floating microplastics behind the Three Gorges Dam (Zhang *et al.,* 2015)
	Beijiang River: from 178 ± 69 to 544 ± 107 items/kg sediment. Majority of heavy metals carried by microplastics were derived from inherent load. Plastic can be chemically degraded to MP.	Microplastics in the surface sediments from the Beijiang River littoral zone: Composition, abundance, surface textures and interaction with heavy metals (Wang *et al.* 2017)
	Lake Taihu (developed area): $0.01 \times 10^6 – 6.8 \times 10^6$ items/km^2 in plankton net samples, 3.4 –25.8 items/L in surface water and 11.0 – 234.6 items/kg dry weight in sediments, 0.2 – 12.5 items/g wet weight in Asian clams (*Corbicula fluminea*). Mostly fibre and cellophane. Highest MP concentration found in lake globally is this plankton net sample. Uptake of microplastics in clams was negatively correlated to microplastics in sediments.	Microplastics in Taihu Lake, China (Su *et al.*, 2016)
General	Assumption: MP in soil is carried to rivers and the same factors influencing sediment transport and soil erosion influences MP. approximately 16–38% of the heavier-than-water MPs hypothetically added to soils. In the stream, MPs < 0.2 mm are generally not retained. Low stream flow areas are MP riverine deposition hotspots.	A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. (Nizzetto *et al.*, 2016)
	Fresh water systems have similar problems relating to microplastics as marine systems. Similar quantitative microplastic densities are present in marine and aquatic systems. Differences between marine and aquatic microplastics: closer proximity to source in fresh water, size of particles (smaller in aquatic) and mixing and transport of particles. What is known about fresh water microplastics: presence and distribution in environment, transport pathways and factors that affect distribution, methods for detection and quantification, extent of impact on aquatic life?	Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs (Eerkes-Medrano *et al.*, 2015)
	Micro- and mesoplastics (>0.3mm). Mesoplastics tend to be carries onshore faster because of Stokes drift. Most secondary microplastic form on beaches because of UV light and mechanical degradation.	Selective transport of microplastics and mesoplastics by drifting in coastal waters (Isobe *et al.*, 2014)
	Annual plastic release to land is estimated at 4–23 times that released to oceans. Freshwater is the most significant source of oceanic MP pollution.	Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities (Horton *et al.*, 2017)
	Effect of polymer density and biofilm is not large, but particle size has a great effect on the movement and accumulation of MP's. Lowest retention for intermediate sized particles (5μm). River hydrodynamics greatly influence the size distribution.	Fate of nano- and microplastic in freshwater systems: A modelling study (Besseling *et al.*, 2017)

	Greatest source of MP is abrasion on larger plastics. MP ingestion lead to lower food intake and therefor lower energy. Low bioaccumulation. Environmental MP concentrations are too low to harm biota.	Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. (Duis & Coors, 2016)
Biotic effect	Plastic decomposing organisms and pathogens are more common on microplastic particles in rivers. Taxa composition differs from that of organic debris. MP biofilms are much less diverse. *Pseudomonas* can degrade PVA.	Microplastic is an abundant and distinct microbial habitat in an urban river. (McCormick *et al*., 2014)
	Mud snail (*Potamopyrgus antipodarum)*: MP had no effect on morphology, embryogenesis, life-history and juvenile development. Biological effect is dependent on the chemical composition and size of the plastic ingested.	Hazardous or not – Are adult and juvenile individuals of *Potamopyrgus antipodarum* affected by non-buoyant microplastic particles? (Imhof & Laforsch, 2016)
	MP >400 µm did not impact microalgae growth in early stages of colonisation. PP formed part of hetero-aggregates (50% of hetero-aggregate is MP – density 1.2). This process is important in vertical movement of PP. Sugar production in algae is enhanced by MP (overproduction of sugar) – especially HDPE and PP.	Microplastic interactions with freshwater microalgae: Hetero-aggregation and changes in plastic density appear strongly dependent on polymer type. (Lagarde *et al*., 2016)
Gaps identified	MP sampling methods in plankton must be improved and standardised.	Distribution patterns of microplastics within the plankton of a tropical estuary. (Lima *et al*., 2014)
	Standardisation of techniques.	Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities (Horton *et al.*, 2017)
	Studies are necessary to enable the identification of harmful synthetic polymers as some of them may be problematic and should be declared as hazardous whereas others may have relatively moderate or no effects	Hazardous or not – Are adult and juvenile individuals of *Potamopyrgus antipodarum* affected by non-buoyant microplastic particles? (Imhof & Laforsch, 2016)

Table 3-2: Summaries of the research done in South Africa and associated oceans on microplastics.

Theme	Findings	Source
Quantitative data	Quantitative assessment of microplastic particles in different estuaries around Durban. Correlation was found between industrial activity in the catchment and the plastic concentration in the estuaries. Estuary sediment and water surface plastic concentrations are similar to that of surrounding beaches. Bayhead area has highest plastic concentrations (745.4 $\pm$ 129.7) of the areas examined, because of low water exchange rates in the bay.	Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa (Naidoo et al. 2015)
	Five seabird species from the south Atlantic and west India oceans were sampled in the 1980s, and 1999 to 2006. The amount of plastic ingested in seabirds decreased slightly over this period, but the composition of plastic types ingested changed significantly. The greatest decrease in consumed plastic pellets (10.5 to 1.6 pellets per bird) was in the great shearwater, but an increase in user plastic (secondary plastic) was recorded.	Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans (Ryan, 2008)
	Vast majority of collected debris on Macquarie and Heard islands were plastic (95% and 94% respectively) West facing beaches had the greatest accumulation of debris. Daily sampling rates of debris on beaches are much greater than that of weekly samples collected because longing lifetime of some debris on the beaches.	Daily accumulation rates of marine debris on sub-Antarctic island beaches (Eriksson et al. 2013)
	Plastic pellets were collected from 3 beaches in South Africa (1 on the west coast and 2 on the south-eastern coast), and 82% of collected pellets were polyethylene. Polyethylene concentrations decreased proportionally to other polymers.	Long-term decrease in persistent organic pollutants in South African coastal waters detected from beaches polyethylene pellets (Ryan et al. 2014)
	Microplastic densities on south-eastern coast of South Africa range between 688.9 $\pm$ 348.2 and 3308 $\pm$ 1449 particles per m^2 of sand. Equivalent values for the water column varies between 257.9 $\pm$ 53.36 and 1215 $\pm$ 273.7 particles per m^3 of water.	A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa (Nel et al. 2015)
	The incidence of plastic ingestion by post-hatchling loggerhead turtles along the South African south coast has increased since the 1960s (from 12% to 60%), indicating a definite increase in marine plastic debris in the area.	Impact of plastic ingestion on post-hatchling loggerhead turtles of South Africa (Ryan et al. 2016b)
Plastic structure	Beach- and estuary sediment plastic consists greatly of fibrous plastics. Water surface plastics are mostly film plastics, originating from packaging material. Most of the plastics found were <5mm in diameter (typical of mangrove ecosystems).	Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa (Naidoo et al. 2015)

and composition	South to north longshore drift causes higher plastic concentrations on the northern side of beaches. The risk of smaller plastic particles encountered more frequently, and because of surface area to volume ratio, it can carry higher a contaminant load.	
	The portion of the ingested virgin plastic pellets in seabirds decreased significantly (44-79%). The conclusion is made that the composition types of microplastics in the ocean has changed from the 1980s to 2000s to consist of more user plastic and less plastic pellets.	Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans (Ryan, 2008)
	The percentage of primary pellets in loggerhead turtles' carcases, which is used as an indication of oceanic microplastic composition, has decreased radically from the 1970s to recent years (from 70% to 3%). This confirms the results Ryan, *et al.* (2008). Of the microplastics found in dead post-hatchling loggerhead turtles on the South African south coast most were hard plastic (77%), 10% flexible packaging, 8% fibres and 3% primary pellets.	Impact of plastic ingestion on post-hatchling loggerhead turtles of South Africa (Ryan et al. 2016b)
	Surface texture and structure influence fouling rates of different plastic types, causing it to sink at different rates. Rough surfaces tend to sediment faster.	Biofouling on buoyant marine plastics: An experimental study into the effect of size on surface longevity (Fazey et al., 2016b)
Distribution and movement	It was found that the two factors with the greatest influence on the movement of debris in the ocean, and accumulation thereof on beaches are winds and tides. Winds and tides had a lag time effect on the accumulation of debris on the beaches examined. The presence of *Lepas* spp. on debris can be used as a rough indication of the origin and age of debris.	Daily accumulation rates of marine debris on sub-Antarctic island beaches (Eriksson et al., 2013)
	There is little variation in the spatial distribution pattern of microplastics in beach sediment and the coastal water column in this area. Neither were there any significant density differences between bays and open coast. The study concluded that microplastic densities are governed by water circulation, and not population density or proximity to sources.	A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa (Nel et al., 2015)
	Albatrosses found on different islands, and in different regions of the Southern Ocean contain varying concentrations of ingested plastic.	Regional differences in plastic ingestion among Southern Ocean fur seals and albatrosses (Ryan et al., 2016a)
	Regional differences were noted between the Eastern and Western Cape in the incidence of plastic ingestion of young loggerhead turtles. It is hypothesised that	Impact of plastic ingestion on post-hatchling loggerhead turtles of South Africa (Ryan et al., 2016b)

	there are larger amounts of floating plastics on the Agulhas Bank off the east coast than along the west coast (east coast turtles died closer to their nesting grounds).	
	Fouling of marine microplastics may cause it to sink. Because smaller particles have larger surface to volume ratios, it would become fouled faster, and sink (applicable on microplastic scale - <5mm).	Biofouling on buoyant marine plastics: An experimental study into the effect of size on surface longevity (Fazey et al., 2016b)
Biotic effects	Plastics in the eThekwini district especially threaten biota at Isipingo, uMgeni and in Durban bay.	Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa (Naidoo et al., 2015)
	Because the microplastic composition in the ocean is changing to have higher concentrations of user plastics, and lower levels of plastic pellets, marine animals and seabirds are more likely to be exposed to toxins associated with user plastics.	Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans (Ryan, 2008)
	Different plastic concentrations were found in different species of albatross and in individuals of the same species living on different islands – thus concentrations vary between species and populations. Because of likely regurgitation of ingested plastics, albatrosses contain lower quantities of plastics than petrels. Contrary to what was expected when considering data from the Norther hemisphere, no plastic was found in any species of fur seals on the islands examined in the Southern Ocean. It is concluded that plastic concentration in animals is region- and species specific.	Regional differences in plastic ingestion among Southern Ocean fur seals and albatrosses (Ryan et al., 2016a)
	Results suggest that the retention of plastic in post hatchling loggerhead turtles is about two months. Harder plastics, like pellets are harder to excrete. It is also concluded that flexible plastics in the gut of these turtles are kept longer than hard plastic. Plastic in the intestines are retained mostly where the rectum joins the cloaca, an area prone to blockage because of a smaller circumference of the gastrointestinal tract. 1-2 fragments of about 20-30g are able to block the digestive tract of juvenile turtles. Plastics in the digestive tracts can rupture the bladder, and cause damage to the cloacal tissue.	Impact of plastic ingestion on post-hatchling loggerhead turtles of South Africa (Ryan et al., 2016b)
	If not regurgitated, the retention time of plastic in albatrosses and petrels are determined by the size of the plastic. The retention time is also species specific. Storm petrels store plastic particles in their proventriculus, where it is subjected to less mechanical wear. Stored plastic is fed to young by regurgitation of this stomach content, increasing the amount of plastic in juveniles, and decreasing the amount of plastic in breeding adults.	How quickly do albatrosses and petrels digest plastic particles? (Ryan, 2015)

POPs	Polyethylene pellets are used as indicators of persistent organic pollutants (POPs) because of their ability to absorb POPs. Mean POPs concentrations decreases. PBC and DDT concentrations in plastics found on rural beaches (less influence of industrial centre pollution) increases from 1990s to 2000s	Long-term decrease in persistent organic pollutants in South African coastal waters detected from beaches polyethylene pellets (Ryan et al. 2015)
Research gaps and problems	More data is needed to confirm the relationship between the ingested plastic concentrations and composition in seabirds, and the plastic concentration and composition in their habitat.	Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans (Ryan, 2008)
	Because it was found that daily collection of beach debris yields ten times greater results than monthly collections (due to debris re-entering the ocean), it is suggested that that the estimate amount of global ocean debris is larder by a magnitude of 1.	Daily accumulation rates of marine debris on sub-Antarctic island beaches (Eriksson et al., 2013)
	The absence of ingested plastic in southern hemisphere fur seals could not be explained.	Regional differences in plastic ingestion among Southern Ocean fur seals and albatrosses (Ryan et al., 2016a)
	Since different studies yield contrasting results, it is not yet certain what the influence of plastic colour on plastic ingestion by different sea turtle species is. The retention times of different plastic types in the intestines of loggerhead turtles are uncertain.	Impact of plastic ingestion on post-hatchling loggerhead turtles of South Africa (Ryan et al., 2016b)
	Marina plastic suspended in the water column (which is not floating nor sediment on the ocean floor) should be taken into account when attempting to calculate the total oceanic plastic load.	Debris size and buoyancy influence the dispersal distance of stranded litter (Fazey et al., 2016a)
	More data is needed to determine the retention time of different plastic types in different seabird species.	How quickly do albatrosses and petrels digest plastic particles? (Ryan, 2015)
	Experiments conducted were done in a controlled environment, thus regional differences (e.g. tropical vs. arctic), and other fouling species that would naturally influence fouling were not accounted for in these experiments. Further research is needed to determine the different regional fouling rates on different floating debris. This would better the model to determine the marine plastic load. It is unclear if the results found in this study could be extrapolated to macroplastics.	Biofouling on buoyant marine plastics: An experimental study into the effect of size on surface longevity (Fazey et al., 2015b)

The composition of microplastic pollution has greatly changed in the past three decades (Ryan, 2008). The relative number of primary pellets decreased because of the increase in secondary microplastics, originating from user plastics (Ryan, 2008). Similarly, polyethylene polymers also decreased with rising concentrations of other polymers (Ryan *et al.*, 2012). According to a study done by Naidoo *et al.* (2015) in estuaries and surrounding beaches, surface water is prone to containing more film plastics, originating from packaging material, while sediments contain largely fibrous microplastics. Contrast was found in the literature concerning the distribution and movement of microplastic. Nel & Froneman (2015) found that the distribution of microplastics is less dependent on the source of pollution than it is on winds and currents in a marine environment, while Naidoo's *et al.* (2015) findings suggest that there is a correlation between industrial activity in the catchment and the plastic concentration in South African estuaries. Currents and winds have a smaller effect on the macro distribution of pollutants in rivers than in oceans and thus it is hypothesised that the finding in this study would correlate with the findings of Naidoo *et al*. (2015). Because smaller particles have larger surface to volume ratios, it would become fouled faster, and sink (applicable on microplastic scale - < 5 mm) (Naidoo e*t al.*, 2015). When attempting to quantify the levels of microplastic pollution in a certain marine or aquatic body, plastic particles suspended in the water column (which is neither floating nor in the sediment) should also be taken into account (Fazey *et al.*, 2016).

3.4 HEALTH RISKS ASSOCIATED WITH EXPOSURE TO MICROPLASTICS

3.4.1 Effects of microplastics on biota

Most plastics are very durable. Plastics may remain in the environment between hundreds and thousands of years (Barnes *et al*., 2009), posing an ever-increasing problem, now and probably for centauries to come, as it keeps on accumulating from current discard. Even though many plastics are naturally buoyant, particles and microorganisms (biofilm), can attach to the particles, increase the density, and cause these particles to sink to the bottom of water bodies. Studies have reported disruptions in the gas exchange on the ocean floor due to the convergence of microplastics. This results in a disruption of the benthic communities and ecosystem functions (Katsanevakis *et al*., 2007; Uneputty and Evans, 1997). Microplastic sizes falls within the size range of zooplankton (Lima *et al*., 2014), filter feeders (Avio *et al*., 2015), and even some smaller fish species (Luis *et al*., 2015). The ingestion of plastic particles by filter and suspension feeders at the base of the food web raises toxicity concerns form pollutants. Microplastics are receiving intensive attention as to their effects on plants and animals. Because there is so much more known on effects of microplastics in marine biota, Table 3-3, merely lists a range of studies, summarised by Cole et al., 2011, on uptake by marine animals.

Microplastics accumulate hydrophobic pollutants present in the environment, including persistent organic pollutants (POPs). Plastic samples taken from the North Pacific Gyre revealed concentrations of polychlorinated biphenyls (PCBs) ranging from 27 to 980 ng/g; aliphatic hydrocarbons ranged from 1.1 to 86 000 µg/g; DDT was as high as 7 100 ng/g, and polycyclic aromatic hydrocarbons (PAHs) 1 200 ng/g (Rios et al., 2007). The ingestion of these particles by organisms may also lead to accumulation in the digestive tract causing starvation due to a false sense of satiation, or even perforation of the gastro-intestinal tract. In addition, organisms that have taken up microplastics may now also pass this on to predators, including, say, from fish to humans (Farrel and Nelson, 2013; Seltenrich, 2015; Sharma and Chatterjee, 2017). This therefore potentially involves the accumulation of microplastics and their associated pollutants to higher trophic levels (Engler, 2012). Examples of studies on effects are listed in Table 3-4, where not all exposures found significant effects.

Table 3-3: List of findings of uptake of microplastics in marine biota (Cole *et al*., 2011).

Organism(s)	Microplastic size (µm)	Reference
Amphipod (*Orchestia gammarellus*) Barnacle (*Semibalanus balanoides*)	20-2000	Thompson *et al*. (2004)
Lugworm (*Arenicola marina*)	20-2000	Thompson *et al*. (2004)
Barnacle (*Semibalanus balanoides*)	20-2000	Thompson *et al*. (2004)
Copepods (*Acartia tonsa*)	7-70	Wilson (1973)
Echinoderm larvae	10-20	Hart (1998)
Mussel (*Mytilus edulis*)	2-16	Brown *et al*. (2004)
Scallop (*Placopecten magellanicus*)	16-18	Brillant and MacDonald (2002)
Sea cucumbers	Various	Graham and Thompson (2009)
Trochophore larvae (*Galeolaria*	3-10	Bolton and Havenhand (1998)
African Penguin (*Spheniscus demersus*)		Engelbrecht and Bouwman (2016)

Table 3-4: A summary of microplastics effects on biota

Effect	Description	References
Increased reactive oxygen species (ROS)	Ingested microplastics have shown to increase free radicals in which leads to cellular and DNA damage.	Bhattacharya *et al*., 2010
Reduced feeding or filtering	Animals containing microplastic in their digestive tracts were found to eat less, resulting in lower energy levels and fat reserves.	Wright *et al*., 2013 Wegner *et al*., 2012
Immune response	Microplastic in animal tissue can induce an immune response leading to inflammation.	von Moos *et al*., 2012 Köhler, 2010
Hepatic damage	Due to metabolic stress caused by microplastics, as well as pollutants accumulating on its surface, liver damage has been found in some organisms.	Rochman *et al*., 2013
Reduced gamete quality	Lower gamete quality causes less offspring to be produces and decrease fecundity.	Sussarellu *et al*., 2014
Mortality	Due to a combination of the physical and physiological effects of microplastic particles on certain individuals' fatality is increased.	Lee *et al.,* 2013
Marine larvae growth	Polyethylene microspheres exposed to sea urchin larvae showed little effect on larval growth.	Kaposi *et al*., 2013

For plastic to have a negative effect on a biotic system, it has to be exposed to it (Figure 3-2). Exposure to microplastics can either be through ingestion of plastic, either by mistaking plastic for food or ingesting plastic with other food (Lusher, 2015). Ingested plastic is also transferred along the food chain, but it is uncertain if concentrations increasing in higher trophic levels (Duis & Coors, 2016). The habitat an organism occupies can also be altered by the presence of microplastics (Lusher, 2015). For risk assessments, knowledge on exposures, uptake, and effects are required. As for chemicals, concentrations (number, or mass of particles per volume, or mass of medium) is required to determine exposure and uptake. In addition, and different from chemicals, is that physical properties and dimensions also play a role in uptake and effects associated with particles. A further complication is that leaching of additives and accumulated pollutants ay also cause toxic effect. Since little is known (see previous sections) about microplastic effects (although the body of literature is expanding), risk assessment will remain a challenge.

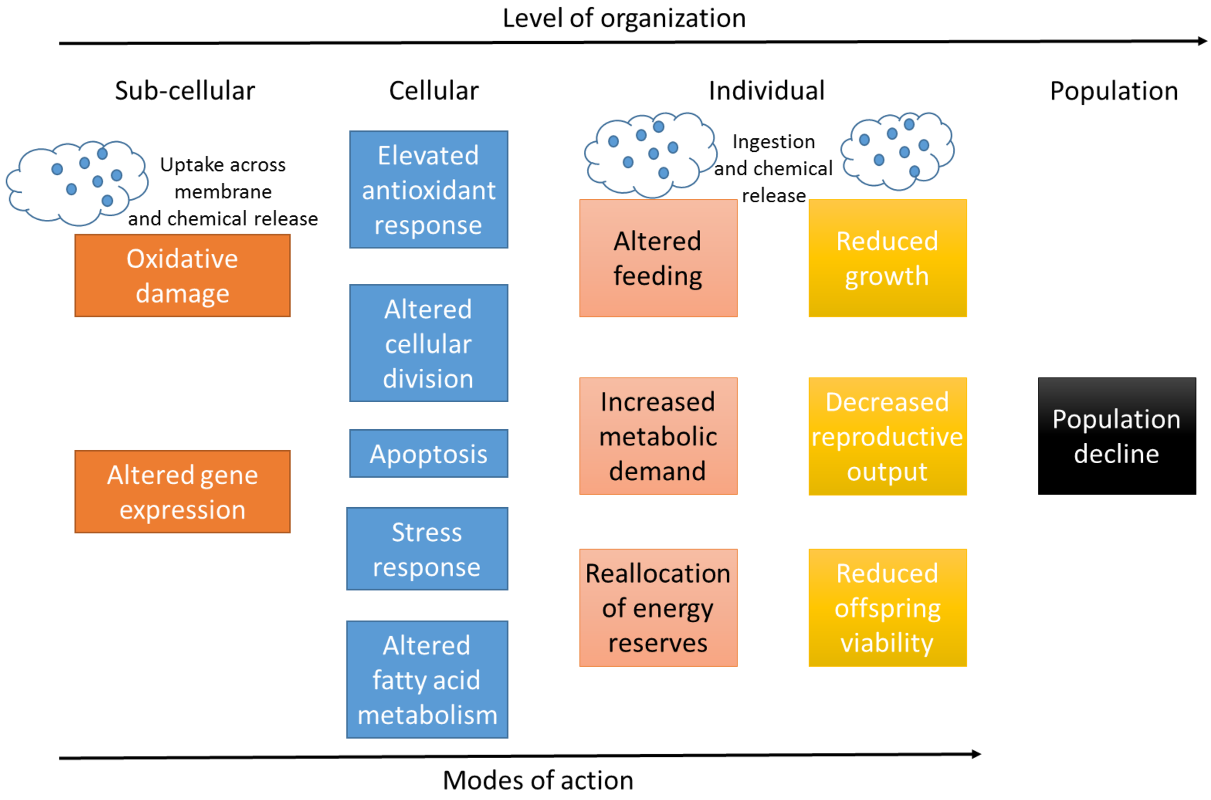


Figure 3-2: Initial adverse outcome pathway (AOP) of microplastics (small blue dots) and associated release of chemicals (blue cloud) exposure after uptake by aquatic species (after Galloway and Lewis, 2016).

3.4.2 Microplastics and the dissemination of antibiotic resistant bacteria (ARB) and (ARGs) genes

It is only recently that the first publications appeared on the relationship between antibiotic resistance and microplastics particles (Adrias-Andres et al., 2018; Eckert et al., 2018; Sun et al., 2018). This is a novel challenge that has, up to now, been overlooked, and is of concern in the water cycle.

Research by Adrias-Andres et al. (2018) demonstrated how the frequency of gene transfer is enhanced by the presence of microplastics. These authors used a two-species microcosm in which an *E. coli* stran that was transformed with a green-florescent protein containing plasmid. They monitored the transfer rate of the plasmid between this species and a *Pseudomonas* sp. recipient and found that the transfer rate was significantly higher in the microcosm containing microplastic particles. Aris-Adres et al. concluded that the favourable conditions provided by the microplastics enhanced the gene transfer potential of this aquatic environment. This may enhance evolutionary processes that will affect organisms at species, population and perhaps community levels. What is even more concerning being the fact that the recalcitrant nature of these microplastics may provide additional transfer potential of these antibiotic resistant bacteria and genes over enormous distances.

A study by Eckert et al. (2018) demonstrated that the mere presence of microplastics impacts on the resistance patterns of microbial communities in wastewater effluents. These authors used a laboratory set-up to mimic wastewater disposal into receiving fresh water. They found that microplastics enhanced the survival of WWTP-derived bacterial species as well as class I integron genes associated with anthopogenically derived antibiotic resistance genetic materials. This also demonstrate the potential threat of distributing these bacteria as well as associated genes in the aquatic environment.

The two examples referred to above had to do with aquatic systems. The role of microplastics in the interaction of bacteria and bacteriophages but specifically focusing on antibiotic resistance genes (ARGs) in soil was investigated (Sun et al., 2018). The authors demonstrated that microplatics provided a barrier that could enhance the interactions of bacteria and phages as well as the distribution of ARGs. Furthermore, they demonstrated that addition of a specific surfactant causes this barrier to be broken down and this interrupted the distribution of ARGs. This particularly study highlights the fact that even in terrestrial environments microplastics could have impacts on ARG dissemination. These examples highlight how complex the interactions of microplastics and the environment (aquatic or terrestrial) are and that there exists an enormous gap in the knowledge, particularly about the impact on dissemination of hazardous microorganisms and their genes in these environments. This calls for further research to understand these impacts in-order to manage them.

3.5 SUMMARY OF RECENT GLOBAL ACTIONS ON MICROPLASTICS

To illustrate the current concerns about microplastics, the following examples:

1. In 2012, Unilever decided to phase out microplastics from all their personal care products globally by 2015, based on environmental concerns.

2. A bill was passed (June 2014) by the state of Illinois, and in 2015 by California (USA), banning the manufacturing and sale of any cosmetic product containing microplastic beads. https://www.chemistryworld.com/news/us-bans-microbeads-from-personal-care-products/9309.article

3. The UNEP (June 2014) report recommends: Since plastic particles can be ingested by marine organisms and potentially accumulate and deliver toxins through the food web, efforts should be stepped up to fill the knowledge gaps and better understand the capacity of various plastics to absorb and transfer persistent, toxic and bio-accumulating chemicals.

4. The USA has banned the production of cosmetics and personal care products containing plastic microbeads from July 2017, and the sale of such products will come into effect in July 2018. Any drugs with microbeads may not be sold after July 2019.

5. On 9 January, 2018, a ban on the manufacture of products containing microbeads has come into force in the United Kingdom, but this may be in breach of European Union trade rules. An estimated 16-86 tons of the plastic microbeads found in cosmetics such as exfoliating scrubs and some toothpastes, are released into the environment each year from the UK.

6. Sweden, Finland, France, Iceland, Ireland, Luxemburg and Norway will ban the sale of cosmetics with microplastics by 2020 and have called on the EU for a EU-wide ban.

7. World Health Organisation – A 15th March 2018 edition of a newspaper article by The Guardian reported that the World Health Organisation is considering launching a health review in response to a study where microplastics were found in more than 90% of some of the world's most popular bottled water brands. https://www.theguardian.com/environment/2018/mar/15/microplastics-found-in-more-than-90-of-bottled-water-study-says?CMP=share_btn_link

CHAPTER 4: SURVEY OF MICROPLASTICS IN SELECTED SOURCE AND TREATED WATERS IN SOUTH AFRICA

4.1 INTRODUCTION

Although the body of literature on freshwater microplastics is growing, the methods used in these studies are inconsistent and varied. Variation in methods for sampling, sample preparation, and plastic particle identification complicates the comparison of studies (Dris *et al.*, 2015; Wagner and Lambert, 2018). A great obstacle to the quantification of microplastic globally is a lack of a standard measurement to quantify it. Depending on the sampling method, plastic can be quantified as particles/L and particles/m^3 when a specific volume of water was filtered, or particles/m^2 and particles/km^2 in continuous sampling methods. Instead of comparing the number of particles, the weight of a specific polymer per area or volume is also used to quantify microplastics in a waterbody. A standardised method for microplastic sampling would therefor serve as a solution to make datasets from around the globe comparable. Refer to Appendix A, Table 1 for a summary of the different sampling methods used by various authors and institutions around the world. One of the aims of this study was to conduct a scoping survey of microplastics in surface waters, ground water, and tap water to test robust sampling and counting methods. The methods followed and results obtained are detailed in this Chapter.

4.2 DESCRIPTION OF SELECTED SITES

South Africa is a semi-arid country, with very few natural lakes and the rivers have highly variable flows between seasons and between years. Most large rivers have been impounded and 98% of the country's surface-water supply options have already been developed. The combination of climatic variabilities and socio-economic water uses place enormous pressure on the water resources, both in terms of quantity and quality. Sampling and analysis for microplastics was done in a variety of freshwaters, including drinking and ground water in selected locations in North West and Gauteng provinces (Figure 4-1). Commercially important river systems such as the Vaal River, Mooi River and Wasgoedspruit River were selected for sampling. The Vaal River is 1300 kilometres long and is a vital part of the South African economy providing water services mainly to Gauteng, the economic hub of South Africa. In addition, site selection was done according to location and accessibility of rivers. Most sites were selected along bridges or riverbanks where deeper parts of the river would be easily accessible. In total, 43 freshwater sampling sites across Gauteng and the North West Province were selected for sampling. Figure 4-2 depicts proximities if the sampling locations in the different provinces, while their coordinates are shown in Table 4-1. Tap (drinking) water samples from selected taps around the Johannesburg and Tshwane were also analysed. Groundwater from four boreholes in Potchefstroom (North West) was also analysed.

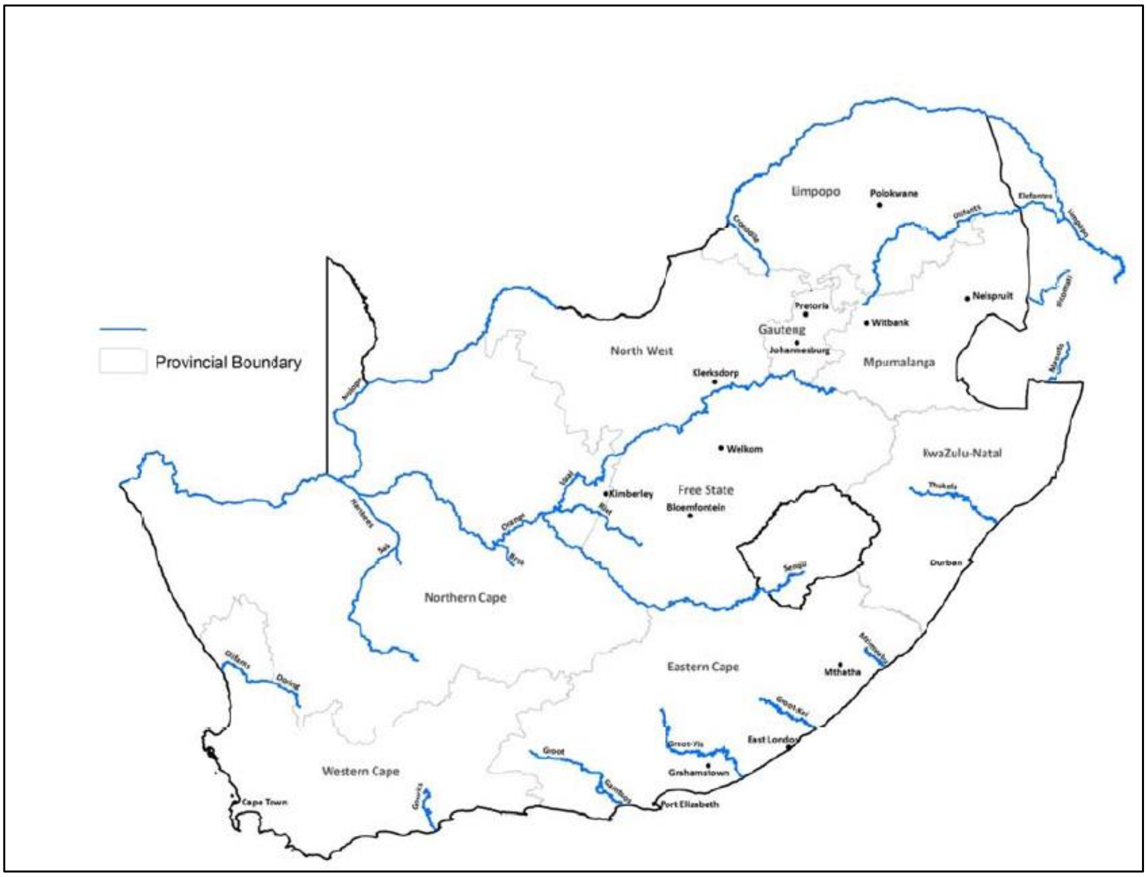


Figure 4-1: Map of South Africa showing major rivers and provincial boundaries. Source: Nel and Driver (2015).

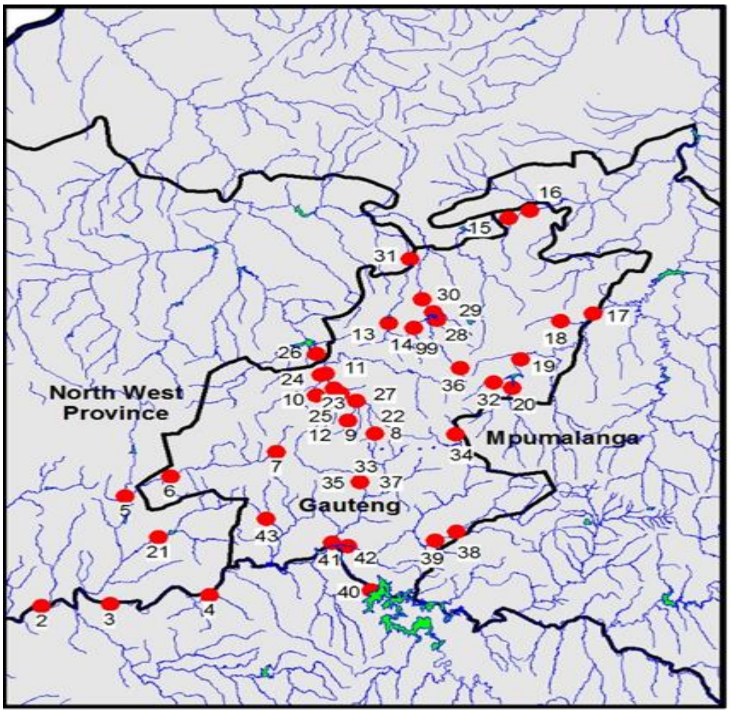


Figure 4-2:Sampling sites in Gauteng and North West Province. Large water bodies are indicated in green.

Table 4-1: Coordinates of the sites where surface water samples were taken.

Sample	S	E
2	-26.945	26.781
3	-26.937	27.057
4	-26.894	27.461
5	-26.445	27.118
6	-26.356	27.302
7	-26.244	27.732
8	-20.162	28.132
9	-26.104	28.022
10	-25.989	27.893
11	-25.895	27.914
12	-26.012	28.058
13	-25.659	28.188
14	-25.680	28.290
15	-25.183	28.673
16	-25.150	28.759
17	-25.617	29.016
18	-25.650	28.884
19	-25.824	28.722
20	-25.953	28.689
21	-26.632	27.254
22	-26.013	28.058
23	-25.955	27.965
24	-25.889	27.933
25	-25.978	27.993
26	-25.798	27.895
27	-26.013	28.058
28	-25.643	28.385
29	-25.608	28.367
30	-25.550	28.325
31	-25.369	28.274
32	-25.930	28.614
33	-26.380	28.071
34	-26.165	28.460
35	-26.380	28.071
36	-25.863	28.477
37	-26.380	28.071
38	-26.609	28.464
39	-26.647	28.376
40	-26.875	28.116
41	-26.658	27.959
42	-26.672	28.023
43	-26.549	27.692
99	-25.680	28.290

4.3 METHOD FOR SAMPLING AND QUANTIFYING MICROPLASTICS

The method used for sampling and quantifying microplastics in South African waters was adapted from the NOAA standard microplastic protocol (Masura *et al*., 2015). As research into microplastic research has increased, there has been many attempts to refine existing sampling and analysis methods for high-throughput with increased polymeric confirmation. A variety of methods have been reported in literature, and these involve; bulk or volume-reduced sampling followed by density separation, filtration/sieving and visual identification (Hidalgo-Ruz *et al.,* 2012).

4.3.1 Description of sampling and filtering methods

Based on the published protocols, a volume of 90 Litres is required for microplastics analysis. However, this may not be practical if a large number of samples has to be collected as it would not to be easy to transport them back to the laboratory for analysis. In this study, the 90 L volume was filtered on site in batches using a 15 Litre metal bucket through a 20 µm sieve. The sieve was pre- and post-cleaned to minimise contamination. Rinsed water was stored in pre-cleaned HDPE bottles and transported to the laboratory (Figure 4-3).

Figure 4-3: Illustration of the sampling procedure used in this study

4.3.2 Description of particle filtration and concentration procedures

Samples were decanted into glass beakers and the bottle rinsed to remove all remaining visible debris. The glassware was then covered with tin foil or a watch glass and placed in a drying oven at 90°C until all the water had evaporated.

Dried material was subjected to wet peroxide as described in Masura *et al*. (2015) to digest biological material. Density separation was then done similar to the method described in Masura *et al*. (2015). Iodine chloride was used instead of sodium chloride, as a sodium chloride solution does not allow PVC to be floated in a density separation, and an iodine chloride solution of the same molar concentration does so. After samples were left overnight in the density separators (Figure 4-4), and clear settling of sediments could be observed, the sedimented layer was removed and retained in a petri dish. This was subsequently inspected for microplastic using a dissection microscope. If any plastics were found it was removed using a pair of forceps and added to the rest of the collection for that sample.

The remainder of the liquid containing the less dense material such as plastic was filtered through a custom-made 20 µm stainless steel filter (Figure 4-5) that is spring-clamped in the place of filter paper, membranes, or sintered discs in a normal 47 mm glass vacuum filtration system. The disc is made entirely of metal and has black rubber O-rings to ensure a seal when clamped. The disks had to be stainless steel as the background of paper or other materials would interfere too much with the FT/IR. Filtered and dried samples were carefully stored in petri dishes until counting.

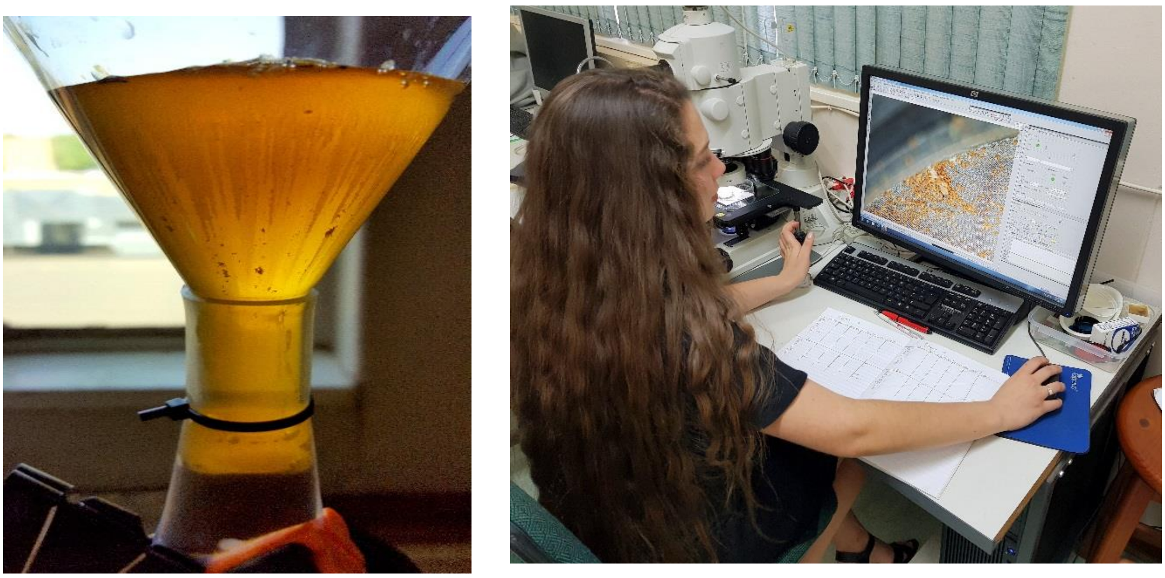


Figure 4-4: Sample preparation and analysis

Figure 4-5: Custom-made stainless-steel filter, with microplastics filtered from 90 Litres of surface water.

4.3.3 Counting and characterisation

Each concentration disc was inspected using a Nikon EZ 100 multi-zoom compound binocular microscope (Figure 4-4). Fragments and fibres were counted separately and by size, as were the colour of each fragment or fibre.

4.3.4 Polymer identification

An Agilent Cary 660 FTIR spectrometer was used to determine polymer compositions.

4.4 MICROPLASTICS IN SURFACE WATER

4.4.1 Geographic distributions

Knowledge on the distributions of plastic particles in water allows a determination of where risks may be expected, and where interventions may be required. Figure 4-6 to Figure 4-11 show the distribution of the combined fibre and fragment numbers per litre in all the freshwater samples. A total of 43 samples were collected Two samples (2 and 3), both from the Vaal River, immediately stands out because of the order of magnitude higher particle counts. The relatively high numbers for the two Vaal River sites makes comparisons with other sites difficult. The data from these sites have been excluded form most of the statistics and will also be excluded from the rest of the maps.

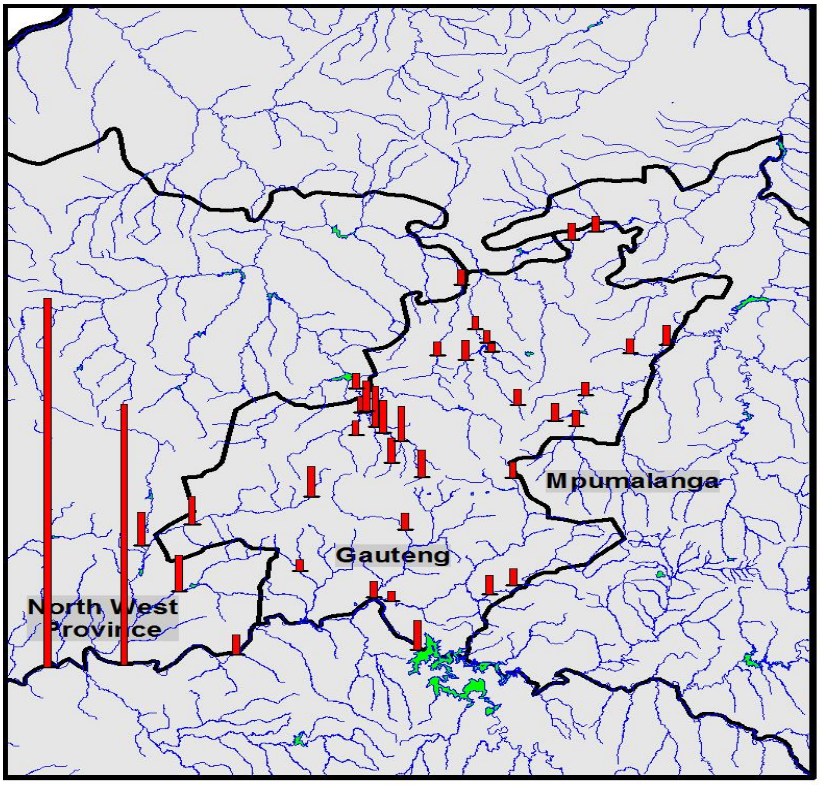


Figure 4-6: Distributions of total particles (fragments and fibres) per litre of freshwater at all sampling sites. The tallest bar represents 56 particles per litre.

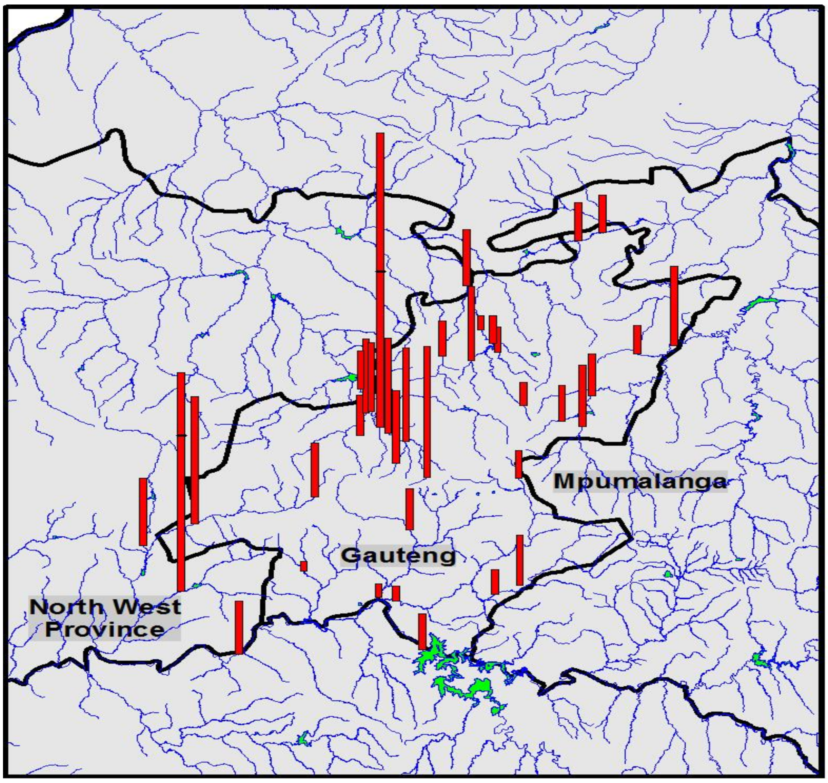


Figure 4-7: Distribution of total particles (fragments plus fibres) per litre of water at all sampling sites. Sites 2 and 3 are excluded. The tallest bar represents 5.12 particles per litre.

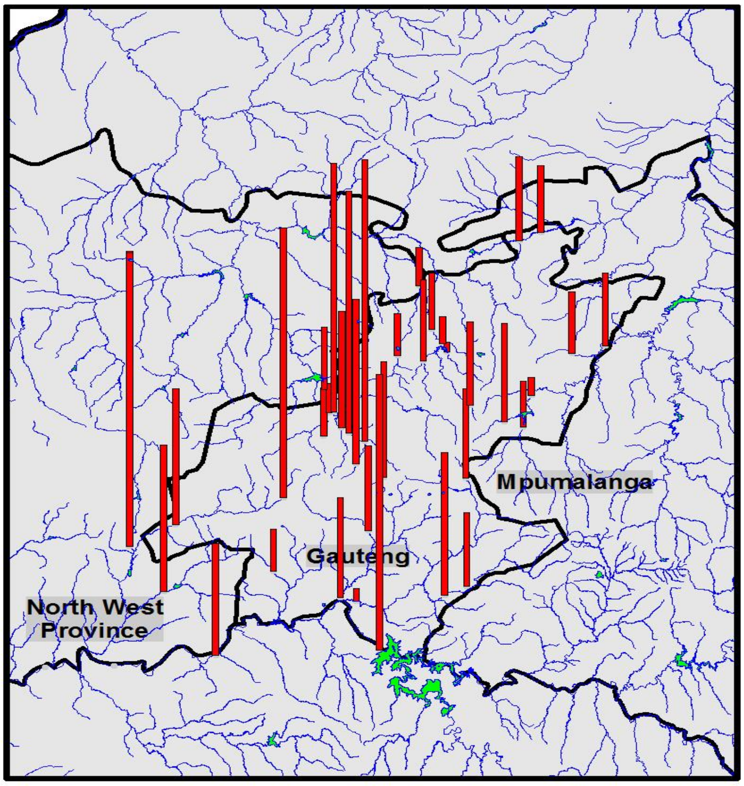


Figure 4-8: Particles per litre of water, per collection site, excluding Sites 2 and 3. The tallest bar represents 4 particles per litre.

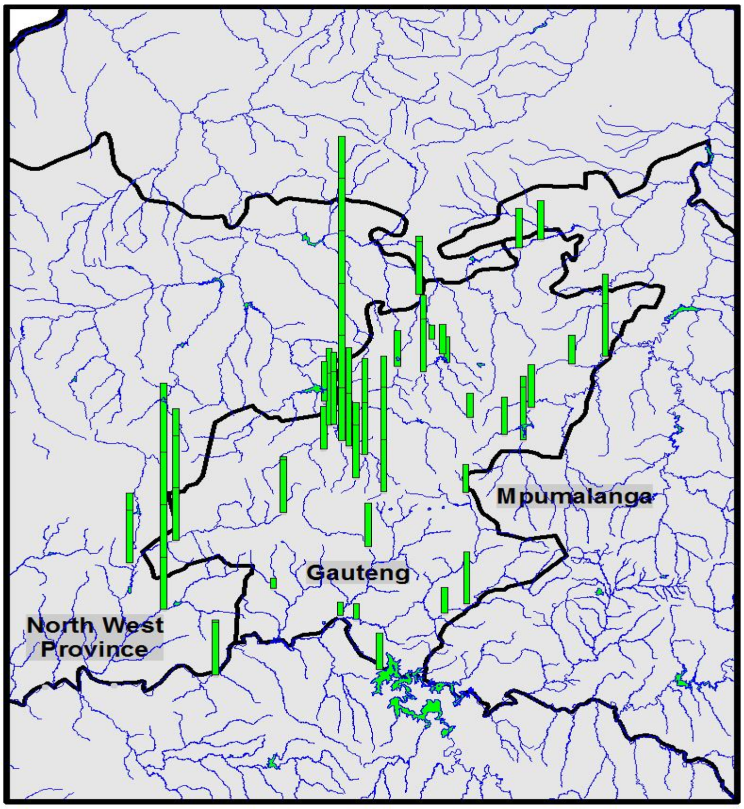


Figure 4-9: Fibres per litre of water, per collection site, excluding Sites 2 and 3. The tallest bar represents 3.9 fibres per litre.

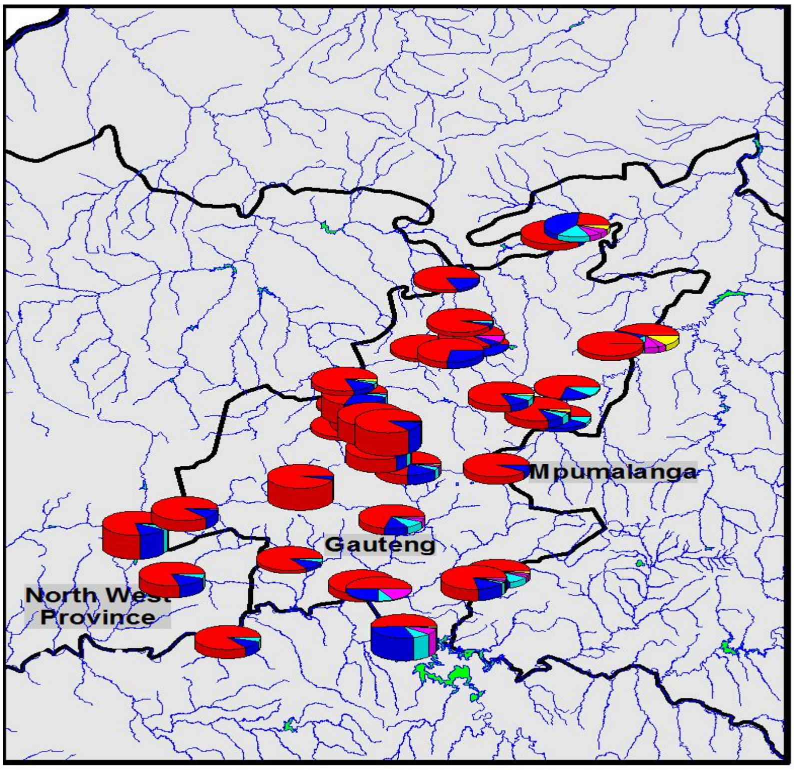


Figure 4-10: Pie charts of the size (µm) composition profiles of fragments. The height of each pie represents the number of fragment particles. Red = 20<300; Purple = 3001-600; Dark blue = 601-900; Light blue = 901-1200; Green = 1201-1500; Yellow = >1500.

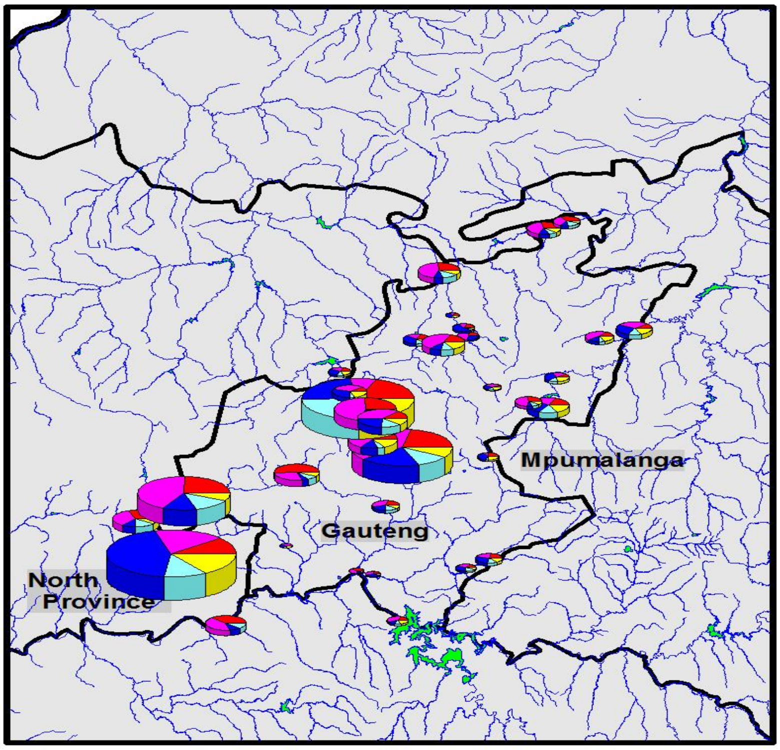


Figure 4-11: Pie charts of the size (µm) composition profiles of fibres. The height of each pie represents the number of fibre particles. Red = 20<300; Purple = 3001-600; Dark blue = 601-900; Light blue = 901-1200; Green = 1201-1500; Yellow = >1500.

4.4.2 Quantitative analysis of microplastic particles in surface water samples

A total of 15 526 fragments and fibres were detected from 43 freshwater samples. The quantitative results are displayed in Table 4-2 as fragments or fibres per Litre. Two samples (2 and 3), both from the Vaal River, immediately stands out because of the order of magnitude higher particle counts. Figure 4-12 shows examples of the types and sizes of microplastics filtered from surface water samples. In most cases, these two samples were not used for statistics or graphs, because of distortions. Excluding the samples from sites 2 and 3, there were 3 963 plastic fragments, and 3 281 fibres. This translates to about 55% of the plastic and fibre composition consists of fragments.

Table 4-2: Counts of fragments and fibres per litre of water from 43 sites according to size classes.

	Plastic particle per size class (um), per litre							Fibres, per size class, per litre							
Sample	**20<300**	**301-600**	**601-900**	**901-1200**	**1201-1500**	**>1500**	**Total**	**20<300**	**301-600**	**601-900**	**901-1200**	**1201-1500**	**>1500**	**Total**	**Grand Total**
2	49.300	5.256	1.022	0.322	0.100	0.000	56.000	0.122	0.122	0.089	0.044	0.033	0.122	0.533	56.533
3	25.778	9.356	2.400	0.689	0.222	0.222	38.667	0.111	0.222	0.178	0.178	0.078	0.233	1.000	39.667
4	1.011	0.089	0.033	0.000	0.000	0.000	1.133	0.256	0.233	0.067	0.044	0.000	0.144	0.744	1.878
5	2.444	0.478	0.078	0.044	0.011	0.011	3.067	0.233	0.178	0.100	0.133	0.044	0.244	0.933	4.000
6	1.267	0.111	0.000	0.011	0.000	0.000	1.389	0.356	0.556	0.300	0.189	0.056	0.278	1.733	3.122
7	2.733	0.067	0.000	0.000	0.000	0.000	2.800	0.344	0.211	0.044	0.044	0.033	0.078	0.756	3.556
8	0.878	0.233	0.033	0.022	0.000	0.011	1.178	0.311	0.589	0.456	0.167	0.078	0.178	1.778	2.956
9	1.511	0.100	0.044	0.033	0.000	0.000	1.689	0.133	0.322	0.144	0.056	0.089	0.256	1.000	2.689
10	0.344	0.078	0.011	0.011	0.011	0.000	0.456	0.144	0.178	0.089	0.033	0.033	0.100	0.578	1.033
11	0.156	0.067	0.044	0.000	0.000	0.000	0.267	0.267	0.422	0.133	0.056	0.067	0.078	1.022	1.289
12	1.156	0.111	0.000	0.000	0.011	0.022	1.300	0.067	0.078	0.089	0.044	0.022	0.133	0.433	1.733
13	0.367	0.011	0.022	0.000	0.000	0.000	0.400	0.056	0.111	0.111	0.067	0.033	0.122	0.500	0.900
14	0.256	0.078	0.011	0.000	0.011	0.022	0.378	0.178	0.078	0.056	0.044	0.022	0.189	0.567	0.944
15	0.778	0.056	0.000	0.000	0.000	0.000	0.833	0.144	0.178	0.089	0.044	0.033	0.056	0.544	1.378
16	0.144	0.244	0.178	0.044	0.022	0.022	0.656	0.144	0.089	0.067	0.067	0.011	0.156	0.533	1.189
17	0.333	0.089	0.111	0.089	0.033	0.067	0.722	0.033	0.200	0.111	0.111	0.067	0.567	1.089	1.811
18	0.600	0.000	0.000	0.000	0.000	0.000	0.600	0.044	0.178	0.078	0.044	0.056	0.011	0.411	1.011
19	0.100	0.033	0.011	0.000	0.000	0.000	0.144	0.022	0.100	0.078	0.067	0.078	0.244	0.589	0.733
20	0.278	0.133	0.022	0.000	0.000	0.000	0.433	0.089	0.178	0.122	0.156	0.078	0.233	0.856	1.289
21	1.233	0.222	0.044	0.000	0.000	0.000	1.500	0.133	0.544	0.800	0.367	0.222	0.878	2.944	4.444
22	0.600	0.078	0.022	0.033	0.022	0.022	0.778	0.044	0.167	0.211	0.033	0.122	0.367	0.944	1.722
23	0.967	0.133	0.022	0.011	0.022	0.022	1.178	0.278	0.256	0.367	0.444	0.444	2.156	3.944	5.122
24	1.678	0.822	0.056	0.022	0.000	0.000	2.578	0.033	0.200	0.144	0.044	0.078	0.456	0.956	3.533
25	2.233	0.222	0.033	0.011	0.000	0.011	2.511	0.244	0.411	0.144	0.100	0.056	0.344	1.300	3.811
26	0.511	0.078	0.011	0.000	0.000	0.011	0.611	0.044	0.089	0.067	0.056	0.044	0.244	0.544	1.156
27	2.667	0.244	0.011	0.000	0.011	0.000	2.933	0.067	0.311	0.178	0.144	0.056	0.522	1.278	4.211
28	0.044	0.011	0.000	0.000	0.000	0.000	0.056	0.078	0.133	0.078	0.000	0.000	0.078	0.367	0.422
29	0.211	0.011	0.000	0.011	0.000	0.000	0.233	0.044	0.067	0.167	0.011	0.011	0.111	0.411	0.644
30	0.522	0.011	0.011	0.000	0.000	0.000	0.544	0.022	0.033	0.056	0.011	0.033	0.067	0.222	0.767
31	0.300	0.056	0.000	0.000	0.000	0.000	0.356	0.167	0.256	0.078	0.089	0.033	0.156	0.778	1.133
32	0.833	0.089	0.033	0.011	0.000	0.022	0.989	0.111	0.156	0.056	0.033	0.022	0.133	0.511	1.500
33	0.411	0.078	0.022	0.000	0.000	0.000	0.511	0.022	0.033	0.078	0.022	0.033	0.222	0.411	0.922
34	0.856	0.044	0.000	0.000	0.000	0.000	0.900	0.067	0.044	0.078	0.022	0.067	0.122	0.400	1.300
35	0.533	0.067	0.011	0.000	0.000	0.000	0.611	0.067	0.100	0.089	0.011	0.022	0.033	0.322	0.933
36	0.700	0.089	0.033	0.000	0.000	0.011	0.833	0.011	0.089	0.033	0.044	0.044	0.122	0.344	1.178
37	0.578	0.167	0.067	0.022	0.011	0.000	0.844	0.078	0.122	0.089	0.078	0.022	0.200	0.589	1.433
38	0.400	0.222	0.067	0.011	0.011	0.011	0.722	0.078	0.100	0.089	0.078	0.033	0.322	0.700	1.422
39	1.156	0.233	0.022	0.011	0.033	0.000	1.456	0.033	0.089	0.078	0.056	0.011	0.100	0.367	1.822
40	1.444	0.956	0.278	0.144	0.011	0.033	2.867	0.044	0.111	0.033	0.056	0.044	0.222	0.511	3.378
41	0.833	0.056	0.033	0.022	0.011	0.056	1.011	0.078	0.056	0.033	0.000	0.011	0.033	0.211	1.222
42	0.044	0.022	0.011	0.011	0.000	0.000	0.089	0.044	0.056	0.078	0.011	0.000	0.044	0.233	0.322
43	0.356	0.033	0.011	0.000	0.000	0.000	0.400	0.000	0.067	0.022	0.022	0.033	0.022	0.167	0.567
99	0.578	0.233	0.000	0.000	0.000	0.000	0.811	0.100	0.278	0.078	0.111	0.078	0.378	1.022	1.833

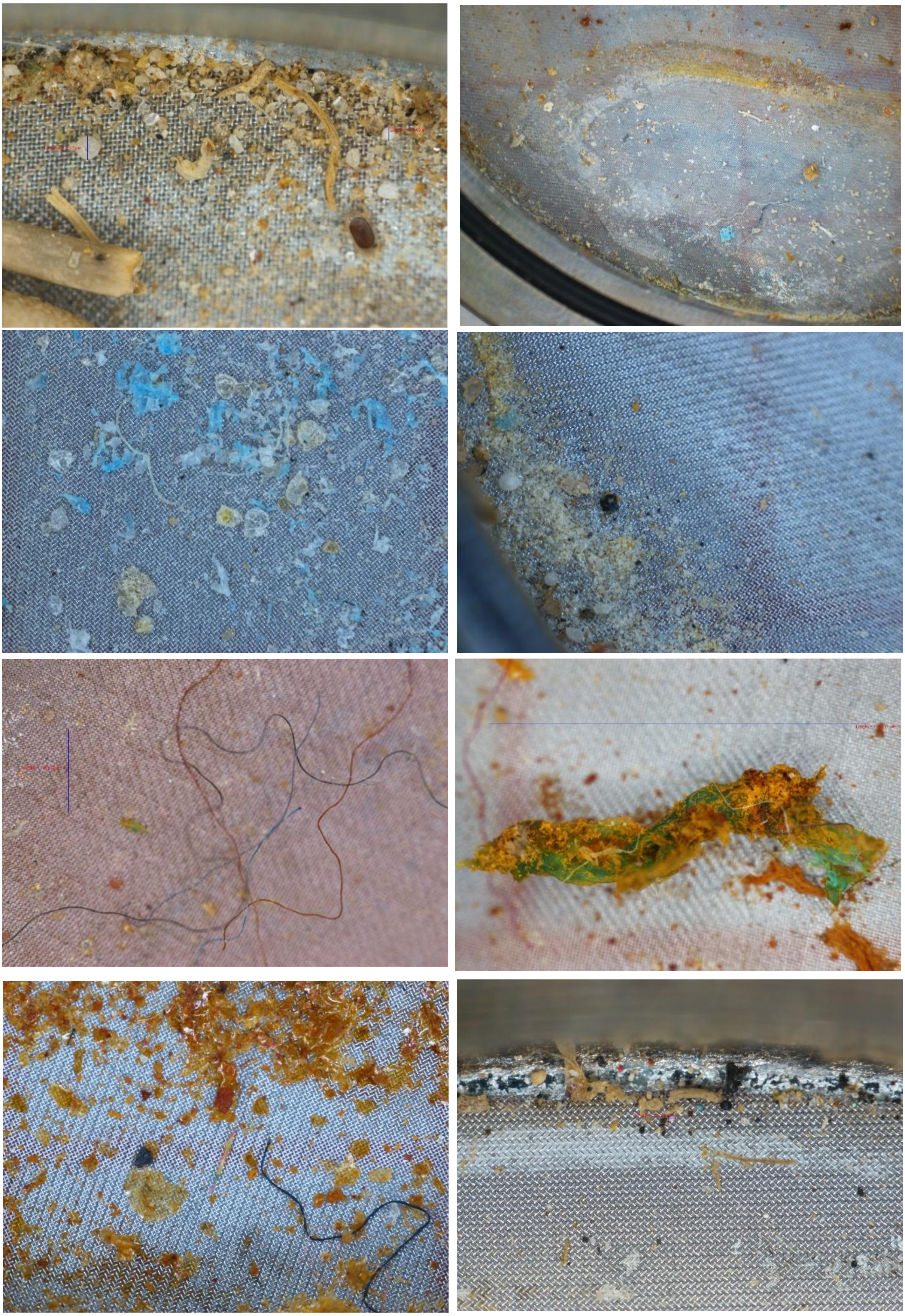


Figure 4-12: Examples of the types and sizes of microplastics filtered from surface water samples

The various size classes for fragments and fibres were plotted and presented in Figure 4-13. The log-transformed plots of the data are also shown, as the distributions per size class were not Gaussian. Please note that samples 2 and 3 are not plotted. For fragments, there was a clear skewing towards the smaller sizes (Figure 4-13a and b). The Kruskal-Wallis tests for log-transformed data (Figure 4-13b) showed a highly significant difference between particle size classes ($p < 0.0001$). Subsequent Dunn's multiple comparisons tests showed significant differences between the 20 < 300 and 301 - 600 µm, and the 301 - 600 and 601 - 900 µm size classes (log-transformed) only. A post-test for linear trend between log-transformed size classes was also highly significant ($p < 0.0001$). There was no discernible pattern for fibre size-classes. The Kruskal-Wallis test for log-transformed fibres was also highly significant ($p < 0.0001$) (Figure 4-13d). Dunn's multiple comparisons showed significant differences between 20 - 300 µm and 301 - 600 µm ($p = 0.0309$), and between 301 - 600 µm and 601 - 900 µm ($p < 0.0001$) size classes.

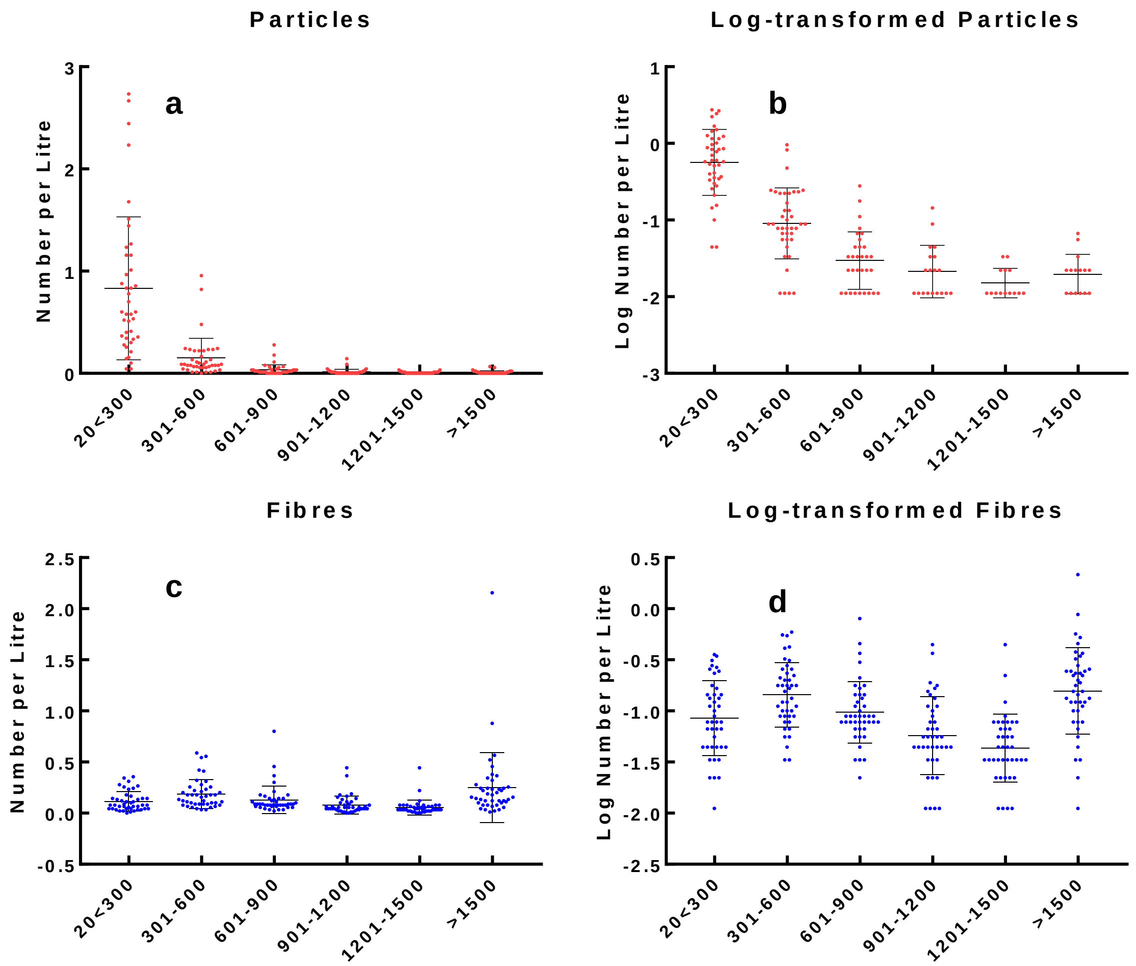


Figure 4-13: Scatterplots of untransformed and log-transformed size-class data for fragments (a and b) and fibres (c and d). Mean and standard deviations are shown. Two samples (2 and 3) were not included in any plot.

The summary statistics for fragments and fibres separate are presented in Table 4-3. The summary statistics for fragments and fibres combined are shown in Table 4-4, while Figure 4-14 shows the log-transformed data, that includes the data for Sites 2 and 3.

Table 4-3: Summary statistics for the 41 freshwater sites (particles/Litre). Samples 2 and 3 are not included.

	Particles						
	20<300	**301-600**	**601-900**	**901-1200**	**1201-1500**	**>1500**	**Total**
Minimum	0,04	0,00	0,00	0,00	0,00	0,00	0,06
Maximum	2,73	0,96	0,28	0,14	0,03	0,07	3,07
Median	0,60	0,09	0,02	0,00	0,00	0,00	0,58
Mean	0,83	0,15	0,03	0,01	0,01	0,01	0,81
Standard deviation	0,70	0,19	0,05	0,03	0,01	0,02	0,83
	Fibres						
Minimum	0,00	0,03	0,02	0,00	0,00	0,01	0,17
Maximum	0,36	0,59	0,80	0,44	0,44	2,16	3,94
Median	0,08	0,16	0,09	0,06	0,03	0,16	0,58
Mean	0,12	0,19	0,13	0,08	0,06	0,25	0,82
Standard deviation	0,09	0,14	0,14	0,09	0,07	0,34	0,72

Table 4-4: Summary statistics for fibres and fragments combined (particles/Litre).

	All[3]	**Depleted**[4]
Minimum	0,32	0,32
Maximum	56,53	5,12
Median	1,42	1,38
Mean	4,01	1,86
Standard deviation	10,10	1,24

[3] All = includes the data for sites 2 and 3

[4] Depleted = data for sites 2 and 3 omitted

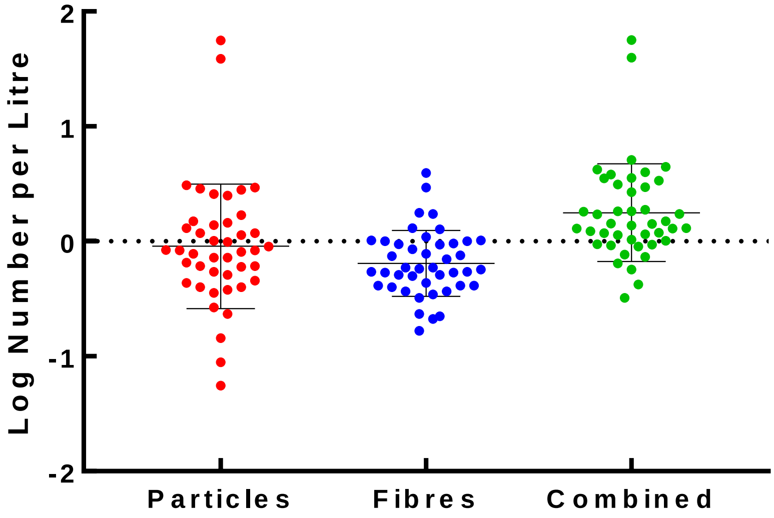


Figure 4-14: Log transformed data of fragments, fibres, and combined data, that includes data from Sites 2 and 3, are presented in this scatterplot. Means and standard deviations are shown.

A two-tailed Wilcoxon matched-pairs signed rank test of log-transformed fibre and fragment data (excluding data from Sites 2 and 3), produced a p-value of 0.1330. The pairing though, was significant (p = 0.0032) for a Spearman correlation r-value of 0.4197, showing some relationship between numbers of fibres and numbers of fragments in the same samples. A linear regression between fibres and fragments (again excluding Sites 2 and 3), showed a poor fit of the data to the regression line (r-value 0.07669) and a non-significant regression at p = 0.0796 (Figure 4-15a). For log-transformed data, however, there was a significant regression (p = 0.0053) (Figure 4-15b), but the fit of the points to the regression line remained poor (r = 0.1828).

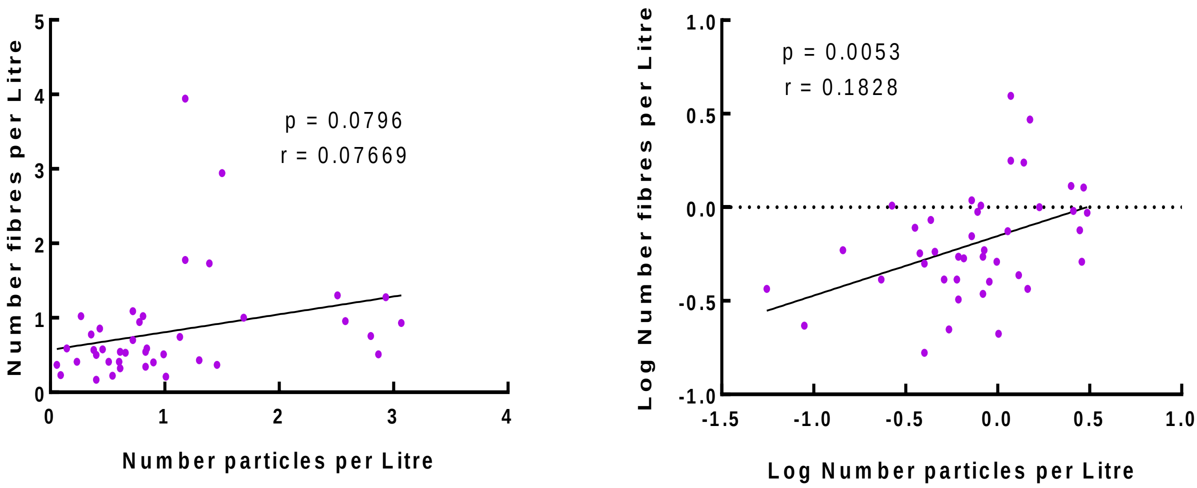


Figure 4-15: Linear regression of untransformed (a) and log-transformed (b) numbers of fragments and fibres per litre.

4.4.3 Discussion and summary of findings

Based on the sites used for this project, freshwater sources were found to contain microplastics between 56 and 0.33 particles per litre. Two sites had very high concentrations of plastic particles; 56 and 39 particles per litre, respectively. We excluded these from most analyses, as the rest of the samples had a mean of 1.86 per litre (Tables 4-2, 4-3 and 4-4). The geographic distributions are also insightful. The heavily used Crocodile River that drains most parts of Johannesburg dominates the total particle, fragment and fibre concentrations (Figures 4-6 to 4-11). Fragments and fibres are also prominent to the west near Potchefstroom, while northern and eastern parts have noticeably lower concentrations. As has already been shown, small particles dominate at all sites (Figure 4-13). However, at Vaal Dam and towards the north, larger particles make up greater proportions. The very high fragment concentrations at Sites 2 and 3 remain unexplained and needs further investigation. The fibre size classes were more homogenously distributed. This also reflects the little differentiation seen in Figure 4-13, where there was no discernible trend between size classes.

Fragments had a very clear pattern when compared against size classes (Figure 4-13a). The smallest size class (20-300 µm) had four times more particles than the other fragment particle size classes combined. This trend was also significant (Figure 4-13b). This pattern could be due to a significant release of small manufactured fragments in excess of larger particles, the resultant effect of the breakdown from larger to smaller fragments, or a combination of both. However, a comparison with fibres data might shed light on which of these processes would be dominant. For fibres, there was no size-class pattern discernible (Figure 413 c and d), although the Kruskal-Wallis analyses did indicate some size-class differences. Longer fibres, conceivably, would break down into smaller particles the same as for fragments particles. Since this is not apparent from our data, it seems that the release of small manufactured particles would make up the bulk of the fragment pattern.

However, caution should be expressed about this argument as fragments and fibres might behave and distribute differently in the same aquatic medium, due to possible differences in water resistance, reaction to turbulence, specific mass, or density, and surface to volume ratios. Heavier fragments might settle out of water faster into sediments, while fibres of the same mass might be prone to remain in suspension for longer, while the smaller particles would be less prone to settle, dominating the smaller size-classes in water. These factors would need more investigation, including the analyses of fragments and fibres in sediments, as well as the measurement of water velocity at each site in the future. Size classes might affect impact, as smaller sizes could cross membranes more easily.

Due to the amount of literature available on freshwater microplastics, as well as the varied differences in the sampling methods used in other studies, there is very narrow scope for comparison. In this study microplastic were quantified as particles/fibres per volume of surface water and not per surface area sampled, the results of studies applying a similar sampling method are shown in Table 4-5.

Table 4-5: Comparable results from other studies[5]

Location	Microplastics per litre of water	Reference
Austrian Danube, Austria	Mean: 3.2 x10^{-4} Maximum: 5.0 x10^{-3}	Lechner *et al*., 2014
Goiana Estuary: Brazi	Maximum: 1.5 x10^{-4}	Lima *et al*., 2014
WWTP effluent: Paris, France.	Untreated waste water: 260-320 Effluent: 14-50	Dris *et al*., 2015
Italy: Lake Bolsena and Lake Chiusi	0.0027 0.0034	Fischer *et al*., 2016
Dutch river delta and Amsterdam canals	Mean: 100 Max: 187	Leslie *et al.,* 2017
USA general	Mean waste water treatment effluent: 0.5 ± 0.024	Mason *et al*., 2016
North America: 29 Great Lakes tributaries	Mean: 0.0042 Maximum: 0.032	Baldwin *et al.,* 2016
Los Angeles river, San Gabriel river, Coyote Creek	13	Moore *et al.,* 2011
China: Lake Taihu (developed area)	3.4–26	Su *et al*., 2016
China: Three Gorges Dam	Mean: 4.1 Maximum: 12.6	Di & Wang, 2017
Yangtze Estuary	Mean: 4.1 Maximum: 10.2	Zhao *et al*., 2014
China: Lakes, Wuhan	8.9	Wang *et al.,* 2017
Gauteng and North West Province	**Mean: 1.9** **Maximum: 5.12**	**This study**

4.5 MICROPLASTICS IN GROUNDWATER

4.5.1 Quantitative analysis

Groundwater from four boreholes in Potchefstroom (South Africa) had very low concentrations of particles per Litre (Table 4-6), when compared with open water (Table 4-2). In open waters, fragments and fibres had the same mean of about 0.8 particles per Litre. Particles in ground water was an order of magnitude lower that in surface water.

Proportional composition between size classes of fibres and fragments (Figure 4-16) shows that fragment profiles were distinctly skewed towards the smallest size class in both ground and surface waters, while fibres showed an opposite trend with the greatest relative proportion in the largest size class.

[5] Some results were re-calculated to particles per Litre.

Table 4-6: Counts of fragments and fibres per Litre of groundwater from four boreholes in Potchefstroom, according to size classes (µm)

Sample		20<300	301-600	601-900	901-1200	1201-1500	>1500	Total	Grand total
		Plastic particle/fibre per size class (um) per litre							
52	particle	0,0444	0,0222	0	0	0	0	0,0667	0,1333
	fibre	0	0,0222	0,0111	0	0,0111	0,0222	0,0667	
54	particle	0,0111	0	0	0	0	0	0,0111	0,1222
	fibre	0	0	0,0333	0,0111	0	0,0667	0,1111	
55	particle	0	0	0	0	0	0	0	0,1222
	fibre	0,0111	0,0222	0	0,0222	0,0333	0,0333	0,1222	
56	particle	0,0778	0,0111	0	0	0	0	0,0889	0,2889
	fibre	0	0,0222	0,0444	0,0222	0,0444	0,0667	0,2000	
Mean	particle	0,0333	0,0083	0	0	0	0	0,0417	0,1667
	fibre	0,0028	0,0167	0,0222	0,0139	0,0222	0,0472	0,1250	0,1667

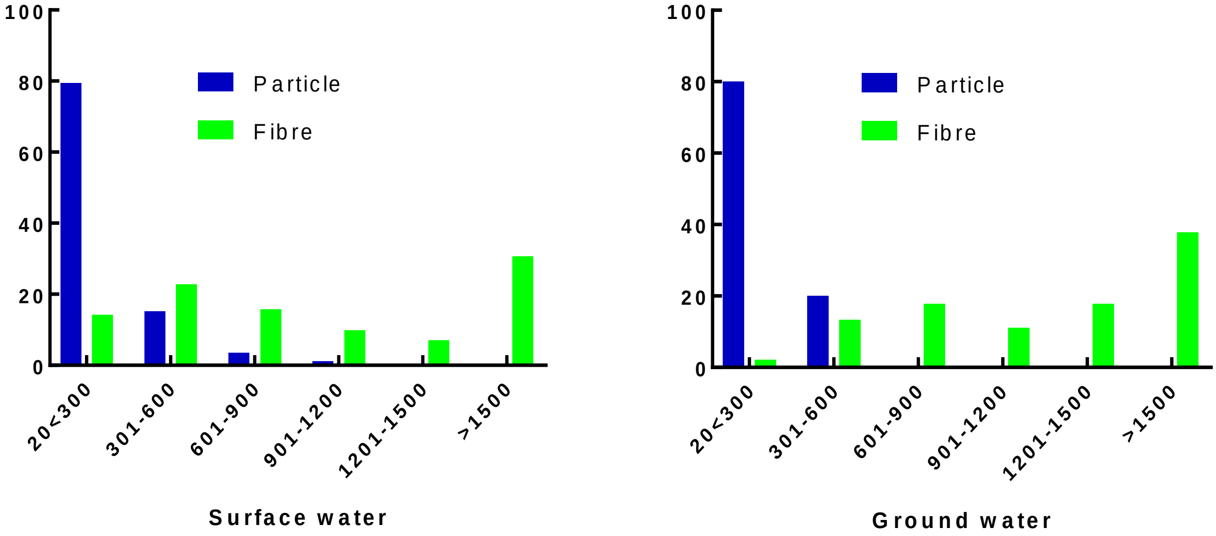


Figure 4-16: Comparisons of relative distributions (percentages) of size class composition of fragments and fibres in surface and ground water samples.

4.5.3 Discussion and summary of findings

Microplastic fibres and fragments are known from agricultural soils due to sludge applications (Zubris and Richards, 2005). Fibres and fragments can be expected to behave differently in soil pore water than in open surface waters (Nizzetto *et al.*, 2016; Rillig *et al*., 2017a; Rillig *et al*., 2017b). Fibres can also remain in soil-applied sludges for 15 years and may travel horizontally and laterally along flow paths and via earthworms (Rillig *et al*., 2017b). As far as we are aware, this study is the first that quantified fibres and fragments into size classes. The size class profiles seem similar between soils and water, albeit with much lower numbers of both. The fragment proportion is also much lower in soils compared to surface water (Tables 4-2 & 4-3). Only fragments in the two lowest size classes were found in soil water, but fibres occurred in all size classes. The reasons for this difference between ground and surface water are not known. However, in many places, people get their prime household consumption water from groundwater. Therefore, more studies would be needed to determine the factors involved, as well as the possible health implications it may have.

4.6 MICROPLASTICS IN TAP (DRINKING) WATER

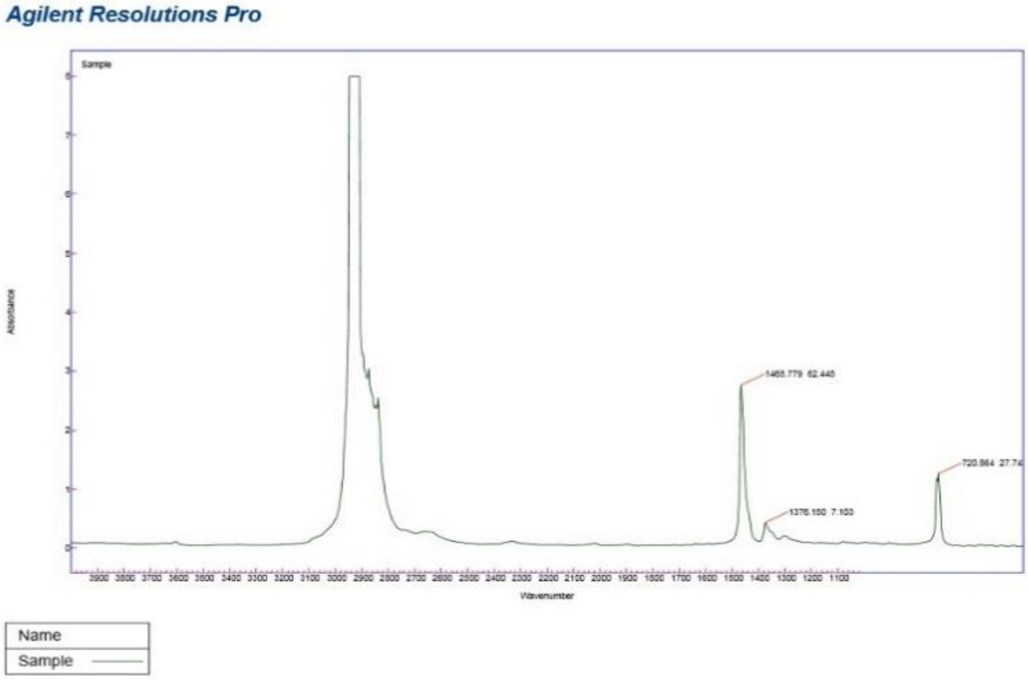
Tap water samples were collected from selected tap in City of Johannesburg and Tshwane regions. One sample was analysed from each region and the results are shown in Table 4-7. Tap water samples collected from the Tshwane region seemed to have fewer fragments compared with Johannesburg. In Johannesburg tap water, particles seem to be distributed homogenously between different size classes, while in the Tshwane region tap water only had particles in the two smallest size classes.

Table 4-7: Counts of fragments and fibres per Litre of tap water from Johannesburg and Tshwane, according to size classes (µm).

		Plastic particle/fibre per size class (um), per litre						
Sample		**20<300**	**301-600**	**601-900**	**901-1200**	**1201-1500**	**>1500**	**Total**
Tshwane	particle	0,167	0,022	0,000	0,000	0,000	0,000	0,189
	fibre	0,133	0,278	0,122	0,089	0,078	0,167	0,867
Johannesburg	particle	0,133	0,278	0,122	0,089	0,078	0,167	0,867
	fibre	0,100	0,356	0,278	0,256	0,111	0,700	1,800

4.7 POLYMER ANALYSIS

We successfully analysed the polymer compositions of polyethylene (Fig. 2.15) and polystyrene (Gig. 2.16), using the Agilent Cary 660 FT-IR. Polymer analyses will become very important in determining possible sources, but also rates of change and decay, as well as prediction of impacts. The results are similar to that found by Mintenig *et al.* (2017) and Löder *et al.* (2015) who found primarily polypropylene, polystyrene, and polyester.



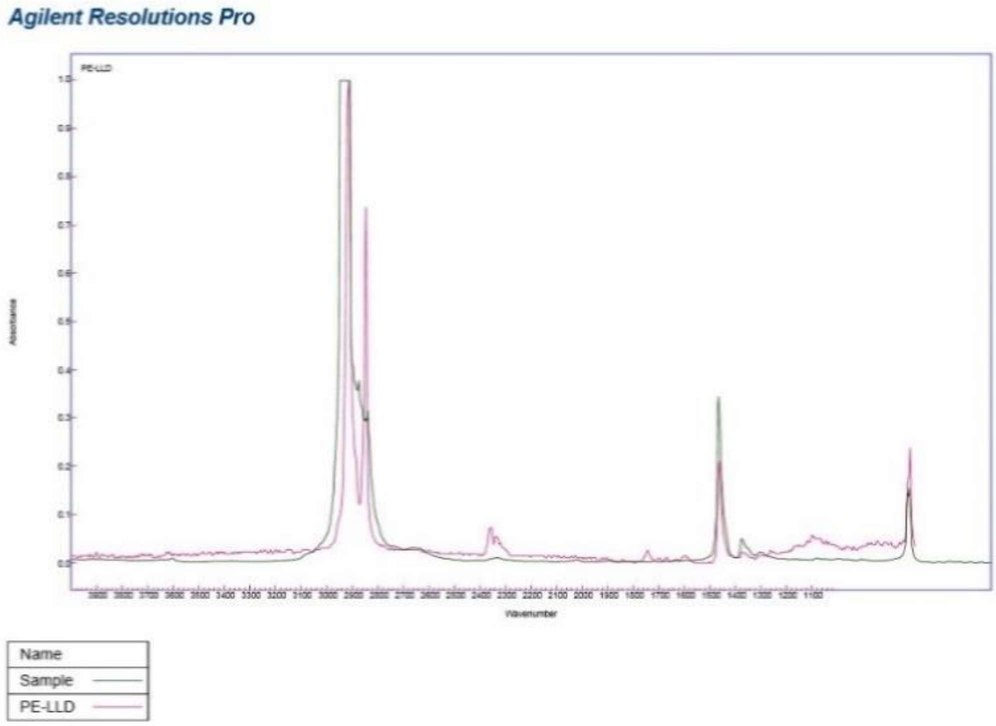
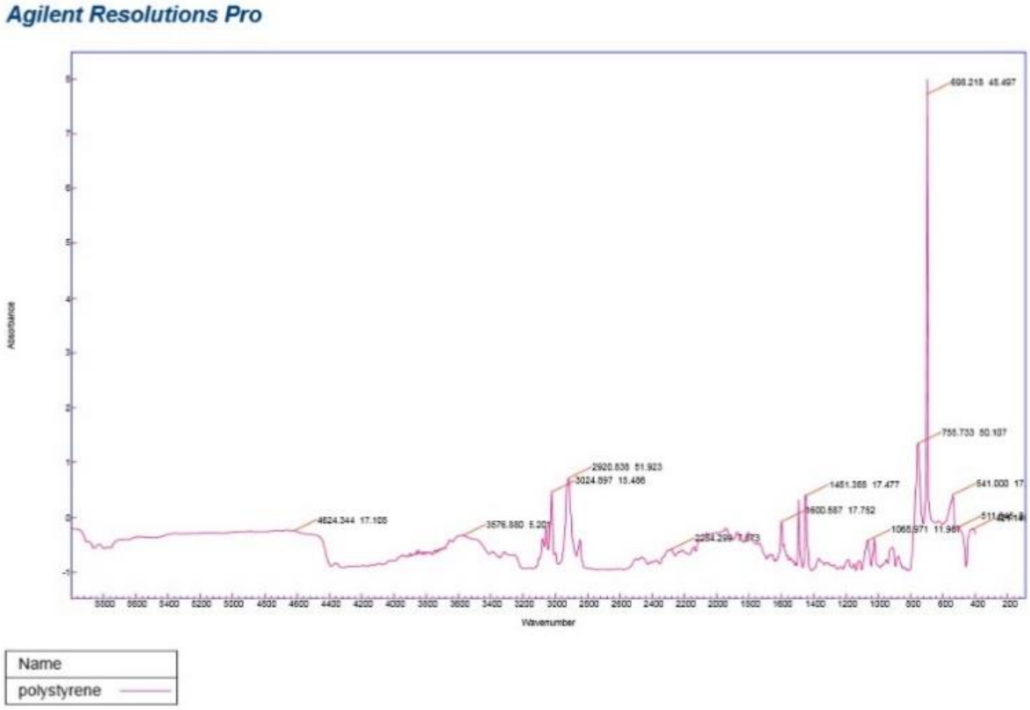


Figure 4-17: FTIR spectra of polyethylene



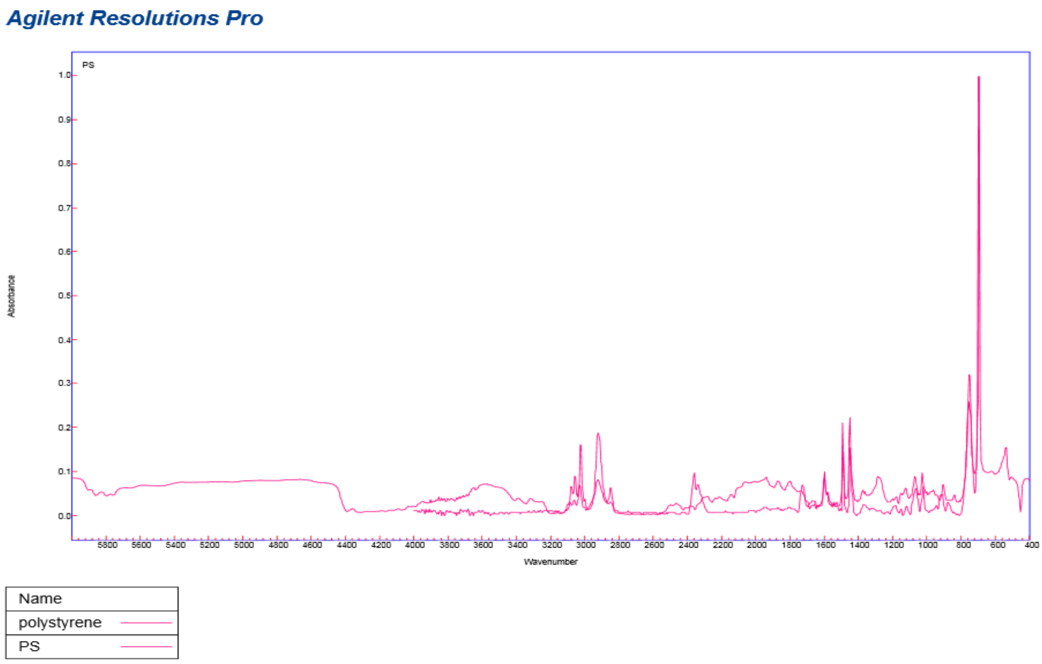


Figure 4-18: FTIR spectra of polystyrene

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

This study demonstrated the presence of substantial amounts of plastic particles in surface, tap, and ground water sources in South Africa. The developing science on the toxicological impact hereof precludes risk statements, but it allows for the first time a baseline to be set for South African inland waters. Based on the findings, with regards to microplastic levels in different sites, and the differences between size classes according to fibres and fragments, it can be concluded that the sampling and analysis method used is robust. However, more research is required to fully validate fully the technique, in particular, the following is recommended:

- Expand the use of field blanks by taking clean water and filtering on site, to determine possible procedural contamination.
- Check for repeatability, by taking more than one sample per site, alternating the filtering of sub-samples between different containers.
- Use standards in the extraction process to determine any possible losses and extraction efficiencies.
- Scan for a wider array of polymers.

5.2 RECOMMENDATIONS

Given that microplastics were found in drinking water, there is a need to explore sources as in some cases the water is conveyed using pvc pipes, as well as other types of conduit, pump, and reservoir elements which may also contribute microplastics to drinking water after treatment and release into the reticulation system. In South Africa, water is increasingly being re-used, thus the levels of microplastics needs to be evaluated within the whole water value chain. There is no consensus yet on any health impacts as the science is still in its infancy. Based on impacts seen in aquatic organisms, this aspect of science should be monitored and interpreted for South African contexts. Based on the results of this scoping study and a host of other reports and publications, the following is recommended:

5.2.1 Scientific

- Research outputs on plastics and microplastics in all environmental compartments are expanding globally. Monitoring of the trends and new findings should therefore continue, to advise on threats, new insights, and trends.
- Microplastics and fibres are present in South African fresh, coastal, and marine waters, as is the case elsewhere in the world. Given the expanding interests in the potential environmental and human health effects, we recommend that plastic particles be included in the panoply of research concerns about water quality that needs attention.
- Compared with the few international studies on microplastics in freshwaters, the South African surface water concentrations falls within the low to medium range. It can safely be assumed that

microplastics will be present elsewhere in freshwaters in South Africa. Surveys should therefore be undertaken countrywide to obtain a picture of pollution, and to establish a baseline against which to measure concentration trends.

- The effectiveness of WWTPs in removing microplastics should be investigated in South Africa. However, the sludge management may also become a source of microplastics to the environment. Land application may result in groundwater pollution.
- The few tap water samples we analysed showed the presence of microplastics. Knowledge is still lacking on the effectiveness of removal of microplastics from raw water during treatment. Again, the management of the water treatment residue should also be monitored, as this might also become a secondary source.
- There were no studies found on groundwater pollution (although work has been done on soils, indicating travel of particles along flow channels). Since ground water is very often used and consumed untreated, more research should be conducted to ascertain the current situation, and to establish a baseline against which to measure concentration trends.
- No studies were done on sediments or biota. Based on results from elsewhere microplastics are most likely present in these compartments. Research on concentrations and impacts should be conducted to ascertain the current situation, and to establish a baseline against which to measure concentration trends.
- Identify other sources of microplastics to the environment. For example, very little has been done on the use of polymer particles in sandblasting.
- Identify and characterise exposure pathways (including human) under South African conditions. Water management and consumption differs from more regions where much more research has been done (Europe and North America), while water contact patterns and water restricted ecologies may differ from assumptions from elsewhere. Appropriate measures and mitigations can be developed, based on these considerations. Much may be learned from work done on POPs and manufactured nanoparticles.
- A number of institutions are conducting research on microplastics in fresh, coastal and marine waters. There also seems to be more institutions from African countries becoming involved. The research capacity of the South African institutions should be supported and where necessary expanded to cover priority and new research avenues, as well as student training. Establishing linkages with other African institutions should be explored and possibly supported.
- At the African Marine Waste Conference held in Port Elizabeth in 2017, a paper was developed for the journal Marine Policy. The manuscript has been accepted and is available through open access at https://www.sciencedirect.com/science/article/pii/S0308597X17305286.

Having scanned the literature, the following research questions and themes, as well as our own insights, seems appropriate for South Africa.

- Factors that affect release, transformation, persistence, and transportation in surface and ground waters
- Baselines and time trends

- Polymer compositions of microplastics
- POPS (including DDT and PFAS), metals, and other chemicals in plastics and microplastics
- Leaching of chemicals from plastics under South African conditions (high temperatures, dry periods, and UV).
- Biological effects studies in laboratory and field
- Sinks and sources
- Runoff and waste sites
- Accumulation in humans, animals, plants, and other biota
- Microplastics in ground- and tap waters
- Aerial deposition
- Investigate the interaction of microplastics, bacteria, and antimicrobial resistance

5.2.2 **Regulation**

- Following the actions taken in the USA, Sweden, UK and elsewhere, one of the most effective actions that can be taken is the immediate ban on the import, manufacture, use, formulation, sale, and export of microbeads in South Africa.
- A review of the laws and regulations in other countries may indicate how South Africa can strengthen its responses to plastic pollution. Mauritius, for instance, has complete banned plastic shopping bags. A number of articles on this topic has already appeared, but a review, focussed on South African conditions, seems warranted.
- Although plastic does not seem to feature as a component of pollution in South Africa, increasing awareness raising, (taking Sky News as a possible example) most likely will reduce the consumption of single use plastics, and increase the use of value added plastics, thereby reducing environmental plastic pollution.
- Plastic packaging seems to be the most obvious and visible component of inland plastics pollution. Given market forces and few regulations, meaningful voluntary reduction of the plastic components of packaging, or promoting the use of recyclable or re-usable plastics (which are more expensive), seems remote. However, even ‘remote’ opportunities can be advanced, and these opportunities should be investigated.

REFERENCES

1. Adrias-Andres, M., Klumper, u., Rojas-Jimenez, K., Grossart, H-P., 2018. Microplastics increases gene exchange in aquatic ecosystems. Environmental Pollution 237. 253-261.
2. AMWN. 2017. African Marine Waste Conference: Workshop outcomes report, Port Elizabeth, South Africa.
3. Andrady, A.L., 2011. Microplastics in the marine environment. Marine Pollution Bulletin 62. 1596-1605.
4. Ashton, K., Holmes, L., Turner, A., 2010. Association of metals with plastic production pellets in the marine environment. Marine Pollution Bulletin 60. 2050-2055.
5. Avio, C.G., Gorbi, S., Milan, M., Benedetti, M., Fattorini, D., d'Errico, G., Pauletto, M., Bargelloni, L., Regoli, F., 2015. Pollutants bioavailability and toxicological risk from microplastics to marine mussels. Environmental Pollution 198. 211-222.
6. Arthur, C., Baker, J., Bamford, H., 2009. Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris. In: NOAA Technical memorandum NOS-OR&R-30, p. 49.
7. Bagaev, A., Mizyuk, A., Khatmullina, L., Isachenko, I., Chubarenko, I., 2017. Anthropogenic fibres in the Baltic Sea water column: Field data, laboratory and numerical testing of their motion. Science of the Total Environment 599-600. 560-571.
8. Bakir, A., Rowland, S.J., Thompson, R.C., 2014. Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. Environmental Pollution 185. 16-23.
9. Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B-Biological Sciences 364. 1985-1998.
10. Bhattacharya, P., Turner, J. P., Ke, P.C., 2010. Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. The Journal of Physical Chemistry 114. 16556–16561.
11. Besseling, E., Quik, J.T.K., Sun, M., Koelmans, A.A., 2017. Fate of nano- and microplastic in freshwater systems: A modeling study. Environmental Pollution 220. 540-548.
12. Biginagwa, F.J., Mayoma, B.S., Shashoua, Y., Syberg, K., Kahn, F.R., 2016. First evidence of microplastics in the African Great Lakes: Recovery from Lake Victoria Nile perch and Nile tilapia. Journal of Great Lakes Research 42. 146-149.
13. Blair, R.M., Waldron, S., Phoenix, V.& Gauchotte-Lindsay, C., 2017. Micro- and Nanoplastic Pollution of Freshwater and Wastewater Treatment Systems. Springer Science Reviews 5. p.19-30.
14. Brillant, M., MacDonald, B., 2002. Post-ingestive selection in the sea scallop (*Placopecten magellanicus*) on the basis of chemical properties of particles. Marine Biology 141, 457–465.
15. Bolton, T.F., Havenhand, J.N., 1998. Physiological versus viscosity-induced effects of an acute reduction in water temperature on microsphere ingestion by trochophore larvae of the *serpulid polychaete Galeolaria caespitosa*. Journal of Plankton Research 20, 2153–2164.
16. Buksa & Niekrewicz., 2016. Microplastic pollution: A survey of waste water effluent in Plattsburgh, NY. Canter for Earth and Environmental Science: Student Posters Book 26.
17. Castaneda, R.A., Avlijas, S., Simard M.A., Ricciardi, A., 2014. Microplastic pollution in St. Lawrence River sediments. Canadian Journal of Fish and Aquatic Science 71. 1-5.
18. Cedo, A., Cleary, J., 2015. Microplastics in Irish freshwaters: a preliminary study. 14th International Conference on Environmental Science and Technology.
19. Claessens, M., Van Cauwenberghe, L., Vandegehuchte, M.B., Janssen, C.R., 2013. New techniques for the detection of microplastics in sediments and field collected organisms. Marine Pollution Bullutin 27. 227-233.

20. Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin 62. 2588-2597.
21. Collignon, A., Hecq, J.H., Galgani, F., Collard, F., Goffart, A., 2014. Annual variation in neustonic micro- and mesoplastic particles and zooplankton in the Bay of Calvi (Mediterranean-Corsica). Marine Pollution Bulletin 79. 293-298.
22. Corcoran, P.L., Norris, T., Ceccanese, T., Walzak, M.J., Helm, P.A., Marvin, C.H., 2015. Hidden plastics of Lake Ontario, Canada and their potential preservation in the sediment record. Environmental Pollution 204. 17-25.
23. Depledge, M.H., Galgani, F., Panti, C., Caliani, I., Casini, S., Fossi, M.C., 2013. Plastic litter in the sea. Marine Environmental Research 92. 279-281.
24. Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: A review. Marine Pollution Bulletin 44. 842-852.
25. Desforges, J.P.W., Galbraith, M., Dangerfield, N., Ross, P.S., 2014. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. Marine Pollution Bulletin 79. 94-99.
26. Do Sul, J.A.I., Costa, M.F., 2014. The present and future of microplastic pollution in the marine environment. Environmental Pollution 185. 352-364.
27. Doyle, M.J., Watson, W., Bowlin, N.M., Sheavly, S.B., 2011. Plastic particles in coastal pelagic ecosystems of the Northeast Pacific ocean. Marine Environmental Research 71. 41-52.
28. Dris, R., Gasprei, J., Rocher, V., Saad, M., Renault, N., Tassin, B., 2015. Microplastic contamination in an urban area: a case study in Greater Paris. Environmental Chemistry 12. 592-599.
29. Duis, K., Coors, A., 2016. Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. Environmental Sciences Europe 28. 2.
30. Eckert, E.M., Di Cesare, A., Kettner, M.T., Adria-Andres, M., Fontaneto, D., Grossart, H-P., Corno, G., 2018. Microplastics increase impact of treated wastewater on freshwater microbial community. Environmental Pollution 234. 495-502.
31. Engler, R.E., 2012. The complex interaction between marine debris and toxic chemicals in the ocean. Environmental Science & Technology 46. 12302-12315.
32. Ellen MacArthur Foundation. 2015. Towards a Circular Economy: Business rationale for an accelerated transition, The Ellen MacArthur Foundation.
33. Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans. More than 5 trillion poeces weighing over 250,000 tons afloat at sea. PLOS One. Doi10.1371/journal.pone.0111913
34. Eriksson, C., Burton, H., Fitch, S., Schulz, M., van den Hoff, J., 2013. Daily accumulation rates of marine debris on sub-Antarctic island beaches. Marine pollution bulletin 66. 199-208
35. Farrington, J.W., Takada, H., 2014a. Persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), and plastics examples of the status, trend, and cycling of organic chemicals of environmental concern in the ocean. Oceanography 27. 196-213.
36. Farrel, P., Nelson, K., 2013. Trophic transfer of microplastic: *Mytilus edulis* (L.) to *Carcinus maenas* (L.). Environmental Pollution 177. 1-3.
37. Fischer, E.K., Paglialonga, L., Czech, E., Tamminga, M., 2016. Microplastic pollution in lakes and lake shoreline sediments – A case study on Lake Bolsena and Lake Chiusi (central Italy). Environmental Pollution 213. 648-657.
38. Geyer, R., Jambeck, R.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Science Advances 19 Jul 2017: Vol. 3, no. 7, e1700782.
39. Graca, B., Bełdowska, M., Wrzesień, P., Zgrundo, A., 2013. Styrofoam debris as a potential carrier of mercury within ecosystems. Environmental Science and Pollution Research. 21, 2263-2271.
40. Graham, E.R., Thompson, J.T., 2009. Deposit- and suspension-feeding sea cucumbers (*Echinodermata*) ingest plastic fragments. Journal of Experimental Marine Biology and Ecology 368, 22–29.

41. Fazey, F.M.C. and Ryan, P.G., 2016A. Debris size and buoyancy influence the dispersal distance of stranded litter. Marine Pollution Bulletin 110. 371-377.
42. Fazey, F.M.S. and Ryan, P.G., 2016B. Biofouling on buoyant marine plastics: An experimental study into the effect of size on surface longevity. Environmental Pollution 210. 354-360.
43. Fok, L., Cheung, P.K., 2015. Hong Kong at the Pearl River Estuary: A hotspot of microplastic pollution. Marine Pollution Bulletin 99. 112-118.
44. Free, C.M., Jensen, O.P., Mason, S.A., Erikson, M., Williamson, M.J., Boldgiv, B., 2014. High levels of microplastic pollution in a large, remote mountain lake. Marine Pollution Bulletin 86. 156-163.
45. Fries, E., Dekiff, J.H., Willmeyer, J., Nuelle, M., Elber, M., Remy, D., 2013. Identification of polymer types and additives in marine microplastic particles pyrolysis-GC/MS with scanning electron microscopy. Environmental Science: Processes and Impacts 15. 1949-1956.
46. Farrington, J.W., Takada, H., 2014. Hydrocarbons (PAHs), and plastics examples of the status, trend, and cycling of organic chemicals of environmental concern in the ocean. Oceanography 27. 196-213.
47. Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: Microplastics in facial cleansers. Marine Pollution Bulletin 58. 1225-1228.
48. Fries, E., Zarfl, C., 2012. Sorption of polycyclic aromatic hydrocarbons (PAHs) to low and high-density polyethylene (PE). Environmental Science and Pollution Research 19. 1296-1304.
49. Gasprei, J., Dris, R., Bonin, T., Rocher, V., Tassin, B., 2014. Assessment of floating plastic debris in surface water along the Seine River. Environmental Pollution 195. 163-166.
50. Gasprei, J., Dris, R., Rocher, V., Tassin, B., 2015. Microplastics in the continental area: an emerging challenge. The Norman Network Bulletin 4.18-19.
51. GESAMP 2015. Sources, fate and effect of microplastics in the marine environment: A global assessment. Anderson, A., Andrady, A., Arthur, C., Baker, J., Bouwman, H., Gall, S., Hidalgo-Ruiz, V., Köhler, A., Lavender Law, K., Leslie, H., Kershaw, P., Pahl, S., Potemra, J., Ryan, P., Joon Shim, W., Takada, H., Thompson, R., Turra, A., Vethaak, D., Wyles, K. International Maritime Organization, London.
52. Hagger, J.A., Jones, M.B., Leonard, P., Owen, R., Galloway, T.S., 2006. Biomarkers and integrated environmental risk assessment: Are there more questions than answers? Integrated Environmental Assessment and Management 2. 312-329.
53. Hahladakis, J.N., Velis, C.A., Weber, R., Iacovidou, E., Purnell, P., 2018. An overview of chemical additives presents in plastics: Migration, release, fate, and environmental impact during their use, disposal and recycling. Journal of Hazardous materials. 344. 179-199.
54. Hart, M.W., 1991. Particle captures and the method of suspension feeding by echinoderm larvae. The Biological Bulletin 180. 12–27.
55. Hartmann, N.B., Rist, S., Bodin, J., Jensen, L.H.S., Schmidt, S.N., Mayer, P., Meibom, A., Baun, A., 2017. Microplastics as vectors for environmental contaminants: Exploring sorption, desorption, and transfer to biota. Integrated Environmental Assessment and Management 13. 488-493.
56. Hernandez, L.M., Yousefi, N., Tufenkji, N., 2017. Are there nanoparticles in your personal care products? Environmental Science & Technology Letters 4. 280-285.
57. Heskett, M., Takada, H., Yamashita, R., Yuyama, M., Ito, M., Geok, Y.B., Ogata, Y., Kwan, C., Heckhausen, A., Taylor, H., Powell, T., Morishige, C., Young, D., Patterson, H., Robertson, B., Bailey, E., Mermoz, J., 2012. Measurement of persistent organic pollutants (POPs) in plastic resin pellets from remote islands: Toward establishment of background concentrations for International Pellet Watch. Marine Pollution Bulletin 64. 445-448.
58. Hidalgo-Ruz, V.; Gutow, L.; Thompson, R.C., Thiel, M. 2012. Microplastics in the marine environment: A review of methods used for identification and quantification. Environmental Science & Technology 46. 3060-3075.
59. Holmes LA, Turner A, Thompson RC. 2014., Interactions between trace metals and plastic production pellets under estuarine conditions. Marine Chemistry 167. 25–32.

60. Horton, A.A., Lahive, E., Svendsen, C., Williams, R.J., Read, D.S., Spurgeon, D.J., 2015. Presence and abundance of microplastics in the Thames River Basin, UK. [Poster] In: SETAC Europe 25th Annual Meeting, Barcelona, 3-7 May 2015. Wallingford, UK, NERC/Centre for Ecology & Hydrology.
61. Horton, A.A., Svendsen, C., Williams, R.J., Spurgeon, D.J., Lahive, E., 2017. Large microplastic particles in sediments of tributaries of the River Thames, UK – Abundance, sources and methods for effective quantification. Marine Pollution Bulletin 114. 218-226.
62. Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Science of the Total Environment 586. 127-141.
63. Imhof, H.K., Laforsch, C., 2016. Hazardous or not – Are adult and juvenile individuals of *Potamopyrgus antipodarum* affected by non-buoyant microplastic particles? Environmental Pollution 218. 383-391.
64. Imhof, H.K., Schmid, J., Niessner, R.; Ivleva, N., Laforsch, C., 2012. A novel, highly efficient method for the separation and quantification of plastic particles in sediment of aquatic environments. Limnology and Oceanography. Methods 10. 524-537.
65. Isobe, A., Kubo, K., Tamura, Y., Kako, S., Nakashima, E., Fujii, N., 2014. Selective transport of microplastics and mesoplastics by drifting in coastal waters. Marine Pollution Bulletin 89. 324-330.
66. Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A. Narayan, R., Law, K.R., 2015. Plastic waste input from land into the ocean. Science 347. 768-771.
67. Katsanevakis, S.; Verriopoulos, G.; Nicolaidou, A., Thessalou-Legaki, M., 2007. Effects of marine litter on the benthic megafauna of coastal soft bottoms: A manipulative field experiment. Marine Pollution Bulletin 54. 771-778.
68. Klein, S., Worch, E., Knepper, T.P., 2015. Occurrence and spatial distribution of microplastics in the river shore sediments if the Rhine-Main area in Germany. Environmental Science & Technology 49. 6070-6076.
69. Köhler, A., 2010. Cellular fate of organic compounds in marine invertebrates. Comparative Biochemistry and Physiology—Part A: Molecular & Integrative Physiology 157 (Supplement) 8–11.
70. Lagarde, F., Olivier, O., Zanella, M., Daniel, P., Hiard, S., Caruso, A., 2016. Microplastic interactions with freshwater microalgae: Hetero-aggregation and changes in plastic density appear strongly dependent on polymer type. Environmental Pollution 215. 331-339.
71. Lee, H., Shim, W.J., Kwon, J.H., 2014. Sorption capacity of plastic debris for hydrophobic organic chemicals. Science of the Total Environment 470. 1545-1552.
72. Lee, K.; Shim, W.J.; Kwon, O.Y., Kang, J., 2013. Size-dependent effects of micro polystyrene particles in the marine copepod *Tigriopus japonicus*. Environmental Sciences & Technology 47. 11278-11283.
73. Lenz, R., Enders, K., Stedmon, C.A., Mackenzie, D.M.A., Nielsen, T.G., 2015. A critical assessment of visual identification of marine microplastics using Raman spectroscopy for analysis improvement. Marine Pollution Bulletin 100. 82-91.
74. Leslie, H.A., van Velzen, M.J.M., Vethaak, A.D., 2013. Microplastic survey of the Dutch environment. Institute for Environmental Studies (Amsterdam). Final report number R-13/11
75. Lima, A.R.A.; Costa, M.F., Barlett, M., 2014. Distrubution patterns of microplastics within the plakton of tropical estuary. Environmental Research 132. 146-155.
76. Lima, A.R.A., Costa, M.F., Barletta, M., 2015. Seasonal distribution and interaction between plankton and microplastics in a tropical estuary. Estuarine, Coastal and Shelf Science 165. 213-225.
77. Löder, M.G.J, Kuczera, M., Mintenig, S., Lorenz, C., Gerdts, G., 2015., Focal plane array detector-based micro-Fourier-transform infrared imaging for the analysis of microplastics in environmental samples. Environmental Chemistry 12. 563-581.
78. Lusher, A., 2015. Microplastics in the marine environment: Distribution, interactions and effects. In: Bergmann, M., Gutow, L., Klages, M. (eds) *Marine Anthropogenic Litter*. Springer, Cham.
79. Lusher, A.L., Burke, A., O'Connor, I., Oficer, R., 2014. Microplastic pollution in the North Atlantic Ocean: Validated and opportunistic sampling. Marine Pollution Bullitin 88. 325-333.

80. Mani, T., Hauk, A., Walter, U., Burkhardt-Holm, P., 2015. Microplastics profile along the Rhine River. Scientific Reports 5: Article number 17988.
81. Mason, S.A., Garneau, D., Sutton, R., Chu, Y., Ehmann, K., Barnes, J., Fink, P., Papazissimos, D., Rogers, D.L., 2016. Environmental Pollution 218. 1045-1054.
82. Masura, J., Baker, J., Foster, G., Arthur, C., 2015. Laboratory methods for the analysis of microplastics in the marine environment: Recommendations for quantifying synthetic particles in water and sediment. National Oceanic and Atmospheric Administration (NOAA).
83. McCormick, A., Hoellein, T.J., Mason, S.A., Schleup, J., Kelly, J.J., 2014. Microplastic is an abundant and distinct microbial habitat in an urban river. Environmental Science & Technology 48. 11836-11871.
84. McDevitt, C., Perez, L., Kapp, K., 2016. The presence of microplastic in freshwater systems: Snake river and Palisades Reservoir. Department of Health and Science, Central Wyoming University: Student Poster.
85. Moore, C.J., 2008. Synthetic polymers in the marine environment: A rapidly increasing long-term threat. Environmental Research 108. 131-139.
86. Nahman., A. 2010. Extended producer responsibility for packaging waste in South Africa: Current approaches and lessons learned. *Resour Conserv Recy* 54: 155–162.
87. Naidoo, T., Glassom, D. and Smith, A.J., 2015. Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa. Marine pollution bulletin 101. 473-480.
88. Naidoo, T., Glassom, D. and Smith, A.J., 2015. Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa. Marine pollution bulletin 101. 473-480.
89. Nel, H.A. and Froneman, P.W., 2015. A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa. Marine pollution bulletin 101. 274-279.
90. Nel, J.L. and Driver, A. 2015. National River Ecosystem Accounts for South Africa. Discussion document for Advancing SEEA Experimental Ecosystem Accounting Project, October 2015. South African National Biodiversity Institute, Tshwane.
91. Nizzettp, L., Bussi, G., Futter, M.N., Butterfield, D., Whitehead, P.G., 2016. A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. Environmental Science: Processes & Impacts 8. 1050-1059.
92. Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., Endo, S., Mato, Y., Saha, M., Okuda, K., Nakashima, A., Murakami, M., Zurcher, N., Booyatumanondo, R., Zakaria, M.P., Dung, L.Q., Gordon, M., Miguez, C., Suzuki, S., Moore, C., Karapanagioti, H.K., Weerts, S., McClurg, T., Burres, E., Smith, W., Van Velkenburg, M., Lang, J.S., Lang, R.C., Laursen, D., Danner, B., Stewardson, N., Thompson, R.C., 2009. International Pellet Watch: Global monitoring of persistent organic pollutants (POPs) in coastal waters. 1. Initial phase data on PCBs, DDTs, and HCHs. Marine Pollution Bulletin 58. 1437-1446.
93. Pazos, R., Maiztegui, T., Colautti, D.C., Paracampo, A.H., 2017. Microplastics in gut contents of coastal freshwater fish from Río de la Plata estuary. Marine Pollution Bulletin 122. 85-90.
94. Peters, C.A., Bratton, S.P., 2016. Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA. Environmental Pollution 210. 380-387.
95. Phillips, M.B., Bonner, T.H., 2015. Occurrence and amount of microplastics ingested by fishes in watershed of the Gulf of Mexico. Marine Pollution Bulletin 100. 264-269.
96. Pietrelli, L., Di Gennaro, A., Menogoni, P., Lecce, F., Poeta, G., Acosta, A.T.R., Battisti, C., Lanilli, V., 2017. Pervasive plastisphere: First record of plastics in egagropiles (*Posidonia spheroids*). Environmental Pollution 229. 1032-1036.
97. Plastics Europe. 2013. The compelling facts about plastics 2012. An analysis of plastic production, demand and recovery for 2012 in Europe. Plastics Europe. Brussels. Belgium.
98. Plastics SA. 2014. Plastics industry report on beneficiation portfolio committee: Trade and Industry.

99. Qui, Q., Tan, Z., Wang, J., Peng, J., Li, M., Zhan, Z., 2016. Extraction, enumeration and identification methods for monitoring microplastics in the environment. Estuarine, Coastal and Shelf Science 176.102-109.
100. Ramasamy, E.V., 2016. Microplastics: An emerging contaminant – with potential threat to aquatic systems – less studied in India. Lake 2016: the 10th biennial lake conference.
101. Rillig, M.C., Ingraffia, R., de Souza Mechado, A.A., 2017a. Microplastic incorporation into agroecosystems. Frontiers in Plant Science 8. 1805.
102. Rillig, M.C., Zierch, L., Hempel, S., 2017b. Microplastic transport in soil by earthworms. Scientific Reports. 7. 1362
103. Rochman, C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Scientific Reports 3. DOI: 10,1038/srep03263.
104. Rios, L.M.; Moore, C., Jones, P.R., 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. Marine Pollution Bulletin 54. 1230-1237.
105. Ryan, P.G., 1987. The incidence and characteristics of plastic particles ingested by seabirds. Marine environmental research 23. 175-206.
106. Ryan, P.G., 2008. Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans. Marine pollution bulletin 56. 1406-1409.
107. Ryan, P.G., 2014. Litter surveys detects the south Atlantic ‘garbage patch’. Marine Pollution Bulletin 79. 220-224.
108. Ryan, P.G., 2015. How quickly do albatrosses and petrels digest plastic particles? Environmental pollution 207. 438-440.
109. Ryan, P.G., Bouwman, H., Moloney, C.L., Yuyama, M. and Takada, H., 2012. Long-term decrease in persistent organic pollutants in South African coastal waters detected from beaches polyethylene pellets. Marine Pollution Bulletin 64. 2756-2760.
110. Ryan, P.G., De Bruy, P.J.N. and Bester, M.N., 2016. Regional differences in plastic ingestion among Southern Ocean fur seals and albatrosses. Marine Pollution Bulletin 104. 207-210.
111. Ryan, P.G., Lamprecht, A., Swanepoel, D. and Moloney, C.L., 2014a. The effect of fine scale frequency on estimates of beach litter accumulation. Marine Pollution Bulletin 88. 249-254.
112. Ryan, P.G., Musker, S. and Rink, A., 2014b. Low densities of drifting litter in the African sector of the Southern Ocean. Marine Pollution Bulletin 89. 16-19.
113. Ryan, P.G., Nel, H.A., Froneman, P.W., 2015. A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa. Marine Pollution Bulletin 101. 274-279.
114. Ryan, P.G., Nel, R., Osborne, A., Perlod, V., 2015. Impact of plastic ingestion on post-hatchling loggerhead turtles of South Africa. Marine Pollution Bulletin 107. 155-160.
115. Seltenrich, N., 2015. New link in the food chain? Marine plastic pollution and seafood safety. Environmental Health Perspectives 123. A35-A41.
116. Sharma, S., Chatterjee, S., 2017. Microplastic pollution, a threat to marine ecosystem and human health: a short review. Environmental Science and Pollution Research 24. 21530-21547.
117. Song, Y.K., Hong, S.H., Jang, M., Han, G.M., Rani, M., Lee, J., Shin, W.J., 2015. A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. Marine Pollution Bulletin 93. 202-209.
118. STAP. 2012. GEF Guidance on emerging chemicals management issues in developing countries and countries with economies in transition. (The Scientific and Technical Advisory Panel of the Global Environment Facility). A STAP Advisory Document. Global Environment Facility, Washington DC.
119. Su, L., Xue, Y., Li, L., Yang, D., Kolandhasamy, P., Li, D., Shi, H., 2016. Microplastics in Taihu Lake, China. Environmetnal Pollution 216. 711-719.
120. Sun, M., Te, M., Jiao, W., Feng, Y., Yu, P., Liu, M., Jiao, J., He., X., Liu, K., Zhao, Y., Wu, J., Hu, F., 2018. Changes in tetracycline partitioning and bacteria/phage-comediated ARGs in microplastic-contaminated greenhouse soil facilitated by sophorolipid. Journal of Hazardous Materials 345. 131-139.

121. Sussarellu, R., Soudant, P., Lambert, C., Fabioux, C., Corporeau, C., Laot, C., *et al*., 2014. Microplastics: effects on oyster physiology and reproduction. Platform presentation, International workshop on fate and impact of microplastics in marine ecosystems (MICRO2014), 13–15 January 2014. Plouzane (France).
122. Syberg, K., Hansen, S.F., Christensen, T.B., Khan, F.R., 2018. Risk perception of plastic pollution: Importance of stakeholder involvement and citizen science. In: Wagner, M., Lambert, S., (Eds). Freshwater microplastics: Emerging environmental contaminants? *The Handbook of Environmental Chemistry* Vol 58. Springer Open
123. Talvitie, J., Heinonen, M., Pääkkönen, J-P., Vathera, E., Setalälä, O., Vahala, R., 2015. Do wastewater treatment plants act as a potential point source of microplastics? Preliminary study in the coastal Gulf of Finland, Baltic Sea. Water Science & Technology 72. 1495-1504.
124. Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukawaka, M., Watanuki, Y., 2015. Facilitated leaching of additive derived PBDE's from plastic by seabirds' stomach oil and accumulation in tissues. Environmental Science & Technology 49. 11799-11807.
125. the DTI. 2016. Industrial Policy Action Plan: IPAP 2016/17 – 2018/19. The Department of Trade and Industry. Government of South Africa.
126. Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McDonigle, D., Rusell, A.E., 2004. Lost at sea: Where is all the plastic? Science 304. 838. 220-224.
127. Uneputty, P., Evans, S.M., 1997. The impact of plastic debris on the biota of tidal flats in Ambon Bay (Eastern Indonesia). Marine Environmental Research 44. 233-242.
128. UNEP 2014. http://www.unep.org/newscentre/default.aspx?DocumentID=2791&ArticleID=10903
129. Van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J., Janssen, C.R., 2015. Microplastics in sediments: A review of techniques, occurrence and effects. Marine Environmental Research 111. 5 - 17.
130. Van Cauwenberghe, L., Vanreusel, A., Mees, J., Janssen, C.R., 2013. Microplastic pollution in deep-sea sediments. Environmental Pollution 182. 495-499.
131. Verster, C., Bouwman, H., 2017. Marine and freshwater microplastic research in South Africa. Integrated Environmental Assessment and Management 13.533-535.
132. von Moos, N.; Burkhardt-Holm, P., Kohler, A., 2012. Uptake and effects of microplastics on cells and tissue of the blue mussel *Mytilus edulis* L. after an experimental exposure. Environmental Science & Technology 46. 11327-11335.
133. Wagner, M., Lambert, S., 2018. Freshwater microplastics: Emerging environmental contaminants? *The Handbook of Environmental Chemistry* Vol 58. Springer Open.
134. Wang, J., Peng, J., Tan, Z., Gao, Y., Zhan, Z., Chen, Q., Cai, L., 2017. Microplastics in the surface sediments from the Beijiang River littoral zone: Composition, abundance, surface textures and interaction with heavy metals. Chemosphere 171. 248-258.
135. Whitehead, O.T., Biccard, A., Griffiths, C.L., 2011. South African goose barnacles on various substrata. Crustaceana 84. 635-649.
136. Wilson, D.S., 1973. Food size selection among copepods. Ecology 54, 909–914.
137. Woodall, L.C., Sanches-Vidal, A., Canals, M., Patterson, G.L.J., Coppock, R., Sleight, V., Calaft, A., Rogers, A.D., Narayanaswamy, B.E., Thompson, R.C., 2014. The deep sea is a major sink for microplastic debris. Royal Society Open Science. DOI: 10.1098/rsos.140317.
138. Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: A review. Environmental Pollution 178. 483-492.
139. Wright, S.L., Rowe, D., Thompson, R.C., Galloway, T.S., 2013. Microplastic ingestion decreases energy reserves in marine worms. Current Biology 23(23) R1031–R1033.
140. Young, D., Shi, H., Li, L., Li, J., Jabeen, K., Kolandhasamy, P., 2015. Microplastic pollution in table salts from China. Environmental Science & Technology 49. 13622 – 13627.

141. Wagner, M., Lambert, S., 2018. Freshwater microplastics. Emerging environmental contaminants? *The Handbook of Environmental Chemistry* Vol 58. Springer Open, Cham, Switzerland.
142. Watts, A.J.R., Lewis, C., Goodhead, R.M., Beckett, S.J., Moger, J., Tyler, C.R., Galloway, T.S., 2014. Uptake and retention of microplastics by the shore crab *Carcinus maenes*. Environmental Science & Technology 48. 8823-8830.
143. Xanthos. D., Walker, T.R., 2017. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. Marine Pollution Bulletin 118. 17-26.
144. Zalasiewicz, C.N., Waters, J.I., do Sul, P.L., Corcoran, A,D., Barnosky, A., Cearreta, M., Edgeworth, A., Gałuszka, C., Jeandel, R., Leinfelder, J.R., McNeill, W., Steffen, C., Summerhayes, M., Wagreich, M., Williams, A.P., Wolfe, Y., Yonan., 2016. The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. Anthropocene 13. 4-17.
145. Zhang, K., Gong, W., Lv, J., Xiong, X., Wu, C., 2015. Accumulation of floating microplastics behind the Three Gorges Dam. Environmental Pollution 204. 117-123.
146. Zhao, S., Zhu, L., Li, D., 2015. Microplastic in three urban estuaries, China. Environmental Pollution 206. 597-604.
147. Zubris, K.A., Richards, B.k., 2005. Synthetic fibres as indicator of land application of sludge. Environmental Pollution 138. 201-211.

APPENDIX A - SUMMARY OF MICROPLATIC SAMPLING METHODS

Table A1: Summary of sampling methods used.

Method	Description	Plastic Source	Plastic type and size	Advantages	Disadvantages	Comments	References
NOAA Water Plastic Sampling	Plastic suspended in the water sample is collected by a surface net (0.335mm). Plastics are categorised according to size through sieves. These samples are dried to determine the mass and subjected to WPO to digest labile organic matter. The plastic sample in a NaCl solution is subjected to density separation and plastic debris are isolated through floatation using 0.3mm filter. This is then air-dried and the plastic is weighed to determine concentration.	Plastic suspended in water.	Polyethylene, polypropylene, polyvinyl chloride and polystyrene (hard plastic, soft plastic, films, line, fibres and sheets) 5mm – 0.3mm				Laboratory Methods for the Analysis of Microplastics in the marine environment: Recommendations for quantifying synthetic particles in water and sediment. Masura *et al*., 2015

Method	Description	Plastic Source	Plastic type and size	Advantages	Disadvantages	Comments	References
NOAA Beach Plastic Sampling	Sand sample is collected by spade. The sample is prepared and subjected to density separation. The dry mass of all floating solids is determined and this is subjected to WPO and another round of density separation. This is then filtered and examined under a microscope and subjected to gravimetric analysis.	Plastic in beach sand.	Polyethylene, polypropylene, polyvinyl chloride and polystyrene. (hard plastic, soft plastic, films, line, fibres and sheets)				Laboratory Methods for the Analysis of Microplastics in the marine environment: Recommendations for quantifying synthetic particles in water and sediment. Masura *et al*., 2015
NOAA Bed Sediment Plastic Sampling	Collect bed sediment by corer or Ponar sampler. Dry sediment and disaggregate. Sieve (0.3mm) disaggregated sediment and subject sieve content to WPO in the presence of a Fe(II) catalyst. Dilute WPO mixture in a NaCl solution and subject to density separation. Remove floating plastic, dry and weigh to determine the microplastic concentration.	Plastic in bed sediment.	Polyethylene, polypropylene, polyvinyl chloride and polystyrene. (hard plastic, soft plastic, films, line, fibres and sheets) 5mm – 0.3mm				Laboratory Methods for the Analysis of Microplastics in the marine environment: Recommendations for quantifying synthetic particles in water and sediment. Masura *et al*., 2015

Method	Description	Plastic Source	Plastic type and size	Advantages	Disadvantages	Comments	References
Biomarkers	Use of biological assays to determine the quality of a water body.			Organisms were exposed to conditions in the water over a long period, living through many fluctuations in pollutant levels, and giving a better idea of the mean quality of the water.		It is recommended that this method be used in accordance with other to get a more holistic view of the environment.	Biomarkers and integrated environmental risk assessment: Are there more questions than answers? Hagger *et al*., 2006
Elutriation and floatation	500 mL sediment sample is washed through a 1 mm sieve (to remove large debris) and 35 µm mesh screen with tap water (15 L/h for 15 min.) Solids collected from the mesh screen are centrifuged in as 3.3M NaCI solution. The top layer containing plastics is vacuum filtered over a 5 µm membrane filter. NaCI extraction is repeated and the filter is visually inspected under a dissection microscope.	Sediment	(PVC particles and fibres) < 5 mm	Extraction efficiency of different plastic particles: PVC particles – 100%; Fibres – 98%. Using NaCI solution as density separation liquid, plastics with densities >1.2 g.cm-3 (PVC and PET) are also quantified – not the case when using NaCl solution.	Fibre polymers are limiting to the quantification, because of fibre length and sieve size.		New techniques for the detection of microplastics in sediments and field collected organisms. Claessens *et al*., 2013
Digestion and filtering.	Organisms are kept in filtered artificial salt water for 42 hours to clear gut. Organisms are then subjected to 22.5M HNO3 at room overnight temperature and 2 hours of boiling to digest the	Field organisms	(PVC particles and fibres)	Quantification of microplastics integrated in biotic tissue – especially opening the knowledge field in that of invertebrates.	Nylon fibres cannot be detected after acid digestion.		New techniques for the detection of microplastics in sediments and field collected organisms. Claessens *et al*., 2013

Method	Description	Plastic Source	Plastic type and size	Advantages	Disadvantages	Comments	References
	tissue. Mixture is then diluted and filtered over a 5 µm celluloses micro membrane filter.						
Microscope Identification	Identification and quantification of microplastics in a filtered and dried sample by visual inspection through a stereomicroscope.	Any	All microplastics	Easier and faster.	More likely to miss microplastic particles. Particles are wrongly classified as plastic, or plastic particles can be mistaken for other impurities.	Suitable for plastic particles >1mm.	A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. Song *et al*., 2015
FT-IR identification	Identification and quantification of microplastics in a filtered and dried sample by FT-IR (Fourier transform infrared spectroscope)	Any	<1mm	More accurate at identifying microplastics. Better quantification of microplastics >1mm (especially >50 µm). Identification of polymer type.	Expensive. Time consuming.		A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. Song *et al*., 2015. Focal plane array detector-based micro-Fourier-transform infrared imaging for the analysis of microplastics in environmental samples.

Method	Description	Plastic Source	Plastic type and size	Advantages	Disadvantages	Comments	References
							Löder *et al*., 2015
Raman spectroscopy identification	Identification and quantification of microplastics of filtered and dried sample by Raman spectroscopy	Any	>2-3 µm	Identification of very small microplastic particles (2-3 µm). Gives information about crystalline structure of polymer. Could speed up the quantification of microplastic concentrations by being used in a large sample scanning device. Gives information about crystalline structure of polymer.	Process can be disrupted by the presence of colour, additives and attached contaminants.	Complimentary to FT-IR.	Extraction, enumeration and identification methods for monitoring microplastics in the environment. Qiu *et al*., 2016 A critical assessment of visual identification of marine microplastics using Raman spectroscopy for analysis improvement. Lenz *et al*., 2015

Method	Description	Plastic Source	Plastic type and size	Advantages	Disadvantages	Comments	References
Pyrolysis GC/MS with SEM extraction and identification	Extraction, identification and quantification of microplastics in a sample by Pyrolysis GC/MS (Gas chromatography with mass spectroscopy)	All	All	SEM identifies organic plastic additives.			Identification of polymer types and additives in marine microplastic particles pyrolysis-GC/MS and scanning electron microscopy. Fries *et al*., 2013.
Continuous sampling method	Samples were collected during research cruises from moving research vessels. Sampling duration is calculated by determining the flow rate of water and the time required to filter a known amount of water. Water is collected and fed to an on-board laboratory by pipes.	All	<250 µm	Gives insight into large-scale distribution and movement of microplastics.			Microplastic pollution in the North Atlantic Ocean: Validated and opportunistic sampling. Lusher *et al*., 2014

APPENDIX B - STUDENT DEVELOPMENT

Five students actively participated in this project:

- Carina Verster: Third year student, now continuing with Honours degree in 2018, coordinated and conducted most of the work and is a co-author on this report. She also published a paper as an invited commentary in Integrated Environmental Assessment and Management (Verster *et al*., 2017), together with Karin Minnaar. The paper was based on information gathered during the development phase of the project.
- Karin Minnaar: PhD student, participated with the drafting of the application, as well as the design and practical advice.
- Geraldine van Tonder, a third-year student was drafted in to assist with the laboratory work and counting microplastics.
- Duan van Aswegen, an M.Sc. student, assisted with field work.
- Willie Landman, a PhD student, assisted with the Nikon EZ100 microscope operation and another laboratory trouble shooting.