TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

OVERVIEW OF MICRO AND NANO PLASTICS IN THE ENVIRONMENT AND THEIR POSSIBLE PATHWAYS TO HUMANS

ÜLEVAADE MIKRO-JA NANOPLASTIKUST KESKKONNAS JA VÕIMALIKUD SISENEMISTEED INIMORGANISMI

MASTER THESIS

Student: Sami Akhtar

Student code: 195427EABM

Supervisor: Dr. Arvo Iital, Professor
Department of Civil Engineering and Architecture

AUTHOR’S DECLARATION

I declare I have written the research paper independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

Student’s code: 195427EABM

Student’s e-mail address: debugger@live.co.uk

Author: Sami Akhtar

……………………………………………

(signature, date)

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Supervisor:

……………………………………………

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School of Engineering

THESIS TASK

Student: Sami Akhtar, 195427EABM

Study programme: Environmental Engineering and Management

Supervisor: Dr. Arvo Iital

Thesis topic:

(in English) Overview of Micro and Nano plastics in the environment and their possible pathways to humans

(in Estonian) Ülevaade mikro-ja nanoplastikust keskkonnas ja võimalikud sisenemisteed inimorganismi

Thesis main objectives:

1. To identify nano and microplastics influence on humans by studying their sources and contents in environment.

2. To identify micro and nano plastics impacts on the environment.

3. To address gaps in research, evaluating regulations and proposing recommendations and conclusions based on facts.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Preparation of research materials.	10.03.2021
2.	Study, identify and compile all material to achieve objectives.	20.05.2021
3.	Submission of thesis report	26.05.2021

Language: English **Deadline for submission of thesis:** 26/05/2021

Student: Sami Akhtar …..../…..../2021

Supervisor: Dr. Arvo Iital ..…./……/2021

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PREFACE

The thesis topic in this study was proposed by my supervisor and teacher, Dr. Arvo Iital, Professor at the Department of Civil Engineering and Architecture at Tallinn University of Technology. I would like thank him for his sharing his knowledge and experiences during the entire program and also for guidance in understanding the process flow. He guided me from the very beginning till the end from his continuous support and quick communication despite having covid restrictions in place.

Above all else, I am grateful to Almighty God for providing me this opportunity and for blessing me with family and friends mainly my wife, who supported me throughout this journey. My profound gratitude also goes towards Dr. Karin Pachel for accepting me in this program. I would also like to thank my teachers: Viktoria Voronova, Kati Roosalu, Marija Klõga, Kadri Kaarna, Piret Toonpere and Niina Dulova for sharing their knowledge and experiences throughout the program which helped me to perform better for achieving my goals in this study.

The primary aim of this study is to identify nano and microplastics influence on humans by overviewing their sources and contents in the environment. The findings of this study provides data from various authors, discusses each segment related to sources, impacts and more, to conclude that there is potential of negative long term health effects on humans from Micro and Nano plastics.

Key Words: Plastic, Pollution, Micro Plastic, Nano Plastic, Human Health, Environment

List of Abbreviations

MNP: Micro- and Nano Plastics

MPs: Micro Plastics

NPs: Nano Plastics

POPs: Persistent Organic Pollutants

ROS: Reactive Oxygen Species

PAHs: Polycyclic Aromatic Hydrocarbons

GALT: Gut-associated Lymphatic Tissue

WWTP: Wastewater Treatment Plant

MAR: Managed Aquifer Recharge

PVC: Polyvinyl chloride

PS: Polystyrene

PC: Polycarbonate

PP: Polypropylene

PE: Polyethylene

EP: Ethylene propylene

CFCs: Chlorofluorocarbons

Nm: Nanometer

AChE: Acetylcholinesterase

EPS: Expanded polystyrene

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1. INTRODUCTION

Plastics are regarded as versatile materials having many social benefits. The most prominent feature of plastics is that they can be manufactured at a relatively low cost. Moreover, their adaptability and lightweight feature add to their applications in almost every aspect of daily life, including packaging, medical services, food, consumer products, and construction. With the growing importance of plastic in our daily lives, it is estimated that about 33 billion tonnes of plastic will be added to the planet by 2050 (Bianco and Passananti, 2020). Apart from the great benefits plastic brings to human life, it is also regarded as the biggest threat to human life and environmental health because plastic polymers are highly resistant to degradation. Also, daily use of plastic increases the exposure of dermal, oral, and inhalation to the complex chemical components that adds to the chemicals in the human body.

The world currently is also facing the issue of plastic disposal bringing challenges and burden on the waste management system. Due to indiscriminate disposal, plastic wastes make their way to the ecosystem with the ability to contaminate the food chain and the environment (Wong et al., 2020). The types of plastic that are of particular concern include the microscopic plastic debris present in terrestrial, aquatic, and marine habitats. Sizes of Micro Plastics are still under debate and there is no international acceptance on one size but generally as accepted by majority Micro Plastics are plastics having particles of plastics less than 5 mm having synthetic origin or polymeric matrix of different shapes and similarly while still under debate majority of scientists agree Nano Plastics are plastic solid nanoparticles having size less than 1 μm (between 1 to 1000 nm) both of which cannot be dissolved in water (Frias et al. 2018) The physical and chemical characteristics assure the presence of the nano plastics and microplastics across the globe found commonly across the water column and are also seen to be ingested by many organisms. The contents of nano plastics and microplastics are biochemically inert and can adsorb other chemical substances including persistent organic pollutants (POPs), thus, leading to bioamplification and bioaccumulation phenomena.

The capacity of nano plastics and microplastics that originated from the environment to harm lives on the planet is still under consideration by many researchers and environmentalists. Although numerous hazards associated with microplastics and their recognition as a threat to the "Blue Economy", there is a research gap that needs to address adequately to get a real assessment of their presence in the environment (McCormick et al., 2016). Despite the multiple measures taken at the regional, national and international level for controlling the effects of plastic and reducing the contamination caused by plastic litter, these efforts are still seen to be insufficient for acquiring the proposed goal. Another issue that arises from the increasingly small size of plastics is that it becomes difficult for accurate analysis and sampling limiting the ability to control the harmful effects associated with their presence. An emphasis on small micro-and nano plastics in future research is imperative to be able to develop precise sampling and quantification techniques.

1.2 Aim of the Paper

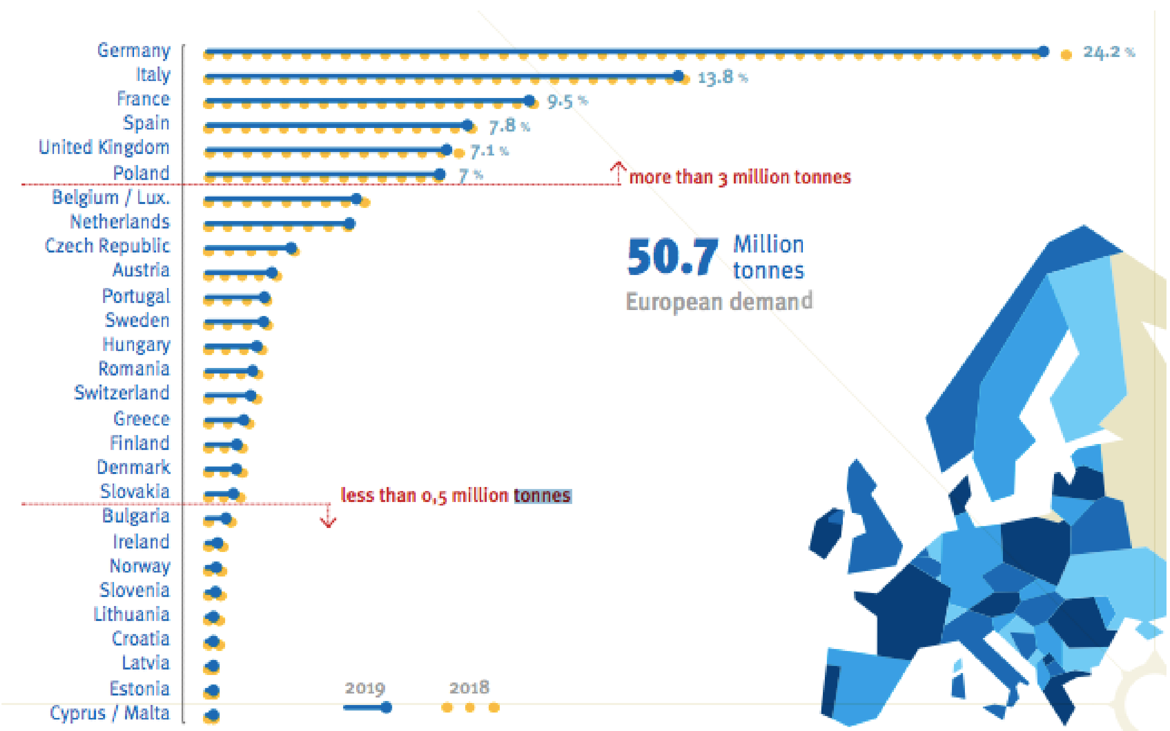
The paper aims to identify nano and microplastics influence on humans by overviewing their sources and contents in the environment. In addition, the paper also aims to address their impacts, current gaps in micro and nano plastic research along with evaluating the regulations and proposing some recommendations for overcoming the limitations.

2. LITERATURE REVIEW

2.1 Plastics

Plastic commonly refers to the plastic polymers composed of the additives added to attain the desired properties of the final product (Erni-Cassola et al., 2019). According to the estimates of the Plastics Europe Market Research Group (PEMRG), the demand for plastics in Europe was 50.7 million tonnes in 2019 (Figure 1).

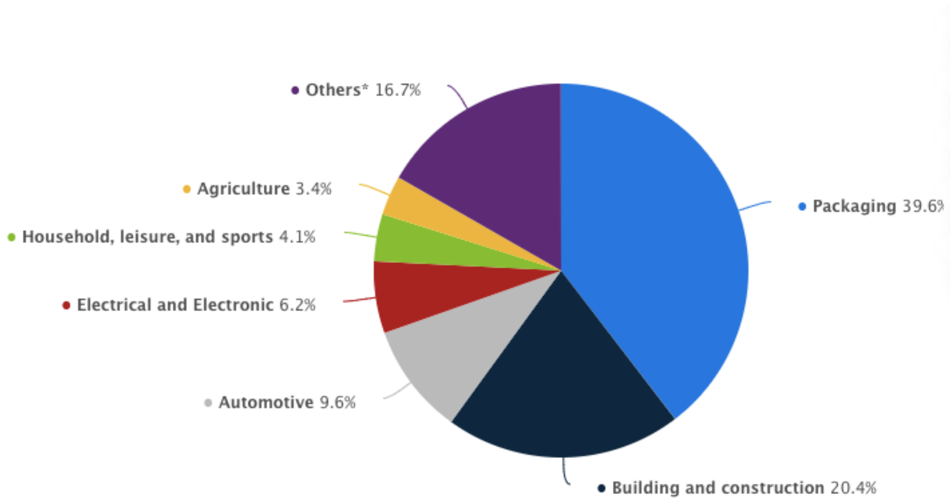
Figure 1: Plastics Demand by Country for the year 2018 and 2019



Source: PlasticsEurope (2020)

Data presented in Figure 2 shows that in Europe 39.6% of the plastic demand comes from the packaging sector, including food and beverage packaging, followed by the construction and building industry accounting for 20.4% of the plastic demand in 2019.

Figure 2: Plastic Demand in Europe by End-Use Industry in 2019



Source: Tiseo (2021)

Thermoplastic and thermosetting are two major types of plastics. Thermoplastics are easily remolded on heating while thermosetting lacks the property of re-softening on heating due to cross-linkages present in the polymers. Based on these properties, further seven categories of plastics are identified based on their ability to be recycled. Table 1 presents the seven categories of plastics along with examples and demand based on the resin type (for Europe). It can be seen that group 1 consisting of polypropylene (PP) has the highest demand mounting 19.4% of total plastics demand in Europe.

Table 1: Plastics Demand Distribution by Resin Type 2019

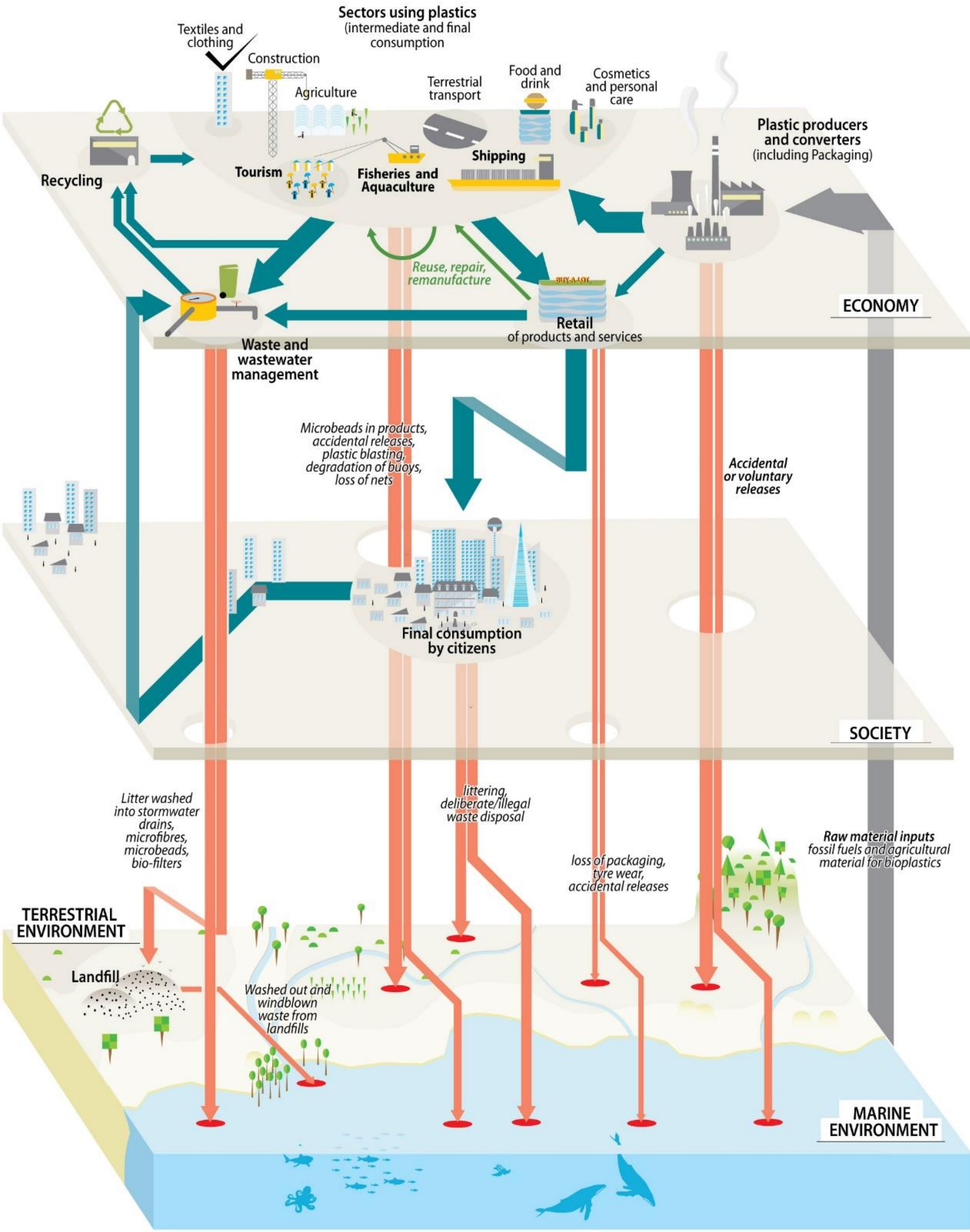
Code	Resin Type	Example	% Demand in Europe in 2019
1	PP	Sweet and snack wrappers, food packaging, pipes, banknotes, automotive parts, hinges caps, etc,	19.4
2	PE-LD/PE-LLD	The agricultural film, food packaging, reusable bags, containers, and trays, etc.	17.4
3	PE-HD/PE-MD	Milk bottles, housewares, toys, shampoo bottles, etc.	12.4
4	PVC	Pipes, window frames, cable insulation, inflatable pools, wall covering, etc.	10
5	PUR	Pillows, insulating foams for refrigerators, mattresses, building insulation, etc.	7.9
6	PET	Soft drinks, cleaners, water bottles, etc.	7.9
7	PS+EPS	Eyeglasses frame, building insulation, electrical equipment, fishery, and dairy food packaging,	6.2

		etc.	
8	Other Plastics	Optical fibers (PBT), Hub caps (ABS), touch screens (PMMA), roofing sheets and eyeglasses lenses (PC), etc.	7.5
9	Other Thermoplastics		11.3
Total			**100**

Source: PlasticsEurope (2020)

Market failure is the leading cause of the emerging issues of the waste and other pollution. There is a great imbalance in the costs associated with the plastic products and the plastic disposal. Figure 3 shows the pathway through which plastics travels to the environment from the economy. The ultimate impact and responsibility of plastic disposal is put on the society rather than consumer or producer. Due to this shortcoming of the system, consumption and production of plastic in large quantity is allowed at a minimal symbolic price. Consumer is least aware by the waste management processes thus lacking the knowledge of actual cost of product.

Figure 3: How plastic moves from the economy to the environment



Source: Pravettoni (2018a)

2.2 Micro and Nano plastics

The litter of plastics is found in a wide range of sizes. Plastics are broadly classified into two main classes: microplastic (smaller than 5mm) and macro plastic (greater than 5mm) (Li, 2018). Frias and Nash (2019) defined microplastics as "polymeric matrices or synthetic solid particle, found in irregular or regular shape and ranging in size from 1 μm to 5 mm originating either from primary or secondary manufacturing sources and having high insolvency in water."

Studies have classified the plastics based on different size and term ranges as shown in Table 2. The literature still does not define the lower unified limit required for the measurement of microplastics but for the studies or real purposes, the group of plastic with measurement *0.3mm is selected and sampled with neuston nets (Lasee et al., 2017). However, there is no lower cut-off developed so far, so the pieces ranging from millimeter to nanometer are included in the definition of microplastic.

Table 2: Types of Plastics based on Size by Different Authors

Class Name	Size of the Class	Size Range	Source
Nano	NMM (Nano, Micro, Millimeter)	Not given	Besseling, Quik, and Koelmans (2014)
	Nano Plastics	Smaller than 0.2mm	Wagner et al., (2014)
		Smaller than 100nm	Koelmans, Besseling, and Shim (2015)
	Micro Plastic	Smaller than 0.5mm	Koelmans et al., (2014)
	Micro Litter	The range between 0.06 to 0.5 mm	Hoellein, McCormick, and Kelly (2014)
		Range btw 0.33 to 5mm	Purba et al., (2019)
		Smaller than 2mm	Lechner et al.

Micro			(2014)
	Small Microplastic	Smaller than 1 mm	Vianello et al. (2013)
		Range btw 0.2 to 1 mm	Galgani et al. (2013)
		Smaller than 0.3mm	Faure et al. (2015)
	Large Microplastic	Range btw 1 to 5 mm	Galgani et al. (2013) Faure et al. (2015)
Meso	Mesolitter	Greater than 0.5mm	Law (2017)
		Range btw 5 to 25 mm	Galgani et al. (2013)
	Meso Debris	Range btw 2 to 20mm	Lechner et al. (2014)
		Greater than 5mm	Sanchez et al. (2014)
Macro	Macro Debris	Greater than 25 mm	Galgani et al. (2013)
		Smaller than 5mm	Faure et al. (2015)
Mega	Mega Debris	100 mm	Sanchez et al. (2014)

Nano plastic is the new term coined in the literature for a separate group of plastics having particles of 0.2mm or smaller, according to the size classification of WG-GES (Sarijan et al., 2020). Nanomaterials are generally defined as particles of size smaller than 100 nm (Mattsson et al., 2018). There is not enough discussion on nano plastics in the literature as seen from the lack of detailed analysis on the quantification and definition of nano plastics. However, studies have also shown that the nature of nano plastics may be the most dangerous out of all other types mainly due to their increased capacity for biomagnification and bioaccumulation (Yang, Chen, and Wang, 2021). The claim of the researchers on the hazardous nature of nano plastics needs further investigation.

For this study, the author has focused on micro and nano plastics (MNP) as one single size group of plastics for the ease of carrying out the review.

2.3 Sources of Micro and Nano Plastics

The sources from which micro and nano plastics originate are classified as primary and secondary sources. The composition and size of the plastics are largely dependent on the source of origin. The manufacturing of primary MNP is carried out intentionally in small sizes for the production of cleaning and personal care items and pre-production shots for other plastic goods fabrication (Peng et al., 2020). Since nano plastics have huge applications in the production of medicines, airplanes, electronic devices, and cars so their manufacturing is likely to be increased in the future (Wong et al., 2020). The disposal of primary MNP is not a speedy process and is often found as such in household and industrial sewage and is treated in the wastewater treatment plant (WWT) to avoid being discharged into the aquatic environment (Wong et al., 2020).

The weathering effects of UV-radiation and mechanical forces' physical defragmentation break down larger pieces of plastics into smaller ones resulting in secondary MNP (Hu et al., 2019). Secondary microplastics are produced by the breakdown of microplastics that further breaks down into nano plastics. The production rates and quantity of MNP depend largely on polymer type and characteristics of the environment (da Costa et al., 2016), thus, it becomes difficult to trace, control and quantify the input of secondary sources into the aquatic environment as compared to primary sources.

The origins of the MNP can be traced from their size, chemical composition, and surface features. For instance, primary MNP used on the personal care items contains additives, smaller than 0.3 mm and mainly composed of polyethylene (PE), and sometimes also show some polyethylene terephthalate (PET), Teflon (PTFE), polypropylene (PP), and polymethyl methacrylate (PMMA) (Liu et al., 2019). The shapes of primary MNP will either be cylindrical or spherical with an approximate size of 5mm found in the shape of pre-production pellets (Kershaw, 2015). Packaging mostly uses polystyrene (PS), polymers PE, and PP, thus showing urban origins while textiles and construction industry largely uses denser polymers like polyester (PES) and polyvinyl chloride (PVC), respectively (Kershaw, 2015). The origins of these plastics show they are secondary MNP fibers and fragments coming from surface runoff and sewage effluent.

Presently, the literature lacks evidence on the relative abundance of primary to secondary plastics and only a few studies are examining the relationship between different sizes fragments (Lee et al., 2015). Further research is needed to fill these knowledge gaps for quantifying the MNP fractions accurately, identifying characterization approaches for the application of precise source, and assessing the relationship between the abundance of classes of different sizes to enhance the understanding of the role of various industrial and urban sources (Lee et al., 2015). Focusing on these knowledge areas will help in the management of issues and informing the policy decisions as it is anticipated that controlling land-based inputs will not control the density of plastic debris in the ocean since they are coming from secondary sources (Eerkes-Medrano, Thompson, and Aldridge, 2015).

The increasing amounts of micro and nano plastics in the in the environment have multiple sources which can come from all over the world. The human intervention in this regard is massive and majority of the sources are from land-based processes. Examples can be mismanagement of solid waste where its collection, treatment and transport are key ingredients, but not all countries have the potential of achieving this fully and the non-presence of proper procedures and maintenance in this regard has caused leakage of plastics in the environment. Increase in human population along with placing their habitats closer to the water resources are also one of the reasons of sources of plastics leading to oceans (Fabres, J et al., 2016) Increase in the use of cosmetic items is also one of the reasons of release of microplastics, a study by Napper 2015 estimates that in about a year, 264 tonnes of polyethlene microplastic is released into the environment (Napper et al., 2015) Also MPs present in air also pose a significant part of micro plastics transport and deposition, atmospheric fall out of MPs can be possible source of MPs in air (Dris et al. 2016; Dris et al. 2017)

In addition, human aspect in terms of manufacturing industries plastic production of fishing nets cigarette filters, plastic bags, food wrappings, caps and lids, beverage bottles, cups, plates, cutlery, straws and stirrers are found in the environment more often than other products which can be prime candidates for weathering and breaking down into smaller plastics. This can be triggered with activities in building and construction, tourism (mainly in coastal areas), agricultural activities, shipping sector which includes fishing and transport (Fabres et al., 2016). It is estimated that fishing nets and gear present in the oceans accounts for most part of the oceans plastic pollution (Sandra, 2019).

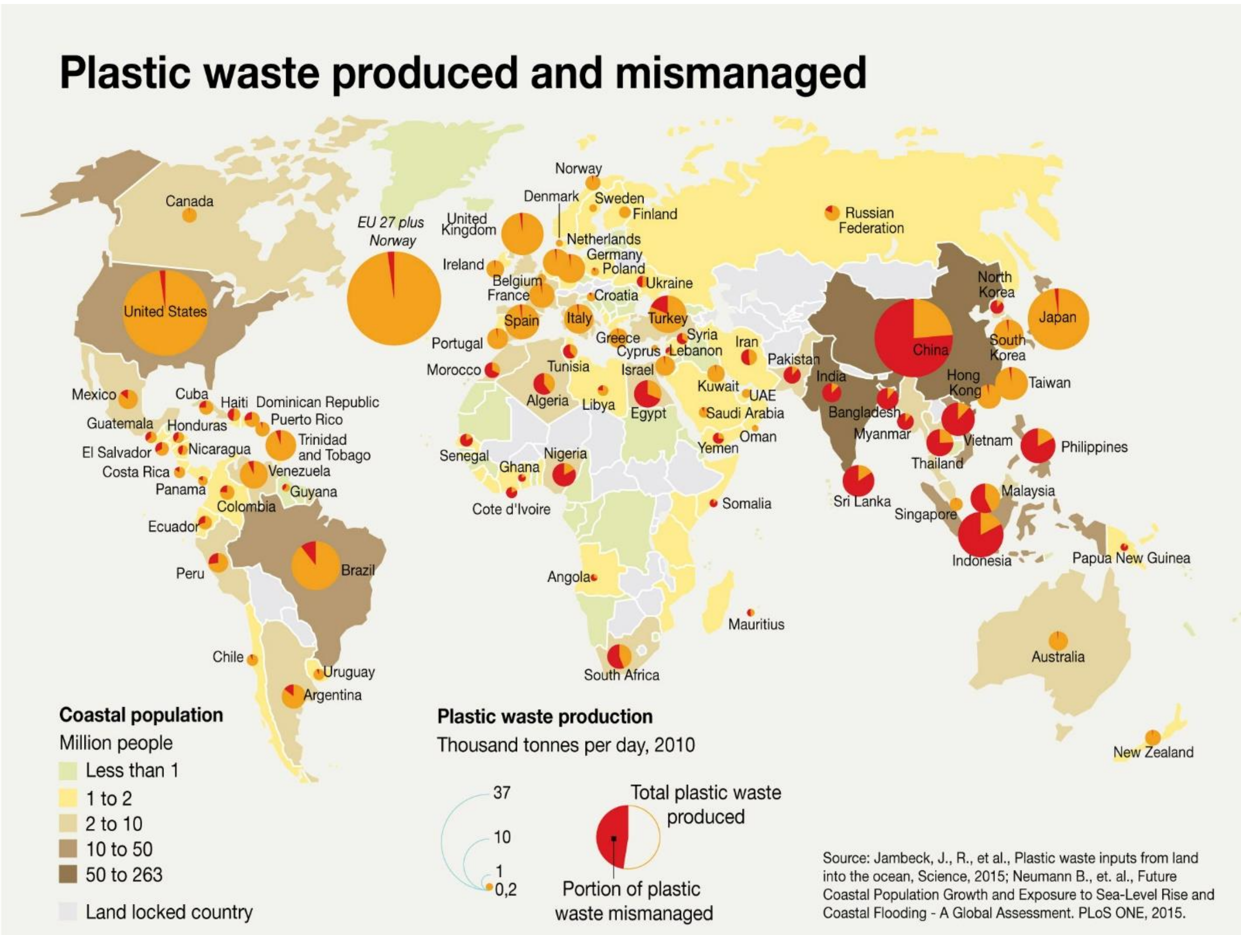
2.4 Content of Micro and Nano Plastics on Environment

2.4.1 Content on Land

The gradual increase in the consumption of oil and gas has accelerated the process of developing petroleum products, specially, petrochemicals that possess significant applications in addition to the energy production. Globally, the level of plastic resulting from petroleum has ascended to more than 300 million tons in 2014 as compared to 1.5 million tons in 1950

(Gourmelon, 2015). According to the experts, this increase in plastic consumption is regarded as the "Our Plastic Age" (Thompson et al., 2009). It is further shown by the studies that if the increasing trend in plastic production followed the same pattern of 5% per year continues, there will be around 33 billion tons plastics to be added around the planet by 2050 (Galloway, 2015). Figure 4 presents a graphic of plastics produced and mismanaged by different countries across the globe.

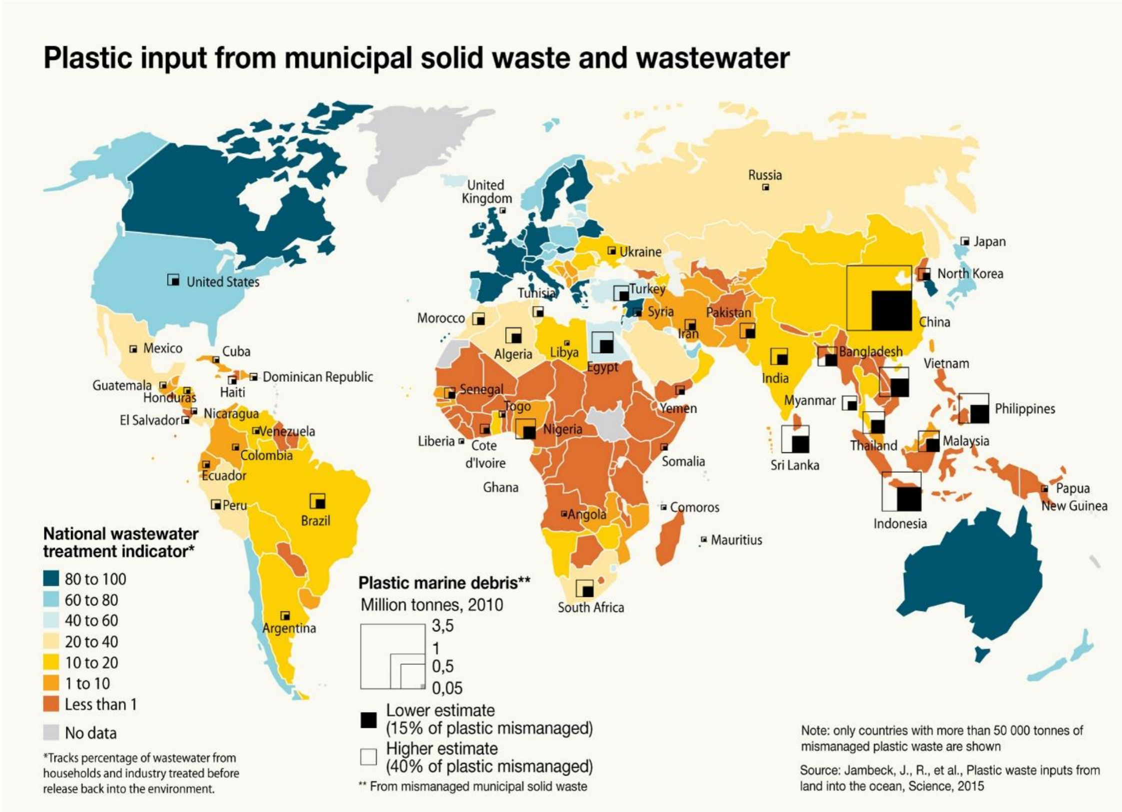
Figure 4: Map showing waste produced and mismanaged by countries



Source: Pravettoni (2018b)

The plastic waste on land resulting from the human activities is sometimes blown by wind or washed by surface runoff into the rivers and travels through watercourses into the ocean. The transportation of plastic into the water resources is also efficiently done because of its near-neutral buoyancy reaching the oceans within few days (Jambeck et al., 2015). Figure 5 shows plastic input from municipal solid waste and wastewater sources. Sometimes debris from the land also rests on the riverbanks or trapped into vegetation that is further moved by the surface runoff or wind helping it to complete the journey downstream. When high discharge events occur from the human-controlled water discharges or heavy rainfall, plastic waste and other debris is easily taken from the river mouth to the far offshore. Debris dispersal is also quick along the coasts where there are large tides or high wave energy or other moving current regimes (He et al., 2019).

Figure 5: Plastic Input from Municipal Solid Waste and Wastewater

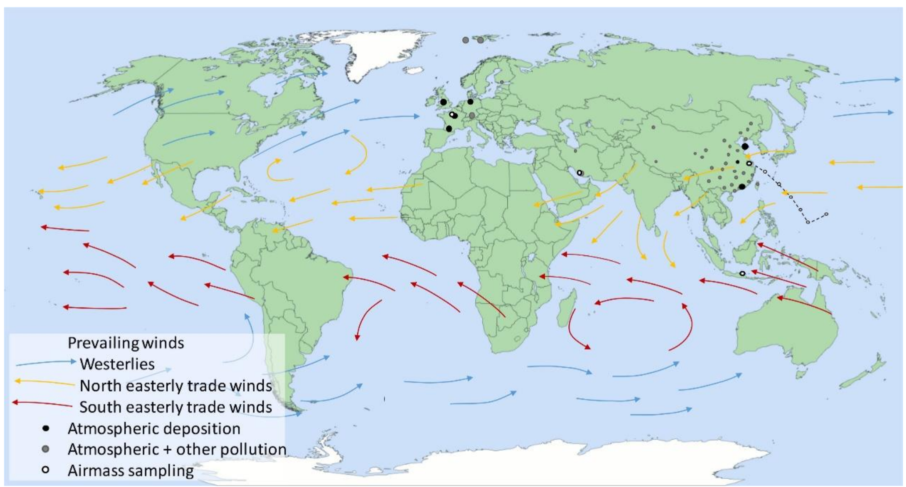


Source: Pravettoni (2018c)

2.4.2 Content in Air

Content of MNP in various parts of the worlds vary depending upon temperature, topography and height. 365 microplastic particles per square meter were recorded falling in southern France in pyrenees mountains. It was astonishing for the scientists to find microplastics in the air at such height as there were supposedly no sources of plastic present there. This shows the transport of MNP in the air is quite significant. Previous studies in major cities of Paris and Dongguan, readings of microplastics were in range of 110 and 228 particles per square meter. When comparing these results with rain or snow events, it is still inconclusive to suggest their roles in causing those particles to transfer from air to ground or water (Allen et al., 2019). It is possible to use different modelling systems for trajectories, dispersion and deposition, as air undergoes movement their pathways can be determined based on their direction and thus it may be possible to get estimates of deposition of MNP in other locations based on the model (Allen et al., 2019) but further research on this topic is required. Studies have shown Microplastic to be present in glacial regions and can be transported to remote regions and ocean surfaces (Ambrosini et al., 2019; Zhang et al., 2019; Liu et al., 2019).

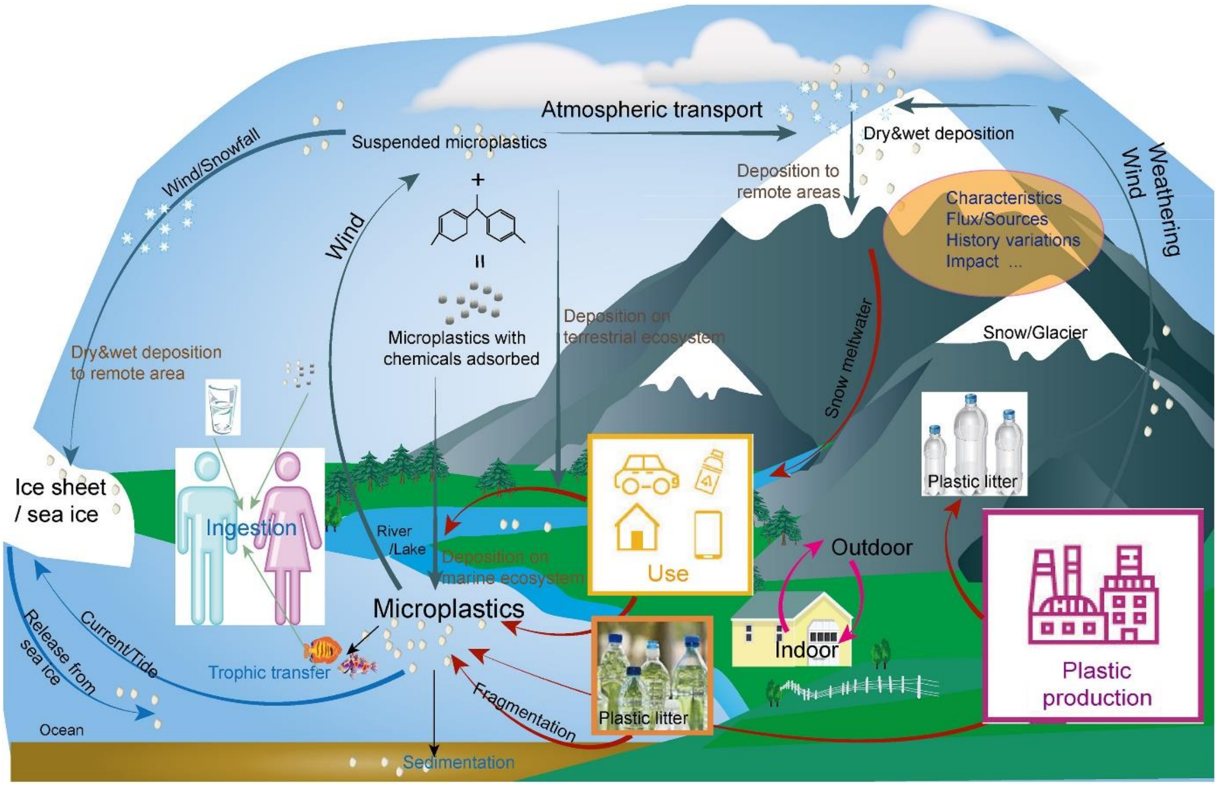
Figure 6: Atmospheric MP movement



Source: Zhang et al (2020)

Figure 7 shows atmospheric MP movement which is resulted based on latest published studies on MNPs. While deposition from Air to ground is still being researched, mostly scientists agree that precipitation and snow are considered as a way of deposition of MNPs. Studies have shown that deposition of MNP in remote areas and in the melted snow in Arctic and Europe accounts to the range between 190 to 154 x 10^3 particles and 0-14.4 x 10^3 particles (Allen et al., 2019; Bergmann et al., 2019)

Figure 7: Conceptual model of atmospheric MP in the environment

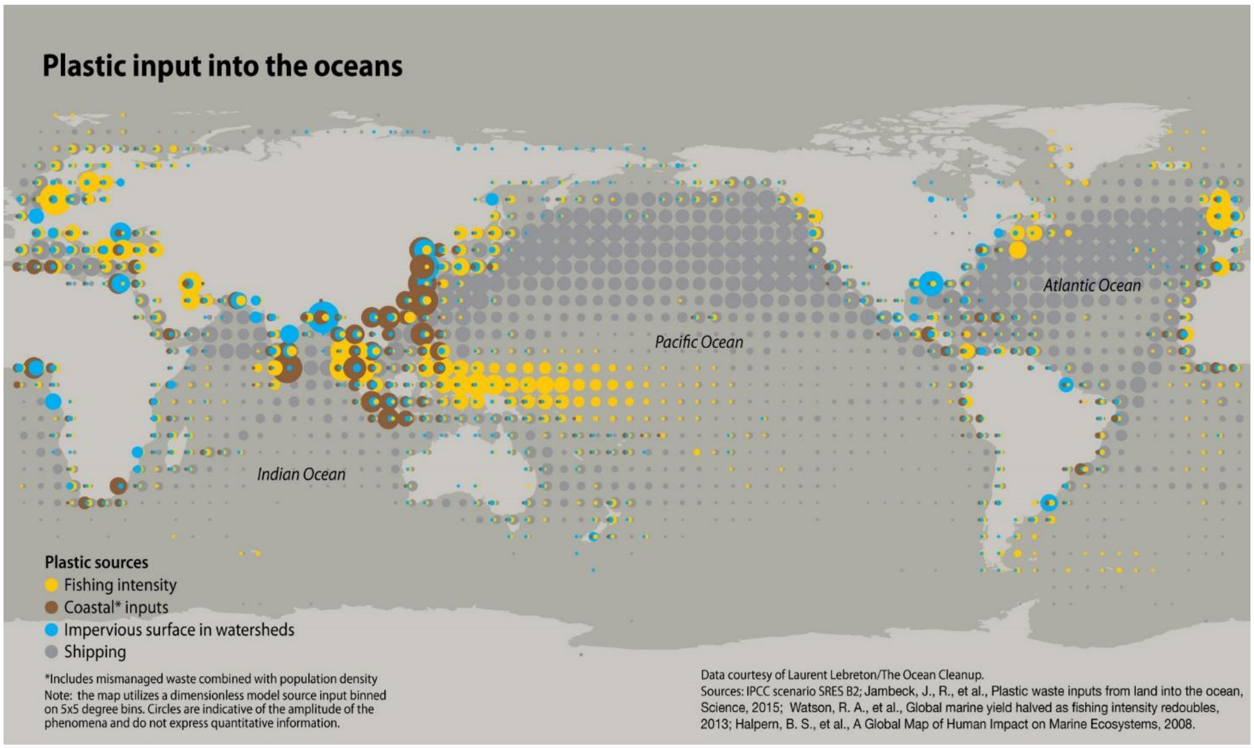


Source: Zhang et al (2020)

2.4.3 Content in Oceans and Seas

Although there is enough literature on the role played by rivers but there is lack of global estimates on the quantity of the debris made by the men reaching the river mouths. That is why, the proportion of litter contributed by rivers to the total 4.8 to 12.7 millions tons of litter entering the marine environment from the land is still unknown (Wagner et al., 2019). Figure 8 show that plastic input into the oceans. The composition and quantity of anthropogenic debris coming from a certain river is shaped by the character and intensity of the population density and socio-economic activities in the river basin. The leakage of debris could be controlled by the formulation and implementation of waste treatment and environmental protection ways. The distribution and extent of impervious surfaces (built-up areas) in watersheds has been used as a proxy for the input of plastic debris through watercourses, as it is directly related to both urbanization and runoff volume (Lebreton et al., 2017).

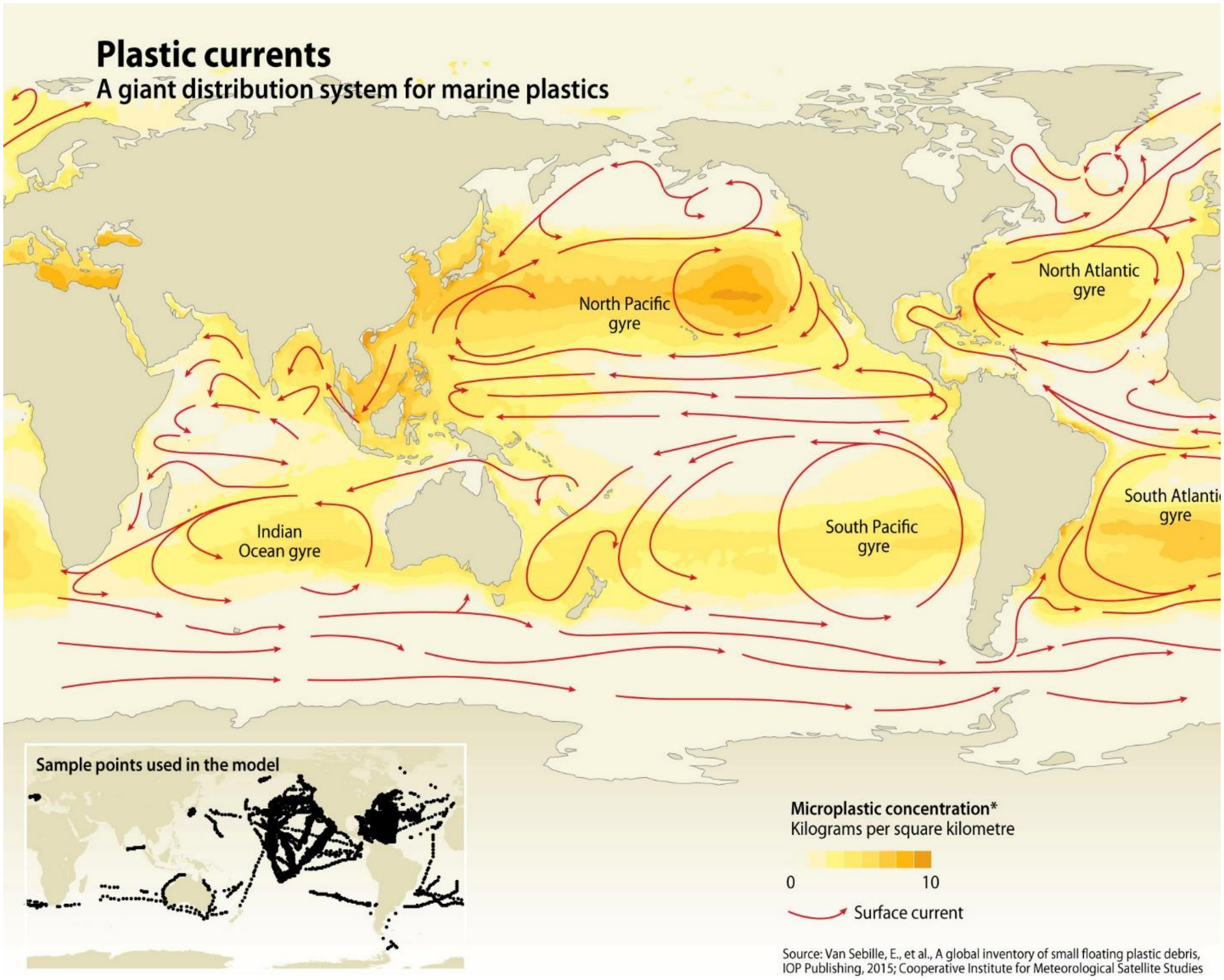
Figure 8: Map showing Plastic input into the oceans



Source: Pravettoni (2018d)

The plastic discarded from the land moving on the surface of the ocean, around the ocean, on the sea floor and in the water column sometimes become stagnant. Figure 9 shows the map of the marine plastics distribution system. Density of plastic waste combines with the prevailing waves, current and wind depicts the pathways through which plastic travels and the entry points that in return strongly impacts the geographical distribution of the marine plastic debris (Rech et al., 2014).

Figure 9: Map showing distribution system for marine plastics



Source: Pravettoni (2018e)

2.5 Impacts of Micro and Nano Plastics on Environment

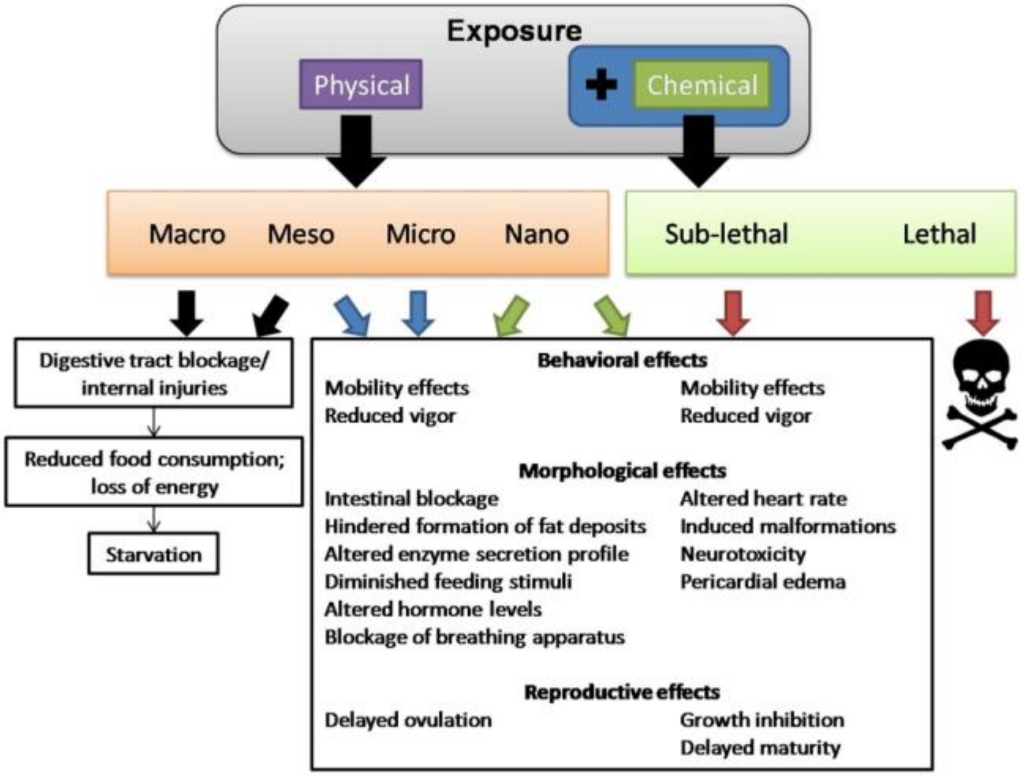
2.5.1 Impacts on Land

The threat of micro and nano plastics is evident on the soil biota since it is predicted and confirmed in studies that they bring changes in the soil habitat. It is found from the empirical calculations that 32% of the total plastics are available in the environment mainly found in the continental systems (Keller et al., 2019) while some studies argue that the capacity of the soil to store microplastic litter is more than the aquatic basins (Xiang et al., 2019). Terrestrial contamination is also the result of different environmental sources and human activities, such as contaminated watercourse (de Souza Machado et al., 2019), plastic mulches (Certini and Scalenghe, 2019), fertilizers used in agriculture (Palacios-Mateo et al., 2021), and atmospheric precipitation (Sander, 2019).

Micro-and nano plastics are also likely to disturb the terrestrial food chain. The food scents and particles carried in the food containers and plastic bags attract animals that eat the plastic. Due to their smaller size, different organisms including planktonic and even big organisms, such as birds, mammals, and fish, digest MNP. Although there is not enough evidence illustrating the level of toxicity of these materials, it is anticipated that the impacts are seen due to ingestion-induced stress such as energy expenditure, physical blockage, and false satiety increased exposure to contaminants such as POPs and chemicals leaked from plastics such as additives (da Costa, Duarte, and Rocha-Santos, 2017). Moreover, within laboratory settings euphausiids, ciliates, barnacles, annelids, copepods, cnidarians, birds, amphipods, tunicates, fish, and mussels are all found to swallow the small-sized polymers (Duis, and Coors, 2016).

The impacts are also evident on the ecosystems since huge piles of plastic litter are found along with the inland water bodies and shores of lakes, disturbing the waterfowl' nesting arrangements. This will further have long-term effects on animals in the food chain, including frogs and small insects that supply food to higher organisms such as reptiles and carnivores living in the wetlands (Corradini et al., 2021).

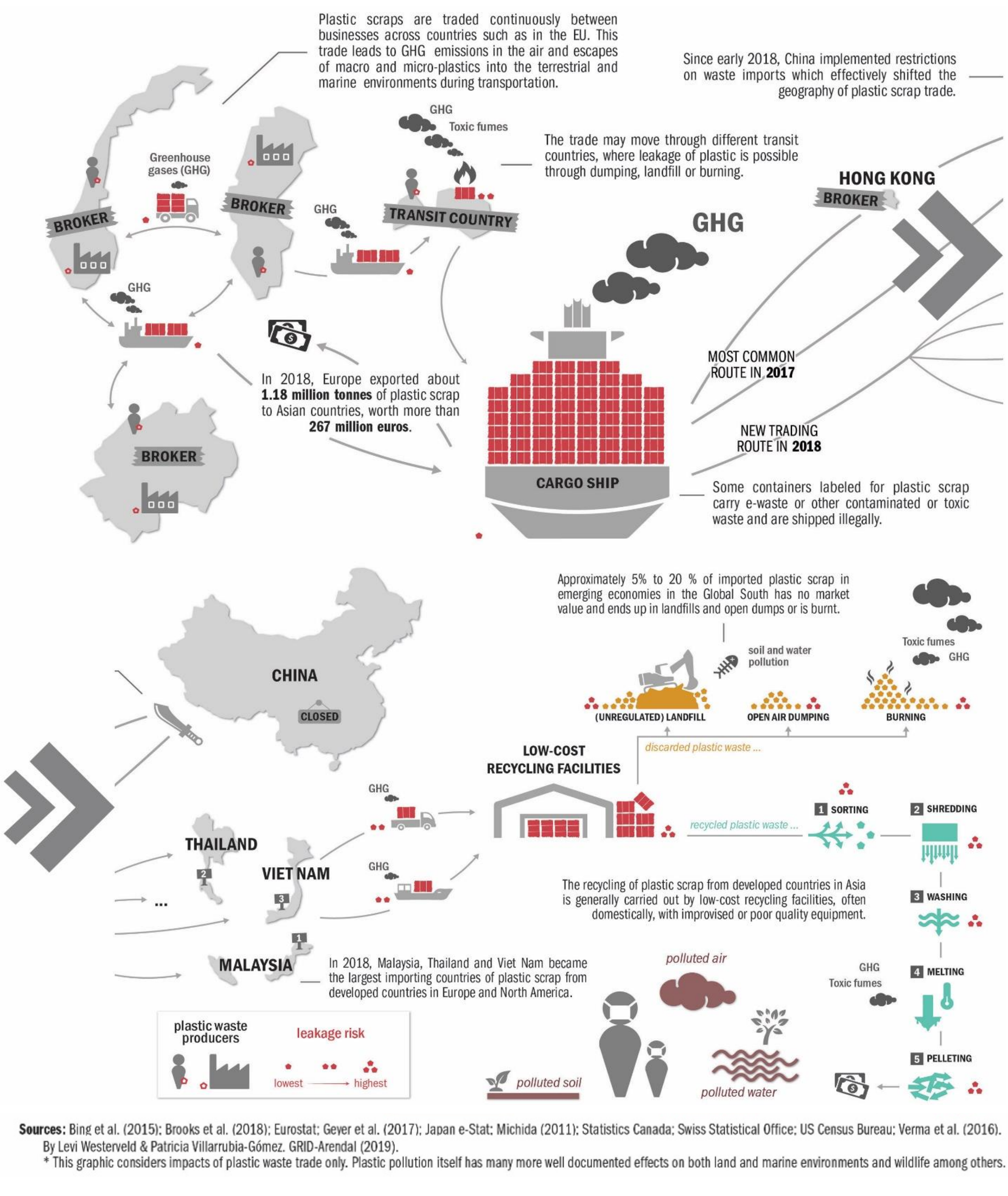
Figure 10: Conceptual Model showing Biological Effects of Plastic of Different Sizes



Source: Da Costa, Rocha-Santos, and Duarte (2020)

Figure 11 shows the way plastic scarp is moved and transferred from industrialized regions and developed economies in the global south. The transboundary movement of plastic waste and discarding and recycling pathways lead to the leakage of the debris in the land and marine environment.

Figure 11: Impacts of plastic scrap transboundary movement



Source: GRID-Arendal (2019a)

2.5.2 Impact on Marine Environment

Although several studies have been conducted on assessing the ecological impact of MNP on the marine environment still they are found to be in the limited scope as indicated by a detailed review of Eerkes-Medrano et al. (2015). MNP, being smaller in size, is easily ingested by aquatic organisms directly and indirectly than larger plastic particles. Most of the time, these particles are mistaken for food leading to disastrous physical effects on marine life (Barboza et al., 2019). Studies conducted on marine life show that ingesting of MNP results in blocked digestive tracts, organ damage, choking, and eventually death (Barboza et al., 2019). It has been observed that marine organisms' ingestion of MNP is similar to marine fauna (Eerkes-Medrano et al., 2015), however, little evidence is presented on the intake of MNP by birds and fish species in lakes (Faure et al., 2015). The food web becomes toxic due to the potential of MNP to absorb POPs reaching human life through bioaccumulation (Carbery, O'Connor, and Palanisami, 2018). The concentration of pollutants also increases in water with the desorption of manufacturing additives like POPs leading to increased vulnerability of larger particles to degradation (Figueiredo and Vianna, 2018). However, resources are scarce on the leaching and sorption of POPs from microplastics and the knowledge on the adverse effects of MNPs comes from the experiments carried out in labs while limited data comes from the freshwater. Moreover, biofilm formation and microbial colonization also occur on the MNP surfaces facilitating the transfer of invasive species and pathogens (McCormick et al., 2016).

2.5.3 Impact on Air

Plastic in the form of fibers is present in the air. Figure 12 presents a general classification of fibers for enhanced knowledge of airborne plastics. The fibers present in the atmosphere are either man-made or naturally produced. The fibers resulting from the activities of men are either organic or inorganic, such as glass, carbon, ceramic, etc. Organic fibers are either produced from synthetic polymers or by transforming natural products (artificial fibers) (Gasperi et al., 2018).

Figure 12: Classification of Textile Fibers

General classification of textile fibers.

Textile fibers					
Natural fibers			Man-made fibers		
Animal fibers	Vegetal fibers	Mineral fibers	From organic chemistry		From inorganic chemistry
			Artificial fibers	**Synthetic fibers**	
Wool, silk	Cotton, jute	Asbestos	Viscose/rayon, acetate, etc.	**Polypropylene, acrylic, polyamide, polyester, polyethylene**	Glass, ceramic, carbon, etc.

Source: Gasperi et al. (2018)

In 2016, the world produced more than 90 million metric tons of textile fibers. Plastic and synthetic fibers constitute two-thirds of the total production. A yearly increase of 6.6% in the production rate has also been observed over the last decade. Apart from synthetic and plastic fibers, other fibers include 6% of cellulosic fibers and 27% of natural fibers; majorly cotton (International Cotton Advisory Committee, 2020). The world has also witnessed an increased use of plastic fibers with a fine diameter of 1e5mm for commercial purposes, such as in the clothing and sports industry (Amato-Lourenço et al., 2020). The fibers due to their small size are readily shed indirectly or directly during washing, drying, or cloth wearing (Cesa, Turra, and Baruque-Ramos, 2017). Fine particles are also produced during the grinding or chopping of synthetic material in the industries. Within the environment, fibrous microplastics (MPs) are degraded through the photo-oxidative process and are also scratched against other particles or shredding with wind resulting in the disintegrating into fine particles. Such fine fibrous MPs are readily inhaled posing the threat of wide contamination in the environment. There is a need to give special attention to their huge production across the world and their ability to divide into fine, more bioavailable fibers. Humans are exposed to MPs through ingestion, for instance, crawling babies could have hand-to-mouth contact with the floor upon which MPs settle and ingesting the dust.

When the level of exposure to fibrous MPs reaches beyond a certain limit, these fibers are likely to result in inflammation due to chronic inhalation (Prata, 2018). Although plastic is considered inactive the shape of fibrous MPs and their bio persistence could result in inflammation. Fibrous particles resulting from vitreous manmade fibers and asbestos cause toxicity within the human body when they come in contact with the cell leading to the release of cytotoxic factors and intracellular messengers eventually causing inflammation in the lungs. It further causes secondary genotoxicity along with the continuous and excessive development of reactive oxygen species (ROS) (Prata, 2018). Prolonged inflammation manifests fibrosis resulting in cancer in most cases (Enyoh et al., 2019). Long fibers result in greater toxicity since they cannot be phagocytosed sufficiently and stimulate the cells to produce inflammatory mediators resulting in fibrosis (Padmore et al., 2017). Although plastic is considered inactive the shape of fibrous MPs and their bio persistence could result in inflammation.

Airborne fibrous MPs due to their hydrophobic surface absorb pollutants from the surrounding environment (Lee et al., 2018). When they interact with the emissions from the traffic and industries in urban areas, they carry transition metals and Polycyclic Aromatic Hydrocarbons (PAHs). Desorption of contaminants could result in detrimental pulmonary outcomes causing primary genotoxicity along with other effects (Prata, 2018). For instance, the metabolism of PAHs associated with fibrous MPs could cause unstable and stable DNA lesions (Prata, 2018).

Plastics also carry particles like additives, unreacted monomers, pigments, and dyes. These particles either leach, accumulate, or volatile cause serious health effects such as carcinogenicity, reproductive toxicity, and mutagenicity (Linares, Bellés and Domingo, 2015). Contamination of dust settled on surfaces in the house with phthalates or polybrominated diphenyl ethers is studied widely and is the result of the fibrous MPS emissions resulting from the use of household plastic textiles (Sukiene et al., 2017).

2.6 Pathways to Human Health

There is a large potential of microplastics to occur in the food items but there is no clear evidence presented so far on the subsequent translocation or unintended ingestion of the microplastics through diet within the humans. The world is, however, showing great interest in using MNPs in the pharmaceutical drug developing pathway to the human body through intravenous, oral, and transcutaneous routes (Greish et al., 2018). The transmission of MNPs into the human body is also made possible through the transfer of nano polymers used in the food packaging material (Arikan and Ozsoy, 2015). The developing stages in the use and transmission of MNPs have given enough opportunities to scholars to analyze the pathways through which MNPs could make their way to the human body, although clear evidence has been presented on different aspects of this field till now.

Gut mucosa within the human body plays an important role in restricting the entrance of harmful organisms or substances into the human body through oral ingestion as it allows uptake of nutritious items only. The pathway of MNPs entering the human body through this route is described by the theory showing particles through the exploitation of prevailing routes possess the potential of entering the body. The literature presents significant data on the uptake of active particles across the gut through oral ingestion (Stock et al., 2019).

Volkheimer in 1974 gave a detailed analysis of large starch particles having a size equal to 150 µm persorpting through the edges of the villi. The analysis showed that the persorption of starch particles is carried out passively in the region of the gut having a single layer covering epithelium on the intestinal mucosa. These persorbed particles are found in the lymph vessels and blood lumen. They are detected within minutes and removed through the urine, showing that large and active particles can be transferred from the gut to other body fluids (Volkheimer, 1974).

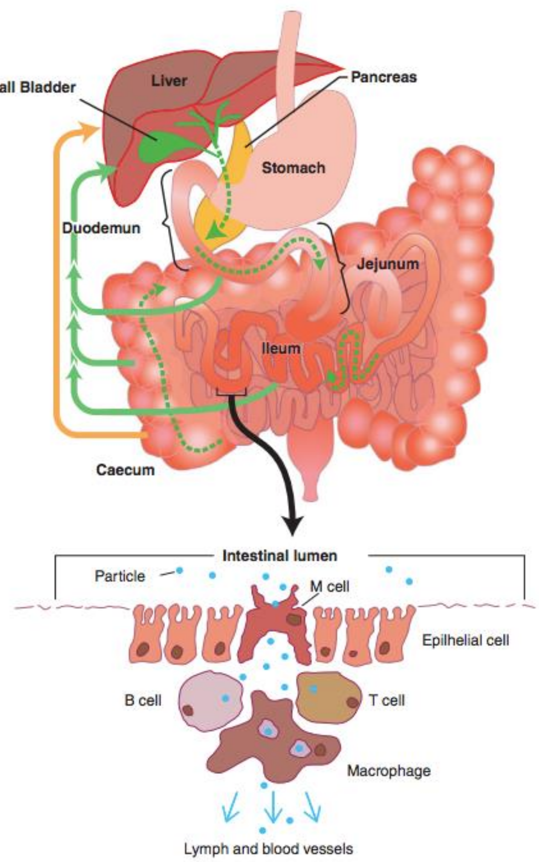
Apart from this, it was also observed that pinocytosis facilitates the absorption of smaller particles in the digestive system, and micro and nano range particles are absorbed through the vesicular phagocytic process. The pathway and extent of uptake of the particles are largely identified through their size. Larger particles have difficulty in finding a way to the human body while smaller particles can easily travel into the body and are thus favored over larger particles for conducting studies. For instance, the absorption of polystyrene microspheres of size 50–100 nm was rapid and easy across the gut's villi and the Peyer's patches as compared to the particles of size 300 to 3000 nm (Liu, Jiang, and Meng, 2019).

On the contrary, a low extent of uptake of 2.5 nm polylysine dendrimers was found as compared to the larger size particles such as polystyrene of size ranging from 100 nm–3 µm showing that size cannot be taken as the only deciding factor (Florence et al., 2000). In fact, uptake affinity is decided by the combination of surface, size, and hydrophilicity (Xia et al., 2017). Gut-associated lymphatic tissue (GALT) is reported to offer a path to the micron-scale particles within the gut, specifically through the Microfold (M) cells present in the Peyer's patches. The composition of M cells shows that they are specified epithelial cells covered with micro folds (border) consisting of a thin luminal surface. These M cells lack microvilli unlike other gut epithelial cells allowing the cells to actively carry the particles from the intestine. The efficiency of the particle uptake differs based on the particle type, study method, and species.

Species such as rabbits having M cells in abundance showed higher uptake of polystyrene microspheres through the gut using this route (Longet et al., 2018). The process further speeds up when the food was present causing a delay in the transit time through the gut (Sæle et al., 2018). Awaad et al. (2012) through quantitative analysis and histological examination used fluorescent organosilica particles to identify that the ideal size for the particles to be taken up by the M cell of the Peyer's patches is around 100nm. They further showed that particles larger and smaller in size than 100nm have slow uptake through M cells. Two alternative uptake paths were also identified facilitating the transfer of nanoparticles through transcellular-E uptake or between paracellular-E uptake enterocytes present in the Peyer's patches. The particles of size greater than 1 μm were previously found to use these two pathways outside of the Peyer's patches but still lack the evidence on the uptake of nanoparticles by the Peyer's patches (Mante et al., 2016).

Garrett and his workers in 2012 applied multimodal nonlinear optical microscopy and bio-imaging technique to assess how enterocytes in the villi of the mouse gut uptake the polymeric nanoparticles. For the study, they selected a novel amphipathic polymer, ammonium palmitoyl glycol chitosan ranging in size from 30 to 50 nm, specifically used in the drug delivery, and found that once enterocytes uptake the particles, they are settled at the base of the villi. They then travel from the base of the villi to the liver through the bloodstream and are detected in the intracellular spaces and hepatocytes prior to their circulation in the bile of the small intestine to move out of the body with fecal matter (Garrett et al. 2012). The results of this study were similar to the ones conducted for the larger micron-scale latex and polystyrene particles showing that both nano and microparticles act in the same way using a pathway of uptake across the gut, circulation through the bloodstream and subsequently leaving the body through urine and fecal matter as shown in the Figure 13.

Figure 13: Recirculation pathway for Nano and Microparticles



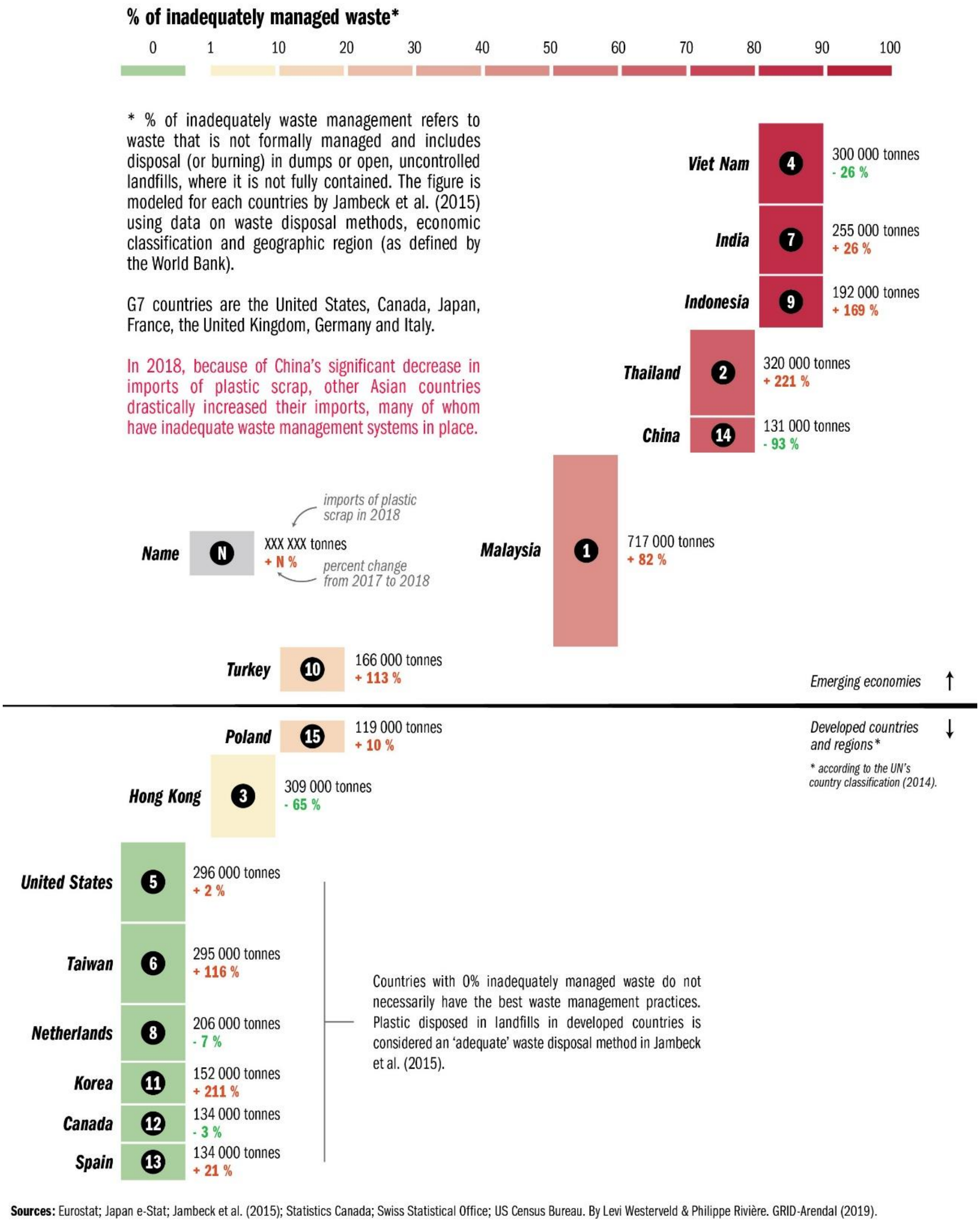
Source: Garrett et al. (2012)

The findings of these studies are significant for drug delivery showing that there is a large number of opportunities, following ingestion for nano and microplastics in water or food to enter, traveling, and bioaccumulating in the body.

2.7 Export and Import of Plastic

The countries across the world are in race of dealing with world's trash. Since the ban imposed by Chins in 2019 on the import of plastic waste, other countries specifically from China have invested in the sector increasing the risk of maritime, land and air pollution (Buchholz, 2020). Although recycling of foreign plastic is a profitable process but the receiving countries are facing large number of issues due to lack of oversight and regulations. After China, Malaysia and Vietnam emerged as the largest importers of plastic waste in Asia followed by the Turkey as the biggest importer of the plastic waste from Europe. It can be seen in Figure 15, the largest importers of plastic scrap along with percentage of their mismanaged waste after restriction imposed by China in 2018 (Buchholz, 2020).

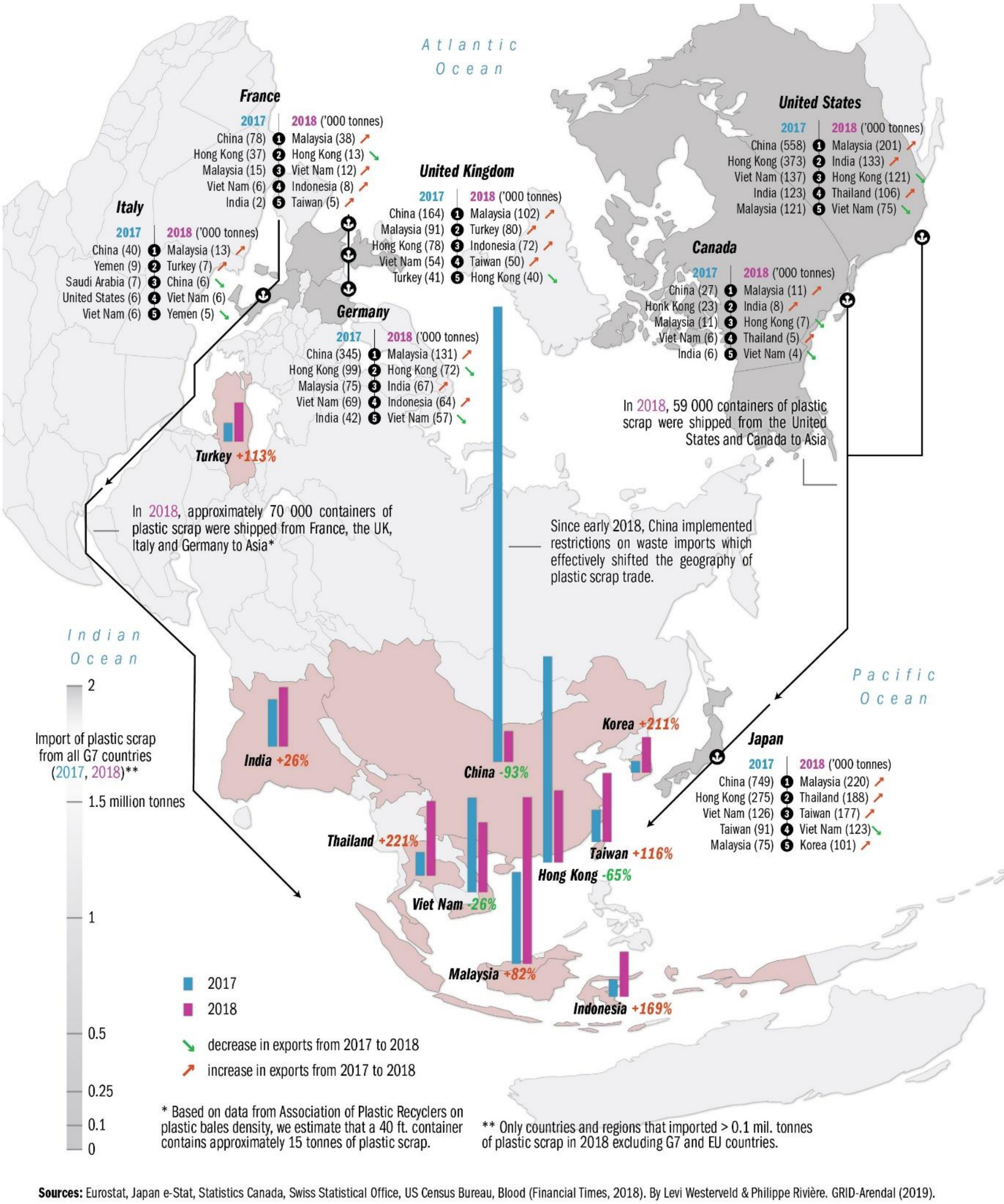
Figure 15: 15 Largest Importers of G7 plastic waste



Source: GRID-Arendal (2019b)

The estimates showed that the quantity of plastic waste from developed nations is increasingly exported by the countries where regulations are not yet enacted. The largest plastic waste producers are German, Japan and the United States that also showed largest net exports of plastic scrap and waste in 2019 (Buchholz, 2020). According to UN Comtrade platform, more than 550,000 tons of plastic waste was shipped by Japan in 2019 while there were no imports of foreign plastic waste were recoded, resulting in 530,000 tons of net exports (Buchholz, 2020). Similarly, the U.S and Germany showed net exports of 317,000 and 413,000 tons of net exports respectively. Figure 16 displays a map showing changes in destination countries and amount of plastic scrap from G7 countries in the period 2017 to 2018. The shift in the geography of plastic scrap trade is because of the strict restriction imposed by China on imports of waste material.

Figure 16: Export of G7 countries' plastic waste overseas in 2017 and 2018

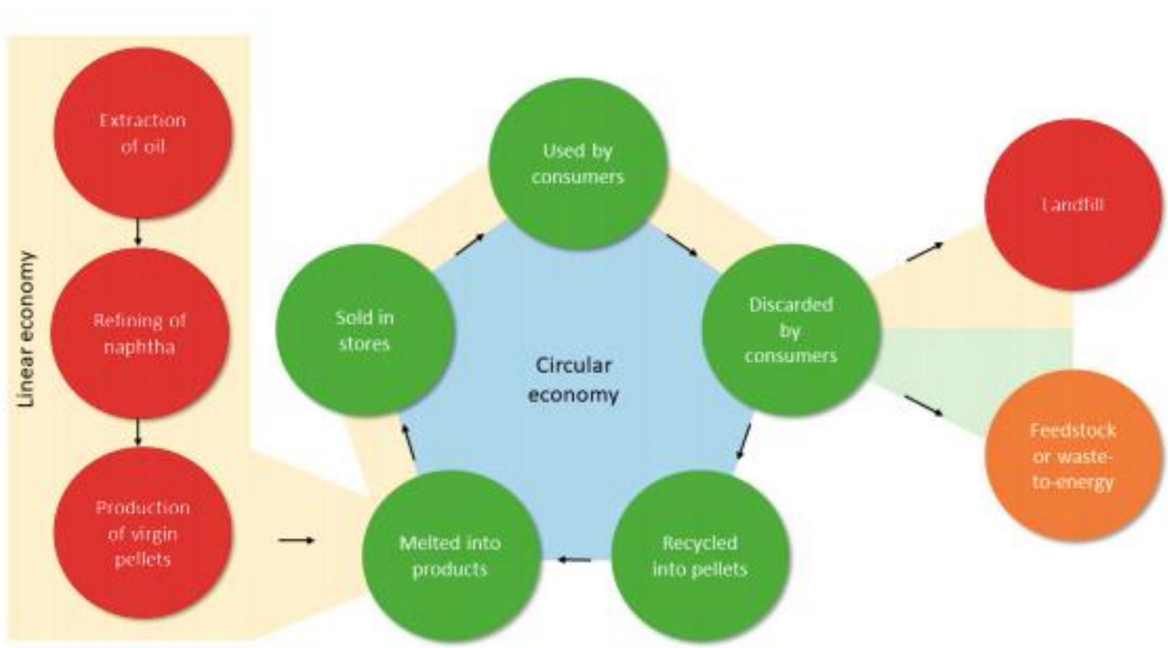


Source: GRID-Arendal (2019c)

2.8 Strategies to Reduce the Impact of Plastics on Environment

One solution that is very valuable in ocean restoration is waste management and source reduction of plastic litter input (Allen, Coumoul, and Lacorte, 2019). A waste management system that is integrated, focuses on the hierarchy of four R's that are (reduce, recycle, reuse, and recover) and it also focuses on the improvement of plastics life cycle (Figure 5), this recycling is very important for the reduction of energy and consumption of resources, so that harmful emissions can be avoided (Schneider and Ragossnig, 2015), and it is also useful because it reduces the amount of mismanaged plastic waste that is going directly into the oceans.

Figure 14: Life-cycle of Plastics



Source: Prata et al., (2019)

The main purpose of this review is to talk about present strategies in the improvement of plastic sustainability during the whole life cycle, this process includes waste management, and giving the stakeholders recommendations that are practical. The organization of strategies has been done into three sections:

2.8.1 Improving Production Efficiency of Plastic Products

At the level of production, plastic use can be reduced by taking certain measures

- Use things that can replace plastic example glass, materials that are recyclable or biodegradable
- An improvement in design for the reduction of the amount of plastic that is used, extend the life of the product, there must be options of repairing and reusing in the product, and the numbers of polymer should be limited so that recycling is improved, the number of additives and mixture should also be limited
- Ban the use of single-use plastics and their several types (Liu, Adams, and Walker, 2018).

The design of plastic bottles should be improved making the caps inseparable from the bottle so that the chances of disposal is correct and increased (Brennholt, Heß and Reifferscheid, 2018), however, this could have an impact on the process of recyclability because there will be present two types of polymers then. There existed demand in the improvement of designs, companies are also gaining benefit from this as their requirement for raw material is reduced. The prices of recycled plastics are more than those plastics which are virgin, however, the effect of recycled plastics are more beneficial to the environment and they are more acceptable at the societal level (Singh and Ruj, 2015) and thus voluntary or mandatory incorporations must encourage their use as they are better than the previous ones (example 10% of weight), it is not as much high as compared to the previous one because of the loss in the process of recycling (Walker and Xanthos, 2018).

2.8.2 Reducing the Consumption of Plastic

The industry's voluntary actions that are also called corporate social responsibility CSR, can be explained as policies of command and control (Ashrafi et al., 2018), which includes consumption regulation like fees, advertisement restrictions, and ban on the products that are of single-use. Even though such measures are supported by consumers, as it has already been seen by citizens support of 94% on the matter of marine litter of the European Union (Eurobarometer, 2014), it is not always the same for retailers and manufacturer like the complaint of free movement violation of goods by the packaging manufacturers of Europe (Pack2Go), when the cutlery that was single-use plastic was banned in France (Prata, 2018). Similarly, the intention of reduction of carrier bags in Europe that were lightweight plastics, the main purpose of it was to reduce 8 billion plastic bags going into the ocean on yearly basis (Kasidoni, Moustakas and Malamis, 2015). In some countries, it was translated into fees (0.10 – 0.15€). In Portuguese, the reduction in free plastic bag use leads to the reduction in the consumption of about 74% (Martinho et al., 2017), and Ireland, this amount was 90% where certain measures were taken to criticize the increase in the sales of trash bags (Convery et al., 2007).

2.8.3 Education and Awareness

A very powerful tool that can be used against microplastic pollution is education [78], as explained by the recovery of marine litter in high amounts from the beach that was released by the citizens of Brazil because of their low literacy rate (Araújo et al., 2018) and when the citizens refused to use microbeads products then the need for awareness campaigns arose (Chang, 2015). However, on microplastic pollution, the information and awareness were very limited until the present times, where 73% of students of Chilean did not know about the problems related to microplastics (Fauziah, Liyana, and Agamuthu, 2015). However, a trend is increasing with increasing interest in the environmental problem that is supported by a lot of free online courses (example MOOC on marine litter) or certain activities or lectures related to the problem (example tech wild, the oceans Nova Scotia) (Owens, 2018), another alternative used for spreading information regarding the problem is media (example BBC's blue planet II, "Planet or Plastic" of National Geographic) and certain apps (example the Marine Debris Tracker, Sea Cleaner) (Merlino et al., 2015) also beach clean-ups are also spreading awareness and remedies regarding the problem (example great Canadian shore clean-up) (Dauvergne, 2018) and last but not least the inexpensive but very valuable citizen science that could help in mapping the marine litter (van der Velde et al., 2017).

3. METHODOLOGY

For this review, there exists an experimental aspect. Because of these purposes, for analysis, a qualitative form is used in this study of particular research. Firstly, this way is most commonly used in the identification and description of different situation's heterogeneity. Secondly, an effective evaluation of data is done that is obtained.

3.1 Research Paradigm

Positivism is the theoretical model adopted in this thesis. Dependence of positivism is put on evidence; the focus must be done by the views on scientific models. Auguste Comter, who was a French philosopher, proposed the concept of positivism (Comte, 1998). A positivist approach is used by this study to science that mostly focuses on the interpretation that is realistic as well as true of the evidence. A more tangible form of it is required, as the obtaining of it is done by observation. Judgment cannot be influenced by feelings or emotions as this study does not allow it, since the presence of these things is in the consciousness of the person.

3.2 Research Approach

The Researcher has used literature (both old and new) from different sources to study and analyze the facts. Fundamentally there exist two types of approaches to the research, which are, inductive and deductive. For interpretation, data that is used is empirical in the inductive method, and then the presentation of a new hypothesis is done on the basis of proof (Soiferman, 2010). In the deductive approach, on the basis of the hypothesis that was previously presented, a theory is given, and then for its testing, scientific data is used (Soiferman, 2010). It is claimed by Lee (1991) that, as a guideline that is basic, usually deductive reasoning is assumed by positivist methodology, while normally the inductive analysis is associated with the theory of phenomenology. In this study deductive methodology is used in specific because analysts of the market are helped by this technique to consider that analysis which has already been performed and done for the creation of a framework in order to expand or change theoretical basis that is particular (Reyes, 2004). A deductive approach has been used by the analyst since the elaboration of the casual interaction that exists between definitions and variables can be done (Lee, 1991). This also adds to the quantification of the term quantitatively, in addition to the result of research's generalization to some degree.

3.3 Research Strategy

Strategy used by the researcher involves analyzing data from multiple sources to find an overall consensus to obtain results and conclusions. Secondary data is used by this study for collecting data that is relevant and related to the subject. Secondary data is such data that can be easily accessed, i.e., this is the data that has already been obtained as well as analyzed by someone in the past. When the secondary data is used by the researcher, it is expected from him to review sources from which the obtaining of data was done. For this purpose, the researcher faces a different type of challenges that arise normally when the obtaining of original data is done. Unpublished or published data can be secondary data. The obtaining of information is done from documents which include economist's publications, academic publications, academic scholar's publications, etc., different data that was published by provisional central governments, state and different publications of the government of foreign countries or international people. A lot of sources for unpublished data are present, this data can also be achieved by biographies that are unpublished, unpublished diaries, unpublished letters, unpublished autobiographies, also they might be available to scholars and authors, trade associations, offices of labor, and different community or private individuals as well as different businesses.

3.4 Methods for studying MNP

Studies that examined the microplastic and Nano plastic and the pathways that are possible of them to humans were retrieved from databases of Google Scholar, Research Gate and ScienceDirect. A broad range of keywords that are searched combined (in variation) used are: Nano plastic, microplastic, impacts, human health, contents of MNPs, and pathway to humans.

The purpose of further studies was to do a lot of researches for a list of references of the articles that were selected. Along with these, on the basis of the paucity of the reports that were published, one more study was included that focused on the pathway of MNPs to the human clearly meeting the criteria that are selected.

The literature reviewed on micro and nano plastics was classified in four categories. The first category included sources of micro and nano plastics and their possible pathways, the second category includes impacts of micro and nano plastic on environment, third category consisted of human health pathways and fourth category is related to possible impacts of micro and nano plastics on humans and other species.

The categorization of literature is shown in the table below:

Table 3: Categorization of literature

Sources of Micro and Nano Plastics and their possible pathways	
Land	1. Galloway (2015) 2. Gourmelon (2015) 3. He et al. (2019) 4. Jambeck et al., (2015) 5. Thompson et al., (2009) 6. Song et al. (2017) 7. Browne et al. (2011) 8. Magnuson et al. (2016) 9. Lassen et al. (2015) 10. Essel et al (2015) 11. Sundt et al (2014) 12. Essel et al (2015) 13. RIVM (2014) 14. Strand et al. (2013) 15. Claessens et al. (2011) 16. Carr et al. (2016) 17. Magnusson and Noren. (2014) 18. Murphy et al. (2016) 19. Mintenig et al. (2017) 20. Lares et al. (2018) 21. Leslie et al. (2017) 22. Gies et al. (2018)
Air	1. Allen et al. (2019) 2. Ambrosini et al. (2019) 3. Bergmann et al. (2019) 4. Liu et al. (2019)

	5. Zhang et al. (2019) 6. Zhang et al. (2020) 7. Dris et al. (2017) 8. Sundt et al. (2014) 9. Lassen et al. (2015) 10. RIVM (2014) 11. Liebezeit et al. (2013) 12. Dris et al. (2016) 13. Klein et al. (2019) 14. Magnusson et al. (2016) 15. Klein et al. (2019) 16. Cai et al. (2017) 17. Zhou et al. (2017)
Oceans and Seas	1. Lebreton et al. (2017) 2. Rech et al. (2014) 3. Wagner et al. (2019) 4. Boucher et al. (2017) 5. Magnuson et al. (2016) 6. Lassen et al. (2015) 7. Gouin et al. (2015) 8. Gouin et al. (2011) 9. Lassen et al. (2015) 10. Sundt et al (2014) 11. RIVM (2014) 12. Circularocean (2015) 13. Norén et al. (2014) 14. Magnusson (2014) 15. Mintenig (2014) 16. Cole et al. (2014)

	17. Lusher et al. (2014)
Impacts of Micro and Nano Plastics on Environment	
Impact on Land	1. Certini and Scalenghe (2019) 2. Corradini et al. (2021) 3. da Costa, Duarte, and Rocha-Santos (2017) 4. Duis, and Coors (2016) 5. Keller et al. (2019) 6. Palacios-Mateo et al. (2021) 7. Sander (2019) 8. Xiang et al. (2019)
Impact on Marine Environment	1. Barboza et al. (2019) 2. Carbery, O'Connor, and Palanisami (2018) 3. Eerkes-Medrano et al. (2015) 4. Eerkes-Medrano et al. (2015) 5. Faure et al. (2015) 6. Figueiredo and Vianna (2018) 7. McCormick et al. (2016)
Impact on Air	1. Amato-Lourenço et al. (2020) 2. Cesa, Turra, and Baruque-Ramos (2017) 3. Enyoh et al. (2019) 4. Gasperi et al. (2018) 5. Lee et al. (2018) 6. Linares, Bellés and Domingo (2015) 7. Padmore et al. (2017) 8. Prata (2018) 9. Sukiene et al. (2017)
Pathways to Human Health	
Pathways to human health	1. Enyoh (2019) 2. Nelms et al. (2016)

	3. Nelms et al. (2018) 4. Cox et al. (2019) 5. Rochman et al. (2015) 6. Karami et al. (2017) 7. Kosuth et al. (2018) 8. RIVM (2014) 9. Liebezeit et al. (2013) 10. Zhang et al. (2020) 11. Gündoğdu et al. (2018) 12. Toussaint et al. (2019) 13. Karami et al. (2018) 14. Arikan and Ozsoy (2015) 15. Awaad et al. (2012) 16. Florence et al. (2000). 17. Garrett et al. (2012) 18. Greish et al. (2018) 19. Liu, Jiang, and Meng (2019) 20. Longet et al. (2018) 21. Mante et al. (2016) 22. Sæle et al. (2018) 23. Stock et al. (2019) 24. Volkheimer (1974) 25. Xia et al. (2017)
Possible Impacts to Human Health	
Possible Impacts to Human Health	1. Zhang et al. (2020) 2. Cox et al. (2019) 3. Salim et al. (2013) 4. Van et al. (2014) 5. Prata (2018)

	6. Vianello et al. (2019) 7. Campanale et al. (2020) 8. Prüst et al. (2020) 9. Hesler et al. (2019) 10. Lim et al. (2019) 11. Laura et al. (2019) 12. Grafmueller et al. (2015) 13. Hwang we al. (2019) 14. Inkielewicz-Stepniak et al. (2018) 15. Paget et al. (2015) 16. Liu et al. (2021) 17. Wick et al. (2010) 18. Karami et al. (2017) 19. Schwabl et al. (2019) 20. Schirinzi et al. (2017)
Possible Impacts to other Species	
Possible Impacts to other Species	1. Curpan et al. (2020) 2. Prüst et al. (2020) 3. Lu et al. (2016) 4. Nelms et al. (2018) 5. Prata et al. (2018) 6. Stock et al. (2019)

Researcher acknowledges categorization of literature in the above tables but there may be some literature not categorized in above mentioned tables used in the study which is listed further in the bibliography section.

4. RESULTS AND DISCUSSION

4.1 Sources, Pathways and Comparisons

There are multiple sources through which plastics enter the environment. The routine activities carried out by humans result in considerable quantities of nano and micro plastics in the environment (Kosuth et al., 2018). Clothes majorly constitute of the synthetic materials such as fleece, acrylic and polyester adding to 1 million tons of synthetic fiber annually (Kosuth et al., 2018). The synthetic fiber released from the clothes on laundering enters the wastewater stream out of which 50% of the water enters into the environment (Wang et al., 2018). In wastewater streams, the major producer of microplastics is toothpaste and exfoliants since 1.6g of the average toothpaste increases production to upto 4000 microbeads (Carr, Liu and Tesoro, 2016). Due to their small size, nano and micro plastics find their way in wastewater and removing them from the water becomes a challenging task even though water is recycled or discharged to the environment (Ziajahromi et al., 2017). During the process of degrading the tires, enormous amount of tire dust is released that further produces up to 1400 mg of microplastics per km (Dubaish and Liebezeit, 2013). Similarly, paint used in the house exteriors and road marking contribute to 10% of the total microplastics effecting the environment (Kosuth et al., 2018).

Based on the origin and source, microplastics present in the environment are categorized in two groups: primary microplastics and secondary microplastics (Cole et al., 2011). The primary microplastics are the one that are released directly from the source such as microbeads present in the beauty products and hygiene (most commonly exfoliants), in the pellets for manufacturing of larger plastic products, in the industrial abrasives and emitting from the 3D printer (Steinle, 2016). Primary sources are identified through their specific sizes, shapes and densities. On the other hand, microplastics from the secondary sources are produced from the fragmentation and breakdown of large plastics released through littering or accidental release in the environment. When mesoplastics (5 to 25 mm), microplastics and macroplastics (smaller than 25 mm) are degraded, the result is the microplastics of irregular size, shape and density having varying chemical composition (Duis and Coors, 2016). Identification of primary sources of microplastics is becoming a complex phenomenon due to the presence of elements resulting in secondary microplastics in the environment. The most common source of secondary microplastics in the environment is the exposure of physical abrasion and ultra violet radiation (Isobe, 2016).

Micro and nano plastics are found entering the environment through both indirect and direct ways. They contaminate the environment directly when plastic is used or applied persistently, such plastic used in greenhouse building material, plastic mulch and soil conditioners (Ng et al., 2018). The presence of micro and nano plastics is evident in the wastewater even after treatment through wastewater treatment plant (WWTP) and the one not entering the wastewater end up in the sludge (Lares et al., 2018.). The routes through which enormous quantity of nano and micro plastics enter the environment is using industrial and urban wastewater (both untreated and treated) for irrigation and land applications of sludge (Anderson, Park, and Palace, 2016). Moreover, industrial effluents and WWTP are discharged to the surface waters and sometimes directly released into aquifers for Managed Aquifer Recharge (MAR) that serves another pathway for MNPs to contaminate freshwater resources (Re, 2019). The common indirect pathways through which MNPs enter the environment are indiscriminate discards, accidental release and inappropriate disposal methods (Rodríguez-Seijo and Pereira, 2017). The accidental release occurs in heavily industrialised regions during manufacturing, transportation and use of plastics contributing to significant MNPs pollution (Andrady, 2017).

Table 4: Research Summarized on Land Sources and possible pathways of MNPs

Sources/Material/Pathway	**Quantities**	**Data Source**
Ultra Violet Exposure on Land on plastics (beach environment)	UV exposure up to 12 months, abrasion with sand 2 months, PE, PP, EPS. PE, PP (6084 ± 1061 and 20 ± 8.3 particles/pellet) in 12 months from UV exposure	Song et al. (2017)
Synthetic Textiles (leading to sewer)	Release MP fibers greater than 1900 fibers per wash	Browne et al. (2011)
Shirt (polyester)	1,160 fibers released per wash	Browne et al. (2011)
Blanket (polyester)	900 fibers released per wash	Browne et al. (2011)
Swedish road wear and abrasion of tyres	13,000 tons/year of MPs	Magnuson et al. (2016)
Artificial turfs (Sweden)	2300-3900 tons per year of MPs	Magnuson et al. (2016)
Loss of industrial plastic pellets (bad handling) (Sweden)	300-530 tons per year (primary)	Magnuson et al. (2016)
Pellet releases from the transport of plastic (Norway)	2500 tons per year (primary)	Lassen et al. (2015)
Pellet loss during production (Germany)	MPs loss 21,000-210,000 tonnes/year	Essel et al (2015) Lassen et al. (2015)
Microplastics emission from land-based sources: pollution (Norway)	More than 8000 tons annually	Sundt et al (2014)

Rubbers, synthetic textile fibers, paints		
MPs Release from consumer applications (Norway)	40 tons/year (0.5% of total release of MPs)	Sundt et al (2014)
Synthetic fibers from clothing and other textiles (Germany)	80-400 tons/year	Essel et al (2015)
Tyre shedding (Germany)	60,000-111,000 tons/year	Essel et al (2015)
Tyre Wear (Netherlands)	17 kilo tons per year (tiny rubber particles)	RIVM (2014)
Sewage Sludge Disposal (Netherlands)	177 million kgs of industrial (wet) sludge used in agriculture sector	RIVM (2014)
Total use of microplastic beads in liquid soap products in Europe	4360 tons per year	Magnusson et al. (2016)
MPs Discharge from laundry (Sweden)	195-2,216 tons per year	Magnusson et al. (2016)
MPs emission from protective coating (Sweden)	93 tons per year	Magnusson et al. (2016)
Artificial turfs (total loss granulates from football field) (Sweden)	2300-3900 tons per year	Magnusson et al. (2016)
Estimated emission of MPs from tyre abrasion and road wear (Sweden)	13,519 tons per year	Magnusson et al. (2016)
Emission of MPs to soil in Sweden (from coatings on commercial vessels)	264 tons per year	Magnusson et al. (2016)
MPs concentration in sediment (Danish coast)	100 per kg of dry sediment (North Sea) 120 per kg of dry sediment (Skagerrak Kattegat)	Strand et al. (2013)

	380 per kg of dry sediment (Belt Sea) 335 per kg of dry sediment (Baltic Sea) >38 µm (size)	
MPs concentration in sediment (Belgian coast)	167 ± 92 (standard deviation) - Harbors 97 ± 19 (standard deviation) – continental shelf 93 ± 37 (stand deviation) - beaches	Claessens et al. (2011)
MPs Concentration in Sewage sludge, activated sludge (USA) (from WWTP)	8 x 10-4 particles per litre (size range 45-400 µm)	Carr et al. (2016)
MPs Concentration in Sewage Sludge (Sweden) (from WWTP)	8 x 10-3 particles per litre (size range >300 µm)	Magnusson and Noren. (2014)
MPs Concentration in Sludge cake from centrifuge, grit and grease (Scotland) (from WWTP)	2.5 x 10-1 particles per litre (size range >65 µm)	Murphy et al. (2016)
MPs Concentration in Sewage Sludge (Germany) (from WWTP)	1 x 10-3- 9 particles per litre (size range 20-5000 µm)	Mintenig et al. (2017)
MPs Concentration in Membrane bioreactor Sludge (Finland) (from WWTP)	4 x 10-1 - 1 particles per litre (0.25-5000 µm)	Lares et al. (2018)
MPs Concentration in Sewage Sludge (Netherlands) (from WWTP)	9 -91 per particles litre (10-5000 µm)	Leslie et al. (2017)
MPs Concentration in Dry Sludge, excess sludge (Canada) (from WWTP)	5 x 10-1 particles per litre (1-65 µm)	Gies et al. (2018)

Table 5: Research Summarized on Air Sources and possible pathways of MNPs

Source	City	Quantities	Data Source
Atmospheric fallout from textile fibers (indoor and outdoor)	Paris, France	Concentration Between 1.0 - 60.0 fibers/m3 (indoor), 0.3 – 1.5 fibers/m3 (outdoor) 33% fiber containing PP	Dris et al. (2017)
Household dust, City dust outdoor (road paint, house paint, tyre dust), indoor dust. by the action of wear and tear	Norway	Possible House hold dust(450t), road paint(320t), house paint(130t), tyre dust (4500t), indoor dust (130t)	Sundt et al. (2014)
Tyre dust	Denmark	1,915 tons/year	Lassen et al. (2015)
Tyre Wear	Netherlands	17 kilo tons per year (tiny rubber particles)	RIVM (2014)
Colored (plastic) fibers in rainwater	Germany	18.1 colored fibers per litre and 3.7 colored fragments per litre of rain	Liebezeit et al. (2013)
Atmospheric fallout over the course of 1 year (synthetic fiber from clothes, houses. Breaking of MPs, landfills and incineration)	Paris	2-355 particles/m2 day (200-400 µm and 400-600 µm)	Dris et al. (2016)

Atmospheric deposition (from 6 sites)	Germany	275 particles per m2/day PE/ethyl vinyl acetate copolymers (48.8%,22%)	Klein et al. (2019)
House hold dust (Total amount)	Sweden	1-19 tons per year	Magnusson et al. (2016)
Atmospheric deposition in metropolitan Hamburg (source: possible road dust, tyre abrasion, road paint, surface)	Germany	2625 MPs particles 275 MPs/m2/day	Klein et al. (2019)
Atmospheric fallout in Dongguan City (source: possible clothes, textiles, plastic bags)	China	175-313 particles/m2/day (PE, PP, PS)	Cai et al. (2017)
Atmospheric Deposition in Yantai (possible source: textile, manufacturing/recycle, industries)	China	365 MPs particles/m2/day (PET, PE, PVC, PS)	Zhou et al. (2017)
Suspended MPs in atmosphere in Shanghai (possible main source: textile clothes)	China	0-4.18 n/m3 (items per cubic meter of air) (PET, PE, polyester and more)	Liu et al. (2019)
MPs concentration in	Passage between	0-14.4 x 103 N liter-1	Bergmann et al.

snow in Fram Strait (from atmospheric deposition) Source: ice floe, air transport	Greenland and Svalbarad	(Varnish, rubber, PE, polyamide) (size: 11-475 μm)	(2019)
MPs concentration in snow in Swiss Alps, Bremen, Bavaria (from atmospheric deposition) Bremen, Bavaria source: automotive emissions	Switzerland, Germany	0.19 x 103 to 154 x 103 N liter-1 (Varnish, rubber, PE, polyamide) (size: fibers longer than artic snow)	Bergmann et al. (2019)
Indoor MPs samples from 39 major cities	China	1550-120,000 mg kg-1 26,800 mg kg-1 median abundance (PET)	Liu et al. (2019)
MPs in terrestrial glacial environment (Forni glacier, Italian Alps)	Italy	Mean ± standard error, 74.4 ± 28.3 items per kg of sediment (dry weight)	Ambrosini et al. (2019)

Table 6: Research Summarized on Ocean/Sea Sources and possible pathways of MNPs

Source	**Quantities**	**Data Source**
Road Runoff into oceans	44% MPs	Boucher et al. (2017)
From Wastewater into oceans	37% MPs	Boucher et al. (2017)
From Wind to ocean deposition	15% MPs	Boucher et al. (2017)
Ocean based release	4%	Boucher et al. (2017)
Swedish municipal wastewater discharge	250-2000 tons plastic particle per year, size >300 μm	Magnuson et al. (2016)

Swedish wastewater treatment plant release	4-30 tons plastic particles per year µm, size >300µm	Magnuson et al. (2016)
Danish MPs in sewage	MPs>100µm (33-9923 fibers/m3) polyester, nylon. MPs>500µm (1-52particles/m3) PE,PP,PVC	Lassen et al. (2015)
Danish Release of MPs in ocean from cosmetics	0.5-2.9 tons/year	Lassen et al. (2015)
Microbeads in personal care products sold in 2012 Denmark	29 tons	Gouin et al. (2015)
Per capita usage of PE microbeads in cosmetic products 2011 USA	2.4 mg/d or 1g/year	Gouin et al. (2011)
MPs in cosmetics release in sewage	9-29 tons/year	Lassen et al. (2015)
Liquid Soap microbead concentration in 2012	6% plastic microbeads, 0.6 of total volume of skin cleansing products sold	Lassen et al. (2015)
Norway Plastic release in sea (from production sites)	180 tones/year	Lassen et al. (2015)
Norway Plastic release in sewage (from production sites)	20 tones/year	Lassen et al. (2015)
Lost discarded MPs items in sea (Norwegian macrolittering from consumer use)	10,000 tonnes (best guess)	Sundt et al (2014)
Netherlands effluent from	39-89 MP particle per litre	RIVM (2014)

WWTP		
Abrasive cleaning agents (Netherlands)	1000-2000kg of microplastic per year used in products	RIVM (2014)
Fishing Gear (Global)	640,000 tonnes lost per year	Circularocean (2015)
Laundry of Synthetic textiles release (Global)	34.8% for primary MPs release	Boucher et al. (2017)
Erosion of tyres release while (Global)	28.3% for primary MPs release	Boucher et al. (2017)
City Dust (Global)	24% for primary MPs release	Boucher et al. (2017)
Personal Care products (Global)	2% for primary MPs release	Boucher et al. (2017)
Marine coating (paint ship)(Global)	3.7% for primary MPs release	Boucher et al. (2017)
Emission of MPs to water (from coatings from commercial vessels) in Sweden	264 tons per year	Magnusson et al. (2016)
MPs coming from fishing equipment due to weathering (Sweden) 2012	Minimum 4 tons and maximum 46 tons	Magnusson et al. (2016)
Total MPs from personal care products, household, dust and laundry reaching WWTP (Sweden)	Inflow (236-2,071 tons/year) Outflow (4.7-42 tons/year)	Magnusson et al. (2016)
MPs concentration (Swedish west coast) (Skagerrack) 2014	13000 per m3 >10 µm (size)	Norén et al. (2014) Magnusson et al. (2016)
MPs concentration in Gulf of Finland	0.73 per m3 (Turku harbor) 0.25 ± 0.07 per m3	Magnusson (2014)

	(Archipelago) 0.48 per m3 (Offshore) ≥300 μm (size)	
MPs concentration in Danish coast water	0.39 ± 0.19 per m3 (North Sea) 3.54 per m3 (Kattegat) 1.44 per m3 (The Belt Sea) >100 μm (size)	Mintenig (2014)
MPs concentration in western English Channel	0.27 per m3 ≥500 μm (size)	Cole et al. (2014)
MPs concentration in Northeast Atlantic Ocean	2.46 per m3 250-1000 μm (size)	Lusher et al. (2014)

Another indirect source of plastics is the plastic present in the oceans and travelling to the land. The specific oceanic zones or gyres contain build-up of plastics due to Ekman currents that are strong vortices in the oceans (da Costa et al., 2017). The plastic is further added to the oceans through anthropogenic activities lining across the coast of the oceans (da Costa et al., 2017). The human or anthropogenic activities discharging plastics to the ocean is regarded as the indirect source of plastics to the oceans. Conversely, the ocean currents facilitate the migration of build-up MNPs from oceanic zones to other land areas. The ultimate result of this process is the contamination of coastal land with MNPs from different zones of the oceans travelling faraway due to the oceanic currents.

Micro and nano plastics are commonly found to travel into the lakes and rivers and their tributaries (McCormick et al., 2016). They travel to the targeted sites through rural and urban landscapes along with discharge from storm water drains and WWTPs, rivers, supply lakes and streams containing MNPs. The large bodies of freshwater such as wetlands, lakes and ponds are contaminated with MNPs through rivers and their tributaries that further assist in travelling to the oceans. The micro and nano plastics reaching the river are further indirectly deposited on shorelines and banks going far away from the original sources due to the river currents.

As soon as plastics reach the sediments or soil, they could be easily moved to faraway places by the climate and weather patterns. They make their way to the water streams through run-off when planned irrigation or storm events occur. The mobilization of plastics due to wind is not only limited to freshwater systems but also travel to other terrestrial environments. The studies conducted on the movement of microplastics through wind showed that the fibers of MNPs are found in huge quantity in the atmosphere (Dris et al., 2017). Thus, both freshwater and terrestrial environments are likely to be contaminated by the deposition of MNPs.

As the larger parts of plastics break down into smaller particles their quantity increases (Isobe et al., 2015). MP have different sizes in different environments as is shown from different samples acquired in different environments. In Water based environment the average size of MP is few millimeters but in case of acquiring samples from smaller nets (50–63 μm) have average size of less than 700 μm (Zeng, 2018) in case of comparison with MP in air environment it is between 50 to 80 percent being in the range of 100 and 500 μm, (Dris et al., 2017) which is more smaller and their deposition accounts for less than 100 μm when seen from sample fragments (Allen et al., 2019). Still there is gap between the linkage between all 3 environments and more research needs to be performed to better correlate between them.

Table 7: Research Summarized on MNPs Pathways for Humans

Pathways	Quantities/sizes	Data Source
Intake from plants (fruits and vegetables)	80g per day	Enyoh (2019)
MPs in mussels	3-5 fibers per 10g	Nelms et al. (2016)
MPs from bottled water (USA)	90000 MPs particles (annually)	Cox et al. (2019)
MPs from tap water (USA)	4000 MPs particles (annually)	Cox et al. (2019)
MNP in sugar (USA)	0.44/g	Cox et al (2019)
MNP in salt (USA)	0.11/g	Cox et al (2019)
MNP in alcohol (USA)	0.03/g	Cox et al (2019)
MNP in bottled water (USA)	0.09/g	Cox et al (2019)
Fishes for sale (Indonesia)	Anthropogenic debris 28% in individual fish and 55 % in all species	Rochman et al. (2015)
Fishes for sale (USA)	Anthropogenic debris 25% in individual fish and 67 % in all species	Rochman et al. (2015)
Dried Fish (4 types) (commonly consumed)	36 MPs particles (59%), PP (47.2%), PE (41.6%), PS (5.56%)	Karami et al. (2017)
Tap water (Sample from 14 countries) (Globally sourced tap water)	(98.3% Fibers) Anthropogenic particles range 0-61 particles/Liter, overall mean 5.45 particles/Liter	Kosuth et al. (2018)
Beer (12 brands) (Laurentian Great Lakes beer)	(98.4 % Fibers) Anthropogenic particles range 0-14.3 particles/Liter, overall mean 4.05 particles/Liter	Kosuth et al. (2018)
Sea Salt (12 commercial brands)	(99.3 % Fibers) Anthropogenic particles range 46.7-806 particles/kg, overall mean 212 particles/kg	Kosuth et al. (2018)
Mussels (Netherlands)	105 MP particles per gram	RIVM (2014)
Oysters (Netherlands)	87 MP particles per gram	RIVM (2014)

Honey (wet/dry deposition on flower)	0.17 MP particles per gram	RIVM (2014)
Honey from supermarkets and producers (Germany, France, Italy, Spain and Mexico)	40 to 660 colored fibers per kg 0-38 fragments/kg	Liebezeit et al. (2013) Zhang et al. (2020)
Honey from keepers of beet and local supermarkets (Germany)	10 to 336 fibers/kg 2-82 fragments/kg	Liebezeit et al. (2015) Zhang et al. (2020)
Table salt 16 brands (Turkish market)	16-84 MPs particle/ kg (sea salt), 8-102 MPs/kg (lake salt), 9-16 MPs/kg (rock salt). PE (22.9%), PP (19.2%)	Gündoğdu et al. (2018) Toussaint et al. (2019)
Canned sardines and sprats in Australian markets (Origin: Canada, Germany, Iran, Japan, Latvia, Malaysia, Morocco, Poland, Portugal, Russia, Scotland, Thailand, Vietnam)	1-3 MPs particles per contaminated brand from 4 brands which are contaminated.	Karami et al. (2018) Toussaint et al. (2019)
Estimated modelled movement of suspended atmospheric MPs in Shanghai (inhalation)	Transport of 120.7 kg suspended atmospheric MPs per year	Liu et al. (2019)

Table 8: Research Summarized on Impacts of MNPs on Humans

Pathways/materials /cells (ex vivo, in vitro)	**Internal Anatomy associated**	**Quantities/sizes/exposure**	**Possible Effects**	**Data Source**

Exposure from Air	Lungs	(0-3.0) x107 items/year MPs particles	Unknown	Zhang et al. (2020)
Exposure from table salt	Liver, Kidneys	(0-7.3) x104 items/year MPs particles	Unknown	Zhang et al. (2020)
Exposure from Drinking water	Liver, Kidneys	(0-4.7) x103 items/year MPs particles	Unknown	Zhang et al. (2020)
Overall MP Exposure	Body	100,000 MPs per capital in 1 year	Unknown	Curpan et al. (2020)
Exposure through consumption of food	Body	39,000-52000 MPs person-1 year-1	Inflammatory response, changes in gut microbe composition and metabolism	Cox et al. (2019)
European Exposure: consumption of bivalves	Body	11,000 microplastics person-1 year-1	Unknown	Van et al. (2014)
Possible Exposure from inhalation	Lung	26-130 airborne MPs day-1	Possible inflammation	Prata (2018)
Light activity Inhalation	Lung	272 microplastics per day	Possible inflammation	Vianello et al.(2019)
Polypropylene (PP), Metal NP, carbon nanomaterials, polyethene, polystyrene MPs	Brain, Epithelial cells	20 µm and 25-200 µm (PP)	Harmful effects, Cytotoxic effects on human brain and epithelial cells	Campanale et al. (2020)

Human-derived cerebral cell line (T98G) and epithelial cells (HeLa)	Cell line	3-16 µm PE-MPs 10 µm PS-MPs	Reactive oxygen species (ROS) generation	Prüst et al. (2020)
Embryonic stem cell (cell cultures)	Development	33 nm PE NPs	(48 h exposure) Cytotoxicity increased and oxidative stress (18-day exposure) Altered gene expression	Prüst et al. (2020)
Placental trophoblast cells (BeWo b30)	Placenta development	5µg/mL (50 nm PS particles)	Adverse effects and High metabolic activity at high concentrations	Hesler et al. (2019), Laura et al. (2019)
Lung epithelial BEAS-2B	Lung	Spherical PS NPs exposure upto 60 nm	Decrease in cell viability	Lim et al. (2019), Laura et al. (2019)
HeLa (cervical cancer cells)	Cell line	Positively charged NPs	Cellular toxicity which effects cell membranes	Liu et al (2011), Laura et al. (2019)

Placental cells	Placenta	50 and 300 nm PP particles introduced	High transfer between fetal to maternal direction, High accumulation in tissue	Grafmueller et al. (2015)
Lung epithelial BEAS-2B	Lung	Spherical PS NPs up to 10 μg/mL	Auphagic , endoplasmic reticulum (ER), stress related metabolic changes	Lim et al. (2019), Laura et al. (2019)
Epithelial cells (Calu-3), human macrophages (2015)	Organs and blood vessels	50 nm PS nanoparticles	DNA damage from animated NPs	Laura et al. (2019)
Normal cells, immune cells, blood cells and murine immune cells	Blood, nervous system	~20 μm and 25-200μm PP particles	PP particles Below 20 μm show toxicity, ROS increase	Hwang we al. (2019)
Intestinal epithelial cell lines, LS174T, HT-29, and Caco-2	Digestion, water and nutrient absorption	~60 nm size PS NPs	Positive charged NPs cause cell death, ROS increase, toxicological effects	Inkielewicz-Stepniak et al. (2018)

pulmonary epithelial cells and macrophages (Calu-3 and THP-1 cell lines)	Lung (from inhalation)	50 nm PS nano beads	DNA damage from aminated nanobeads	Paget et al. (2015)
SARS-CoV 2 (coronavirus)	Lungs	MPs particles less than 10 microns (virus survival on surface for 72 hours)	SARS-CoV 2 (coronavirus)	Liu et al. (2021)
Lung Biopsy	Lung	87% cellulose fibers (n=114) upto 250μm size	Possible inflammation and lung cancer	Prata et al. (2018)
Placental cells	Placenta	PS beads 50,80,240 and 500 nm in diameter introduced (up to 240 nm passable into placenta)	Did not affect viability of explant	Wick et al. (2010)
Salt Consumption (17 salt brands from 8 different countries)	Unknown	Less than 149 μm MPs (maximum 37 particles per year per capita)	Negligible impact	Karami et al. (2017)
MPs in Human stool (8 stool samples)	Unknown	8 volunteers age (33-65) Stool Sample, median of 20 MPs (50-500 μm) per 10g stool (PP,PE,PET)	Unknown	Schwabl et al. (2019)
Cerebral and Epithelial Human cells (T98G, HeLa)	Brain, Tissue	Exposure 24-48h, 10 ng/mL to 10μg/mL PE, PS	Oxidative stress is one of the drivers of increase cytotoxicity at	Schirinzi et al. (2017)

			cell level	
Suspended atmospheric MPs inhaled daily by people in Shanghai atmosphere	Lungs	21 particles of atmospheric MPs inhaled	Unknown	Liu et al. (2019)

Table 9: Research Summarized on Impacts of MNPs on Other Species

Animal Species	**Impact**	**Quantities (Subjected to)**	**Effects**	**Data Source**
Zebra Fish	Gut tissue	5 µm: low (50µg liter-1) high (500µg liter-1)	Inflammation responses, oxidative stress, lipid metabolism changes	Curpan et al. (2020)
Mice	Liver, kidney and gut	For 5 µm MP 0.077, 0.099, 0.417 mg g-1 (ww)	Physical stress, apoptosis, necrosis	Curpan et al. (2020)
Mice	Liver, kidney and gut	For 20 µm MP 0.194, 0.082, 0.234 mg g-1 (ww)	Inflammation, immune responses	Curpan et al. (2020)
Rodents	Nervous system, brain	5-100 nm TiO2 Nanoparticles	Oxidative stress, neuroinflammation, changes in neuro transmitter levels, impairment of motor functions, learning and	Prüst et al. (2020)

			memory	
Mice	Gut, Liver kidneys	5 and 20 µm polystyrene MPs	AChE increase in liver, Oxidative stress, changes in neurotransmitter levels	Prüst et al. (2020)
Zebra Fish	Liver	5 µm and 70 nm PS MPs	Inflammation and lipid accumulation	Lu et al. (2016)
Captive grey seals scat	immune system and reproductive system	out of 31 samples, 15(48%) had 26 MPs particles. EP and PP (27%)	may affect immune system and reproductive system process	Nelms et al. (2018)
wild-caught Atlantic mackerel	immune system and reproductive system	out of 31 fish examined, 10(32%) had 18 MPs particles observed from digestive tract, EP and PP (28%)	May affect immune system and reproductive system process	Nelms et al. (2018)
Fish	Neocortex/brain	(1-5 µm) PE	Reductions in AChE affecting neurotransmission	Prata et al. (2018)
Rodents	body	1,4 and 10 µm PS particles	Does not pose health risk	Stock et al. (2019)

4.2 Human Exposure Pathways

4.2.1 Ingestion

World Health Organization's report on the potential impact of plastics on human health showed that the presence of abundant microplastics in the environment developed great deal of concern on the increased exposure and impact of nano and microplastics on human health (WHO, 2019).

The major pathway for nano and micro plastics into the human system is the intake of contaminated food (Toussaint et al., 2019). The study of Cox et al (2019) showed that the sugar contains 0.44 g of micro and nano plastics, 0.03 MNPs/g in alcohol, 0.11 MNPs/g in salt and 0.09 MNPs/g in bottled water. This shows that humans are consuming about 80 g of micro and nano plastics per day through vegetables and fruits obtaining MNPs from soil contaminated with plastic particles (Ebere, Wirnkor and Ngozi, 2019).

Since, microplastics are found in fragments or fibers, ingesting them is quite easy for the organisms even for the small ones present in the environment bringing serious health and environmental implications (Cox et al., 2019). Any organism ingesting microplastics is likely to cause gastrointestinal tract issues and hindrance resulting in starvation, false satiety and death (Prata et al., 2020). These conditions in the organisms are discussed on the bases of physical implications of the microplastic and do not consider chemical effects. Migration from the plastics is the common practice of plasticide bringing serious impacts to biota. Mostly, the additives present are lipophilic and easily penetrate into the cell membrane and inhibit the biochemical reactions in the cells causing reproductive and behavioral issues. The common form of plastics such as OS, PVC and PC are highly toxic monomers leading to abnormalities in the reproductive system and potentially ending up in cancer (Prata et al., 2020).

Thus, there is increased exposure of humans to plastics through their diet since the uptake by humans is a known fact supported by the evidence presented on the ability of the synthetic particles of size smaller than 150 µm to pass through the gastrointestinal epithelium in the mammals. Further studies on the uptake and impact of these particles showed that only 0.3% of the MNPs are absorbed in the human body while only 0.1% are of size larger than 10 µm and are able to reach both cellular membranes and organs finding their way to brain barrier, blood and placenta (Barboza et al., 2018). However, the concentration of exposure are found to be low although data on the presence of MNPs in the environment is still limited due to the technical and analytical challenges of characterization, extraction and quantification from environmental matrices (Campanale et al., 2019).

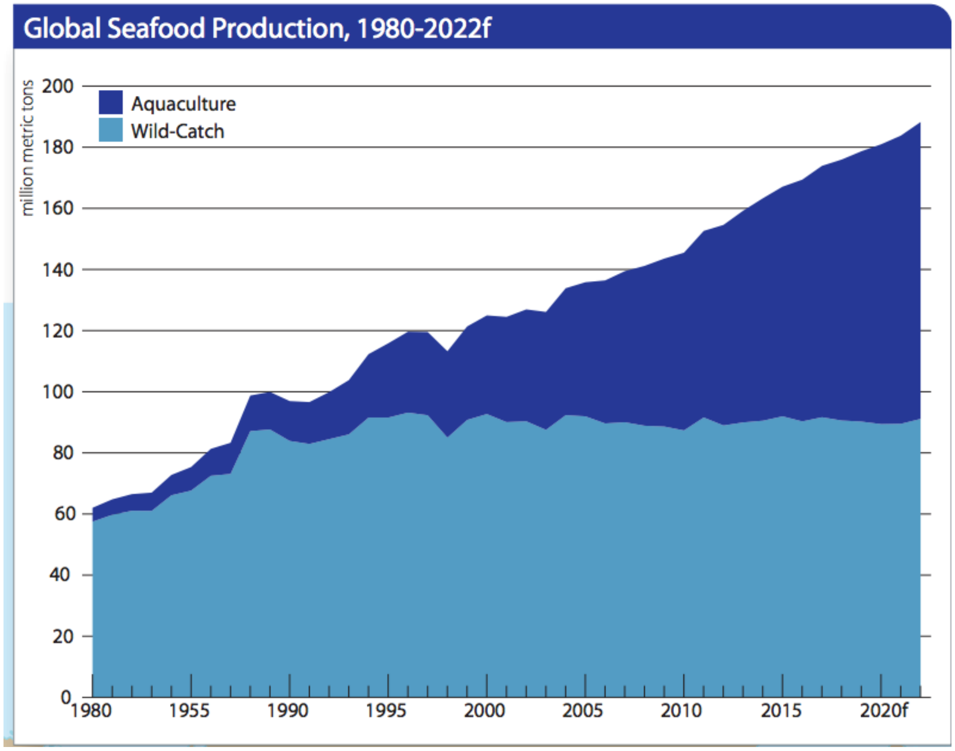
After the ingestion, MNPs of size less than 2.5 µm reach the gastrointestinal tract mainly through the endocytosis carried out by M cells present in the Peyer's patches. M cells are epithelial cells of the mucosa performing special functions associated with lymphoid tissues. These cells assist in transporting particles to the mucosal lymphoid tissues from the intestinal lumen. Sometimes particles are also transmitted through the paracellular persorption. The process of persorption consists of the kneading of solid particles mechanically in the gaps found into the circulatory system and in the single-layer epithelium at the villus tips of the gastrointestinal tract.

Microplastics result in the toxicity through the process of inflammation that occurs due to persistent nature of MNPs and unique properties such as chemical composition and hydrophobicity. It is also found to possess an accumulative effect depending largely on the quantity ingested by the humans (Wright and Kelly, 2017). The assumption on the MNPs level at the gastro-intestine of men was supported by the findings that every 10 g of human stool contains twenty particles of plastic, especially PP and PE varying in size range between 5 and 500mm are present in every (Schwabl et al., 2019). This further shows that the excretory system of human must function in such a way that it should remove up to 90% of the ingested MNPs (Smith et al., 2018).

4.2.2 Sea Food Consumption

Consumption of seafood is the most common pathway for microplastics entering the human body. Statistics on seafood intake across the globe showed that in 2015, there was 17% of animal protein was consumed out of the total protein consumed (Mathiesen, 2015). Trade of seafood across the globe increases at 4% per year as estimated from 2012 to 2017 mounting to about 153 billion USD (de Jong, 2019). According to the recent report of World Seafood Map, the route from Norway to Europe is considered to show largest trade of seafood in terms of value consisting mostly of whitefish and salmon (de Jong, 2019). The next largest trade route of crustaceans and salmon is from Canada and flow of crustaceans and whitefish to the United States from China (de Jong, 2019).

Figure 17: Global Seafood Production (1980-2022)



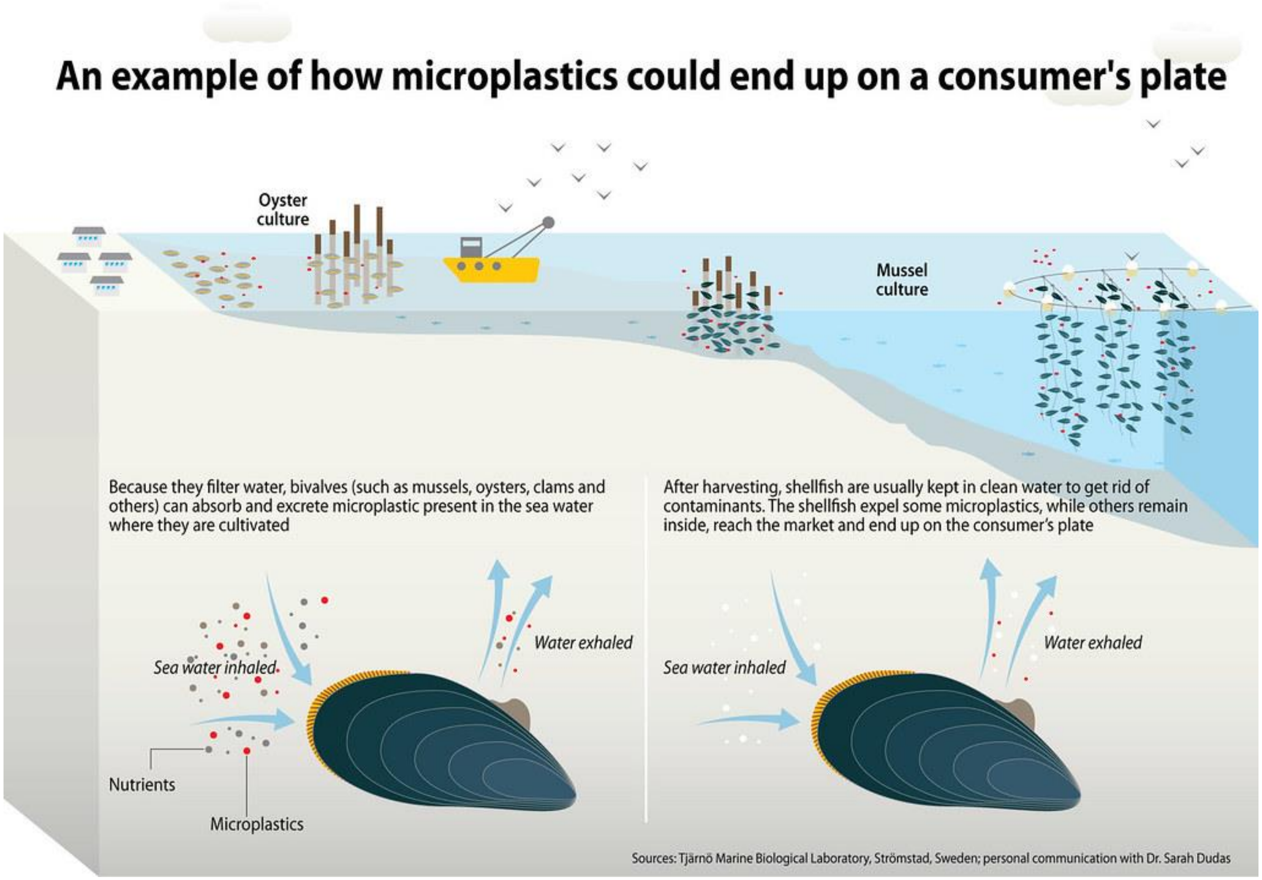
Source: Rabo Bank (2020)

The major imports were carried out of the seafood coming from regions having large plastic pollution and significant waste leakage (Lusher et al., 2017). Half of the seafood imported is wild-caught while the other half is farmed (such as aquaculture). The seafood obtained from the aquaculture is less likely to exposed by MNPs since animals are grown in controlled environmental conditions in the water bodies, tanks or ponds having shorter lifecycle than wild animals limiting the opportunity for microplastics exposure. Due to lack of evidence in the literature, the differences in microplastics from wild and farmed fish and shellfish is still uncertain.

Microplastics are also easily ingested by large number of marine organisms due to their small size. MNPs find their path to the ocean through trophic transfer and are ingested indirectly and directly by the marine organisms. The ingestion of microplastic is found in planktonic organisms and larvae are present at the bottom of the food chain (Steer et al., 2017) in fish (Lusher et al., 2017) and large and small invertebrates (Nelms et al., 2018). Predatory Crucian carps are found to contain large sum of microplastics coming from tropical areas (Mattsson et al., 2018).

The presence of microplastics is evident in the species that are mostly consumed by humans such as crustaceans, invertebrates and fish (Rochman et al., 2015). The plastic particles entering the organism are concentrated in the digestive tracts and when theses organism such as small fish or bivalves are consumed whole increase the exposure of microplastics to the human diet (Kershaw and Rochman, 2015). Figure 18 shows the bioaccumulation of plastics up the food chain and reaching the human diet. It was concluded by Yang et al. (2019) that dietary intake of plastics and other toxins through marine organisms still serve as the minor component of exposure to these toxins as compared to the chemical fires, waste and industrial exposure.

Figure 18: Flow of Microplastics from Sea to Human Diet



Source: Pravettoni (2016)

The findings of Zhang et al., (2020) showed that the concentration of microplastic is higher in farmed mussels as compared to wild-caught mussels. Moreover, Rochman et al. (2015) founded that microplastics of size smaller than 500 μm are present in wild-caught fish commercially sold in the markets of California, USA (containing microplastics in 25% of processed fish) and Indonesia (containing microplastics in 28% of processed fish). The investigation of Karami et al. (2017) showed that microplastics are also present in the tissues of dried fish mainly in eviscerated flesh and excised organs. The four species of dried fish consumed by humans showed 36 isolated foreign particles that were found to be plastic polymer

(Karami et al., 2017). Translocation of particles of microplastics are also found to the liver and gills from digestive tracts of zebra fish, Danio rerio, that is commonly preyed fish (Lu et al., 2016).

The findings of these studies show that microplastics are present in the seafood posing a great threat since it is spreading widely with uncertainty in the environment and increased translocation of the particles from the animals eaten by the humans.

4.2.3 Inhalation

Inhalation acts as another entry point for the micro and nano plastics into the human body (Gasperi et al., 2018). The findings of Catarino et al. (2018) showed that the quantity of synthetic fibers ingested through consumption of mussel is far less in quantity that is inhaled from the dust in the air during the same meal. Wright and Kelly (2017) also reported that during precipitation, per litre of rain contain 18 fibers and 4 fragments of MNPs. These MNPs emitted from the erosion of fertilized lands and agriculture, wastewater treatment leftover, dried sludges, industrial emissions, synthetic clothes fabric, marine aerosol, road-dust and atmospheric depositions are carried by the wind spreading widely in the environment. Such wide transportation of MNPs in the wind results in cytotoxic effects, respiratory distress, autoimmune disease in men and inflammatory effects (Rezaei et al., 2019). Since, the alveolation of human lung is quite wide measured to be ca. 150 m2 with thin lining of tissue of size smaller than 1 μm allowing the particles to enter the bloodstream and travel through whole human body (150). The major cytotoxic and genotoxic effects are produced by polystyrene (PS) particles of size 50nm specifically on the macrophages (THP-1 and Calu-3) and epithelial cells (Paget et al., 2015).

The impact of inhaled particles on the human body varies from person to person due to different susceptibility and metabolism of the individuals but the most common effect observed is the quick bronchial reactions (such as asthma), granulomas with fiber inclusions such as prolonged pneumonia and allergic alveolitis, diffuse interstitial fibrosis, interalveolar septa lesions (pneumothorax), fibrotic and inflammatory change in the peribronchial and bronchial tissue leading to chronic bronchitis (Prata, 2018). The impacts of inhaling air contaminated with MNPs is also found in the workers of the textile industry who work closely with acrylic fibers, nylon, polyolefin and polyester. The microfibers having low depreciation level are commonly found in the patients of pulmonary cancer confirming bio-persistence of such synthetic fibers.

The level of toxicity of the synthetic fibers also varies from the size in addition to their bio-persistence (Wright and Kelly, 2017). It is confirmed from the challenges faced in the removal of fibers of size 15-20 μm from the lungs' macrophages. Xu et al., (2019) showed in the study that PS nanoparticles of smaller size (25nm) are highly toxic capturing cell cycle in the S phase, inducing lower cell viability, capturing cell cycle in the S phase, active inflammatory gene is transcribed and changing pro-apoptosis and cell cycle' protein. Moreover, microplastics are also found carrying the microorganisms from the air and transmitting to other organisms. Such microorganisms get themselves attached to the surface of the microplastics to protect against UV radiation and reach the lungs of the humans leading to infections (Prata, 2018).

4.2.4 Skin and Organ Contact

Skin contact is another pathway identified for microplastics travelling in the human body. Microplastics are transmitted while washing the hands, using cosmetics, scrubs containing nano and microplastics. Moreover, the particles of size smaller than 100 nm could not easily penetrate into the corneous layer so the absorption of microplastics through the skin is unlikely to occur while the probability of nanoplastic absorption is more than the microplastics (Revel, Châtel and Mouneyrac, 2018).

Even though plastic is known as an inert product, microplastics have a variety of properties including hydrophobicity, shape, size, and chemical composition, which can pose a risk and influence particle cytotoxicity in tissues and cells (Wright and Kelly, 2017).

Microplastics have a high tolerance for a wide variety of hydrophobic and persistent organic contaminants, antibiotics, and toxic metals that could be ingested into the body through microplastics uptake due to their increased surface area/volume ratio and hydrophobicity. In the case of heavy metals, an in-vitro analysis of chromium (Cr) absorption/desorption activity in the human digestive system was performed using non-degradable MP forms {polystyrene (PS), polyethylene (PE), polyvinylchloride (PVC), and polypropylene (PP)} as well as degradable MPs {polyvinylchloride, polylactic (PLA), polypropylene (PP), and polyethylene (PE)} (Liao and Yang, 2020). The ability to extract Cr (III) and Cr (VI) from Microplastics into the digestive-gastric process was demonstrated due to the stimulation of the mechanism by stomach acid. While encounters between human organs and microplastics or nano plastics are now being investigated, their potential effects can be estimated using human absorption models of nanomaterials manufactured by industrial processes. The potential of nanoparticles in polystyrene to bypass the placental barrier and primary human renal cortical epithelial (HRCE) cells were illustrated in the studies of (Grafmueller et al., 2015). The potential of nanoparticles in polystyrene to bypass the placental barrier and primary human renal cortical epithelial (HRCE) cells were illustrated in the research of ((Grafmueller et al., 2015).

Using polyethylene (PE) microplastics, metal nanoparticles (NPs) (TiO_2 NPs, sand Al_2O_3 NPs, CeO_2 NP, Ag NP and AuNP, and ZrO_2 NPs,), carbon nanomaterials (Graphene, C60 fullerene), polystyrene (PS) microplastics, cytotoxic effects on T98G and HeLa cell lines (human brain and epithelial cells) have been demonstrated (Schirinzi et al., 2017).

Furthermore, depending on the particle size (20 µm and 25–200µm) and the various concentrations shown in the various experiments, the use of polypropylene (PP) particles clearly shows different yet harmful effects on various cell types. As a result, microplastics' contact with humans can cause undesirable antibodies, cytotoxicity, and hypersensitivity, and acute reactions like hemolysis posing potential harm (Hwang et al., 2019).

Latest in vitro studies investigating the impact of plastics on the human psyche have primarily used engineered nano plastics, which, due to their dimension, charge, and form, can affect their absorption as well as the translocation and development of ROS (Inkielewicz-Stepniak et al., 2018). In reality, the contact between the secretion film of the gastrointestinal epithelium (after digestion the 1st physical obstacle) and positively charged polystyrene nanoparticles (60 nm) was investigated in the study (Inkielewicz-Stepniak et al., 2018). In the intestinal epithelial cell lines LS174T, HT-29, and Caco-2, nano plastics developed high opportunities to connect with the secretion film, affect induce apoptosis and affect cellular vitality. Those cytotoxic results were noted in the analysis of, which used polystyrene nanoparticles of 20 and 40 nm to treat adenocarcinoma colon-rectal human differentiated cells, Caco-2 (Thubagere and Reinhard, 2010).

5. CONCLUSION AND RECOMMENDATIONS

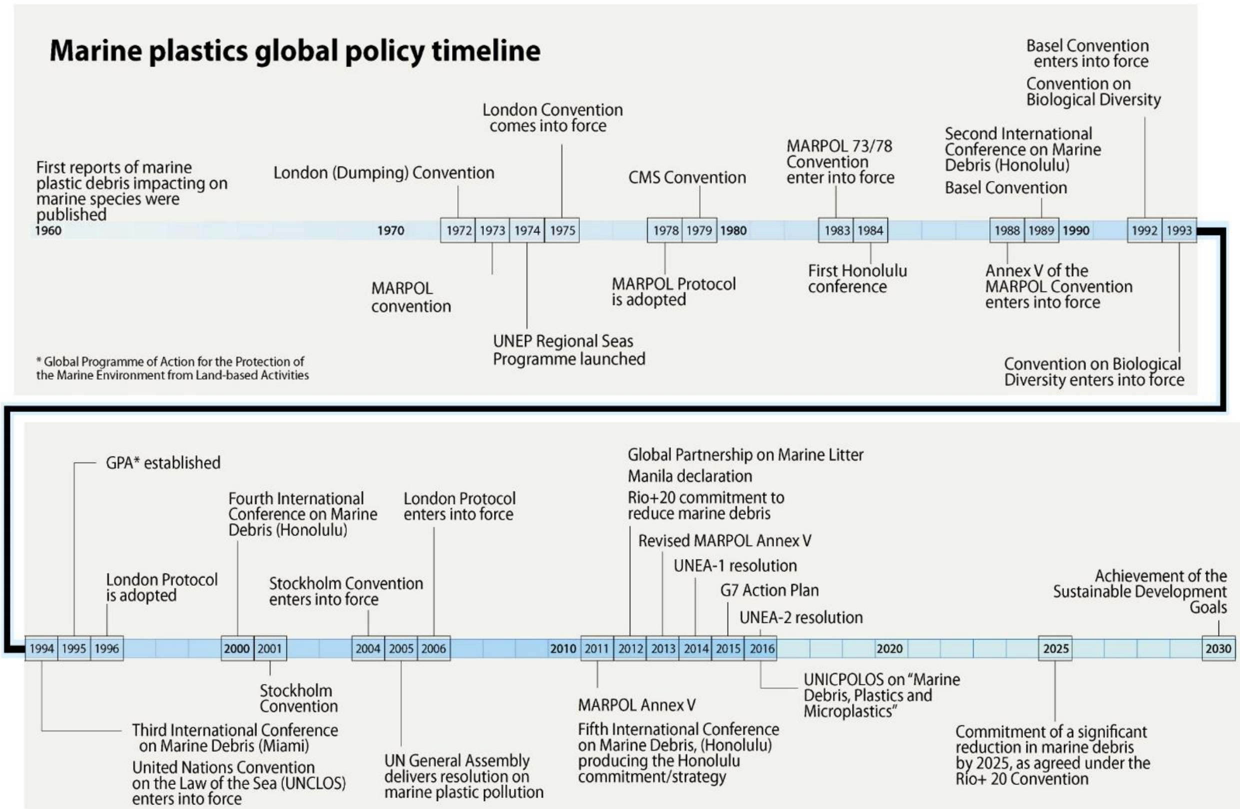
5.1 Recommendations

For the reduction of environmental contamination caused by plastic waste, most of the countries worldwide are working on it by reducing the manufacture of plastics and plastic products, litter collection, prohibiting unnecessary packaging, reusing, and recycling. The following suggestions could be useful in the campaign against plastic pollution:

5.1.1 Policymaking

Real-world policies that are adequately executed and enforced are required to tackle and curb recurring environmental pollution caused by plastics. The need for a global convention on plastic waste must be included to demand plastic manufacturers to reveal all their products and to provide customers with an alert about the possible health effects of those constituents. It is necessary to enforce policies that identify any of the toxic materials used in plastic products. The reclassification of chlorofluorocarbons (CFCs) as potentially harmful in 1989 (Montreal Protocol) and persistent organic compounds in 2004 are both examples of important precedents (Stockholm Convention) (Rochman, Hoh, Kurobe and Teh, 2013). This type of reinstallment can also encourage research and development of new and safe substitutes, that will help us better manage our plastic waste and prevent the accumulation of plastic waste in the environment. The stakeholders of the state must enact and enforce regulations that regulate the manufacture, consumption, use, and possible excessive plastic, regardless of their hazard level. To avoid zero diversion to landfills and indiscriminate waste to the ecosystem, the 3Rs: Reduce, Reuse, and Recycle must be used at all levels. Over the next seven years, around 200 countries have committed to phasing out CFCs and 30 other dangerous chemicals (Rochman, Hoh, Kurobe and Teh, 2013).

Figure 19: Marine Plastics global policy timeline



Source: Pravettoni (2018f)

5.1.2 Plastic waste management and recycling

Waste management is crucial in contributing to the reduction of plastic waste in the atmosphere and human health. Modifications in proper plastic waste collection, processing, and recycling are required for worldwide cuts in plastic litter and marine pollution (Jambeck et al., 2015). Toxic chemicals found in plastic waste to mooch into the surrounding air will cause polluting the surrounding air, surface and underwater, and soil due to insufficient landfill management. Microplastics cannot be released into the atmosphere as a product of proper wastewater management. The majority of treated wastewaters are dumped into rivers or oceans, necessitating a ban, such as Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL) agreement, which prohibits the dumping of plastic waste into the water (Bishop, Styles and Lens, 2020).

5.1.3 Education and public awareness

It is necessary to raise awareness in the public about the possible environmental and public health consequences of plastic waste contamination. This will help in reducing emissions and preserving environmental quality. People must be notified of the chemical components of plastic items as well as their health risks. Plastic emission mitigation and waste management programs must be used as information services in educational curricula at all levels.

5.1.4 Bioplastics as alternative

The plastics manufactured from cellulose are bioplastics, which are extracted from wood pulp, and were invented in the 1850s by a British chemist. Corn starch, weeds, potato starch, cotton, plant oil, cellulose, and other biodegradable and non-biodegradable materials can now be used to make bioplastics (Reddy, Reddy and Gupta, 2013). Under normal conditions, sugar-based bioplastics can biodegrade and be composted. They are eco-friendly because they use less fossil fuel in the manufacturing process than other forms of plastic. Despite the fact that bioplastics were only commercially used in a few products, they are commonly used in consumer items for disposable products such as kitchenware, bowls, cutlery, straws, cups, and packaging (Reddy, Reddy and Gupta, 2013).

The cost and performance of bioplastics are a challenge but they can substitute petroleum-derived plastics in a lot of areas. There could be no favorable use of bioplastics if there is no strict global legislation to restrict the use of traditional plastics. Italy, for instance, has had a law mandating the use of biodegradable plastic bags for shopping since 2011 (Mohanty et al., 2018).

Wood, starch cellulose, and sugar are used as substitutes for fossil fuels in the manufacture of bioplastics. In contrast to traditional plastic processing, this makes bioplastic production more environmentally friendly and sustainable. The production of bioplastics eliminates the use of nonrenewable energy and reduces emissions. We claimed that the dilemma of plastic waste production, as well as the associated environmental and public health consequences, could be addressed if manufacturers worldwide adopted bioplastics (Alabi et al., 2019).

Biodegradability, with few or no harmful products hidden behind, would help in protecting our natural ecosystem from the dangers of toxic plastic waste, as well as protecting our planet's organisms and making the world a better place for living creatures.

5.1.5 Energy conversion

This is nothing but a metaphor for incineration, energy recovery, that can dramatically boost greenhouse gas emissions, and also harmful exposures for populations close and is far from incinerators. As a result, these recycling developments led to a de facto shift of plastic waste's risks to the environment. In terms of climate change, this is deeply damaging as greenhouse gas emissions are indeed estimated to be about 900 kg CO2 equivalent per metric tons of plastic pollution incinerated, which is estimated more than fifteen times the amount of pollution when this trash is disposed of in landfills especially (Smith et al., 2018). Furthermore, incineration does not remove the existence of microplastics and could potentially be an origin of these pollutants. Waste material from urban solid waste incinerators has been reported to contain significant amounts of microplastics, up to one million particles per metric ton of ash (Barboza et al., 2018). However, many factors, and parameters, such as prior waste source separation, furnace type, and operation conditions, can impact the overall amount of microplastics in ash. Incineration's inadequacy as a method for solving the problem of plastic waste is obvious.

5.1.6 Chemical Recycling

A promising technical direction toward waste reduction and circular economy promotion is termed chemical recycling. It is important to investigate all technological tools to accomplish this lofty aim. Even then, a few of these advancements have still not achieved the point of technical readiness where they can be seen as viable options. Conventional gasification, Pyrolysis, and catalytic cracking are examples of these technologies. Furthermore, due to the scarcity of existing evidence and the extremely energetic inputs needed, determining the economic viability of these technologies is challenging (Karami et al., 2017). As a result, these technologies are considerably more expensive than normal techniques of manufacturing these products.

The accessible technologies should be reviewed even more as a key component of a wider solution to the issue of plastic waste. Successful plastic waste separation, when combined with other steps such as enhanced plastic design and limited plastic usage, would make the feedstocks for these technologies more homogeneous, making for possibly lower costs and better-finished products. In general, almost all of the issues that have been identified in chemical recycling are similar to those that have been identified in conventional mechanical recycling: obtaining high-quality feedstock, minimizing pollution, and obtaining the required volumes for the process (Yang et al., 2019). As a result, the “overall” method problems in treating plastic waste continue.

5.2 Conclusion

Human use of microplastics is now well known. Ingestion (via food contamination or trophic transfer), inhalation, or skin contact are all possible routes of entry. The nature and consequences of microplastics after they enter the human body are still uncertain and mysterious. Just microplastics with a diameter of fewer than 20 micrometers should be able to reach organs, whereas those with a diameter of fewer than 10 micrometers should be able to access all organs, cross the blood-brain barrier, enter the placenta, cross cell membranes, meaning that particle distribution in secondary tissues including the brain, liver, and muscles is possible. Microplastic's impact on human health is not well recognized due to a lack of data; but, effects could be caused by microbial biofilm growth, chemical properties (polymer type and additives), concentration, or by physical properties (size, shape, and length). There is also potential for long term effects though this requires further research. Although the exact mechanism by which nasty chemicals desorb or absorb, from, or onto microplastics is unknown, possible mechanisms include pH variations, hydrophobic interactions, polymer composition, and particle aging. Insufficient research has been done to determine the source documents of contaminants found on microplastics, including whether they are intrinsic from the plastic itself, extrinsic from the surrounding ambient space, or, more likely, a mixture of both from a continuous and complex process of absorption and desorption linked to particle spread into the atmosphere and subsequent exposure to climate.

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