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Critical Review on Research Advances in Microfiber Applications and Pollution forNumerous Disciplines

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Abstract
Microfiber can be described as a synthetic fiber or filament with a linear density of more than 0.3 decitex (dtex) and less than 1 decitex. Decitex is the unit used to represent the thicknessof a fiber. Microfibers can be mixed with wool, rayon, or cotton, or can be used as 100% microfiber. The notable features of microfibers that make them unique include their light weight, resistance to wrinkling, ease of portability, comfort to wear, and limited tendency for lint formation. Microfibers have paved the way not only in the textile industry but also in the medical field, construction applications, cleaning purposes, and imitation leathers. Microfibers, a major component of micro plastics, are emerging pollutants that have been found nearly everywhere, mainly in freshwater and marine habitats around the world. Hence, microfibers have created a new path in environmental science research as an emerging pollutant. Nowadays, people are more aware of microfiber pollution, which has led to the invention of Cora balls and guppy bags to trap microfibers from washing machines, as laundering is the primary source of microfiber pollution. In this review paper, the types, properties, applications, sources of pollution, the impact on the environment, how it affects human health and available solutions have been discussed.

Keywords: Cora balls, Domestic drainage, Fleece, Microfiber, Micro

Introduction

The huge demand for textiles has paved the way for the tremendous application of microfibers. Microfibers are a subcategory of micro plastics, which can originate from either primary or secondary manufacturing sources, as synthetic solid particles or water-insoluble polymeric matrices, ranging in size from 1 µm to 5 mm with a regular or irregular shape (Frias *et al*., 2019).Primary micro plastics are microscopic in size and can be found in cosmetics, face cleansers (e.g., face scrubbers), and textile fibers. Secondary micro plastics are the tiny fragments that result from the breakdown of larger plastic particles due to chemical, physical, and biological processes (Åström, 2016). Micro beads are another type of micro plastics, which are miniature pieces of manufactured polyethylene plastics commonly used as exfoliating agents in some cosmetics and toothpastes. These microbeads can easily escape water filtration systems and end up in water resources such as seas, lakes, or rivers.

Plastic production started rapidly in the 1940s and has now exceeded 311 million tons, as plastics have become an essential part of today's world. Fragments of plastics less than 5 mm in size are known as micro plastics and are present in water, sludge, soil, and air. In 2004, Thompson framed the microscopic plastic particles present in the marine environment as "micro plastics." Fibers are the most common type of micro plastics, mainly generated from garments. While fibers can be natural or synthetic, the non-degradable synthetic fibers pose a significant threat to the environment (Almroth *et al*., 2018). The International Union for Conservation of Nature (IUCN) estimates that 0.8 to 2.5 million tons of primary plastic pollutants are dumped into the sea each year, with a large portion contributed by microfibers from the textile industry (Boucher and Friot, 2017). The release of micro plastics into the sea can have a negative effect on organisms and enter the food chain, ultimately affecting human health (Jemec *et al*., 2016). Micro plastics have been found in various human consumables, such as seafood (De Witte *et al*., 2014), salt (Yang *et al*., 2015), beer, and honey (Liebezeit and Liebezeit, 2014), indicating the intensity of microfiber pollution.

Classification

Types of fiber

Technically, fibers are defined as filaments whose length is greater than their breadth. The primary application of fibers in the textile industry is for fabric production. According to the US Federal Trade Commission, fabrics are any type of material that are woven or knitted from natural or synthetic fibers, or from a combination of both. Fibers can be primarily classified as natural and synthetic.

Natural fibers are those that originate from plant or animal sources. Synthetic fibers are the result of various chemical reactions, produced mainly in laboratories, and are primarily derived from petroleum byproducts. Natural fibers can vary in size according to their source, while synthetic fibers are typically long filament-type fibers, also called staple fibers, which are then cut into desired lengths (Houck 2009; Robertson *et al*., 2017; Fitzer *et al*., 2000; Pigliacampi and Riewald 1979; Vlasblom 2018; Crouch *et al*., 2017)

Natural fibers

The main plant parts used for fiber production are leaves, stems, and seeds. Animal-based fibers can be keratin-based or non-keratin-based. Keratin-based fibers are primarily obtained from animals such as sheep, camel, and alpaca, and sometimes even human hair. Non-keratin-based fibers include cultivated silk from the cocoons of mulberry silkworms (Bombyx mori) and wild silk (tussah) from silkworms found in forests, where they produce their own food and form cocoons.In the case of cultivated silk, the silk worms produce two proteins: sericin and fibroin. Sericin is a sticky material that surrounds the structural protein, fibroin, which is removed during processing. The fibroin consists of various amino acids, such as glycine, alanine, and serine, and has a triangular cross-section with rounded edges, giving silk its soft and shiny texture.most common natural fibers in high demand in the textile industry are linen, jute, cotton, silk, and wool. Table 1 provides an overview of fiber types, their sources, and common applications.

Table 1: Most common types of natural fibers from plant and animal origin

<table>
<tr><td></td><td>FIBER</td><td colspan="2">SOURCE</td><td>USE</td></tr>
<tr><td rowspan="5">PLANT ORIGIN</td><td>Linen</td><td colspan="2">From the stems of Linum usitatissimum (flax)</td><td>Commonly used for household textiles</td></tr>
<tr><td>Jute</td><td colspan="2">From the cut stems of Corchorus capsularis (white jute)</td><td>Ropes, rugs, curtains, clothes, furniture etc.</td></tr>
<tr><td>Ramie</td><td colspan="2">Boehmeria nivea</td><td>Ropes, sacks and some clothing</td></tr>
<tr><td>Sisal</td><td colspan="2">From the leaves of Agave sisilana</td><td>Twines, carpets, floor mats, ropes</td></tr>
<tr><td>Cotton</td><td colspan="2">Gossypium seeds</td><td>Most common textile fiber</td></tr>
<tr><td rowspan="2"></td><td>Kapok</td><td colspan="2">From the seeds of Ceiba pentandra</td><td>Used in life preservers and upholstery padding</td></tr>
<tr><td>Coir</td><td colspan="2">Made from the husk of Coco nucifera</td><td>Mainly used for manufacturing floor and door mats</td></tr>
<tr><td rowspan="3">ANIMAL ORIGIN</td><td>KERATIN BASED</td><td>USE</td><td>NON-KERATIN BASED</td><td>USE</td></tr>
<tr><td>Wool</td><td>Saddle cloth, upholstery, blanket, carpet, human cloth</td><td>Cultivated Silk</td><td>For the making of different fabric materials like chiffon, satin, deluxe, plain silk, crepe etc.</td></tr>
<tr><td>Fur</td><td>Felt, coats</td><td>Wild Silk</td><td>Lampshades, cushion covers, table wear, winter clothing</td></tr>
</table>

Synthetic fibers

Synthetic fibers can be further classified into organic and inorganic fibers. In some cases, the natural building blocks, such as cellulose, can be replaced by chemical substitutes. Rayon is an example of such a synthetic fiber. The synthetic fibers produced from various chemicals have their own unique properties and characteristics. Aramid, polyethylene, and aromatic polyester fall under the category of organic synthetic fibers. Inorganic synthetic fibers consist of materials like glass, carbon, boron, and silicon carbide. Table 2 provides a sub-classification of synthetic fibers and their areas of application.

Table 2: Types of synthetic fibers with their area of applications

ORGANIC SYNTHETIC FIBERS			
	Aramid	**POLYETHYLENE**	**AROMATIC POLYESTER**
APPLICATIONS	Ropes	Marine ropes	Soft drink bottles
	Cables	Sports equipments	Photographi films
	Boat hulls	Fishing nets	Insulation in capacitors
	Ballistic protective armors	Medical	
	Coated fabrics		

INORGANIC SYNTHETIC FIBERS				
	GLASS	**CARBON**	**BORON**	**SILICA CARBIDE**
APPLICATIONS	Textile	Fire blocking fabrics for seats in trains, cars, buses, aircrafts etc.	Used in furnaces as high temperature insulation	Flame barriers
	Decoration	Protective clothing		Radiation
		for fire fighters, racing drivers, steel workers etc.		shields
	Insulation			Bag filters for hot gas filtration
	Filtration			

Organic synthetic fibers

Polyamide/Nylon fiber

Polyamide or Nylon fibers are polymers with relatively simple, straight polymer chains, where the units are linked through repeated amide bonds. Nylon is a thermoplastic polyamide formed through the condensation reaction of a diamine and a dicarboxylic acid.

Aramid fibber

Para-aramid fibers are a combination of polymerized benzene-1, 4-diamine [p-phenylenediamine (PPD)] and terephthaloyl dichloride (TCL) in a condensation reaction, resulting in the elimination of hydrochloric acid as a byproduct.

Polyethylene fibber

Polyethylene fibres (UHMWPE-Ultra high molecular weight polyethylene) are a thermoplastic polyolefin polymer created from long molecular chains. These are commonly known as ‘rigid rod molecules’ due to their simple, straight polymer chains, which give them a needle-like characteristic.

Inorganic synthetic fiber

Glass Fiber

Glass fibers used in the textile industry, known as textile glass fibers, are manufactured from molten glass with a circular cross-section. These fibers are used for making fabrics and can be reinforced with plastics for further applications.

Carbon Fibers

Carbon fibers are black in color, with a diameter of around 10 µm, and can be used in the production of felts, yarns, and other textiles. The high strength and low density of carbon fibers make them suitable for manufacturing carbon fiber-reinforced plastics, resulting in a higher demand compared to glass-reinforced plastic products.

Boron and Silica carbide fibers

Boron and silica carbide fibers are considered refractory fibers, which can withstand temperatures above 1000°C. Although they are manufactured on a small scale, these types of fibers are very costly and are primarily developed for thermal insulation purposes.

Types of microfibers

Microfibers have their own unique properties that make them highly sought-after in society. Microfibers are exceptionally drapable and non-electrostatic. The super-fine filaments present in them provide exceptional strength. Microfiber fabrics are very easy to care for and offer good breathability (Sandip and Narsingh, 2007).The important properties of microfibers are illustrated in Figure 1 and Table 3 discussed about lassification of microfibers

Figure 1: Properties of microfiber

Table 3: Classification of microfibers

On the basis of fiber count (dtex)		**On the basis of polymer**	**On the basis of production process**
FIBER	**DECITEX (DTEX)**	Acrylic	Flat weave
Super-micro fibers	>0.3	Polypropylene	Split weave
Micro fibers	1 – 0.3	Cellulose	
Fine fibers	2.4 – 1		
Medium fine fibers	7 – 2.4		
Coarse fibers	<7		

Properties of microfiber and applications

Microfibers have their own unique properties that make them highly sought-after in society. Microfibers are exceptionally drapable and non-electrostatic. The super-fine filaments present

Anu Xavier / Afr.J.Bio.Sc. 6(5) (2024). ***5821-5841***

in them provide exceptional strength. Microfiber fabrics are very easy to care for and offer good breathability. The important properties of microfibers are illustrated in Figure 1 (Sandip and Narsingh, 2007). The unique properties of microfibers, such as softness, strength, luster, surface characteristics, and draping qualities, make them highly attractive. The application of microfibers is not limited to the textile industry but extends to various other domains (Sandip and Narsingh, 2007; Mukhopadhyay and Ramakrishnan, 2008).Some of the common applications of microfibers are listed in Table 4

Table 4: Applications of microfiber

Sl. No	**AREA/SECTOR**	**USES**
1.	Energy conservation	• Enhancement of heat transfer in heat exchanger tubes by using metal coated microfibers. • Increase in number of metal coated fibers will increase the heat transfer.
2.	Cleaning	• Absorbs water many times than its own weight because of its increased surface area and capillary action. • The wedge shape of microfibers can trap the dirt particles more easily when compared to that of normal fibres. • Ultra microfibers contain polyamide which have catonic charge can attract the anionic charged dirt particles like bacteria or pollen and thus enhances the cleaning properties.
3.	Liquid filters	• The splittable microfibers can enhance the filtration mechanisms (Brownian motion, interception, electrostatic effects etc.)
4.	Industrial	• A patented work disclosed the use of microfibers in their product cleaning oil spills.
5.	Fashion clothing textiles	• Woven fabrics was manufactured from a combination of single hollow staple fiber and 0.1 dtex UFF hollow microfiber and that gives the material softness, sense of warmth, light weight etc.
6.	Synthetic game & imitation leather	• Synthetic game leather and other leather materials are manufactured in industries of Japan by infusing nonwovens from PET (Polyethylene terephthalate), PAN (Polyacrylonitrile) and PA (Polyamide) microfibers with UP (Polyurethane). When compared to natural leathers, these products assure uniformity, colour fastness, ease of care and dimensional stability.
7.	Construction	• Microfiber reinforcement in cement increased strength, toughness and stiffness.

8.	Medical	• Microfiber fabrics for wound care because of its excellent breathability. • Low cost and adaptable. • Easy to use, safer and easily disposable • Used in surgical packs, protective face masks, surgical gowns, bedding, gloves etc.
9.	Household	• Long lasting than other conventional towels. • Cloth can be cleaned with water and does not require any chemicals. • Microfiber clothes dries faster and less tendency to form lints
10.	Others	• In the production of mouse pads. • For hair transplantation to conceal thinning of hair • Manufacturing footballs and other sports material.

Sources of microfiber pollution

As the demand and applications of microfibers are increasing, the level of pollution caused by them is also on the rise. The global production of microfibers has become a threat due to their presence in air and water sources. When anything exceeds its natural limits, it can cause trouble to the environment. Similarly, microfibers are also causing problems by contributing to various types of pollution. Since these synthetic fibers are non-degradable and non-renewable, their presence invites additional problems for the environment.

Anything introduced into the environment that produces a harmful effect is termed as pollution. Global microfiber pollution will increase with the increased use of microfibers without a proper disposal method. Ongoing research is focused on identifying the sources of microfiber pollution and finding ways to tackle the problem without negatively impacting the environment.

The major sources of microfiber pollution include textile industries, household laundering, domestic drainage, landfills located near water sources, and the dumping of plastics and used clothes in water bodies (Mishra *et al*., 2019).

Textile Industries

The amount of microfibers is increasing daily due to their non-decomposable nature. Several studies have shown the presence of microfibers in water sources such as seas, rivers, sludge, and topsoil (Almroth *et al*., 2018). The current reliance on polyester fabrics, which are a significant source of microfibers, is worsening water quality due to their non-biodegradable waste production (Brodde, 2017). Ecologist Mark Anthony's 2011 study on the accumulation of micro plastics on shorelines around the world found that 85% of the man-made waste was microfibers from clothing (Center and Wash). Synthetic fibers are produced from crude oil through various processes like polycondensation, polymerization, and polyaddition. The shedding of fibers from clothes can vary depending on the type of fabric, yarn, and texture (De Wael *et al*., 2010). Among the global synthetic fiber production, polyester accounts for 91% (Klar *et al*., 2014). While polyester dominates, nylon still holds a significant share, with 4 million tons produced globally in 2014 (Carmichael, 2015). Textile synthetic fibers are used not only in clothing but also in furniture, sports equipment, buildings, geotextiles, agriculture, and soft toys.

Laundering

Outdoor and indoor laundering is another major source that contributes to microfiber pollution. The primary entry of micro plastics into the sea is through domestic drainage systems. Synthetic and natural fibers found in the ocean are assumed to originate from washing machines. Studies have shown that washing machines are a significant cause of fiber loss, with 100-300 fibers present per liter of effluent. Fleece clothing sheds the most fibers, around 1,900 per wash (Browne *et al*., 2013). Various human activities, including washing, release microfibers into the marine environment through adjoining rivers. It is reported that a single wash can discharge around 22,992 poly-cotton, 82,672 polyester, and 121,465 acrylic microfibers into the ocean (Resnick, 2019). Even the disintegration of non-laundering fabrics, such as flags and sails, can also contribute to pollution. When washing fabrics or using cosmetics containing micro plastics and fibers, the washed-out particles settle in wastewater treatment plants through the drainage system. Around 10,000-100,000 micropollutants per cubic meter have been found in washed-out water, and 70-100% of these fragments are collected by wastewater treatment plants, but numerous pollutants still remain in the treated sewage (Åström, 2016).Figure 2 represents how water bodies get contaminated from the released micro plastic after laundering

Figure 2: Micro plastic pollution of water bodies after laundering

Wear and Tear of Tires

The use of plastics is increasing daily due to their exceptional properties like flexibility, cost-effectiveness, strength, and durability. Consequently, plastics have invaded different sectors, including construction, packaging, household appliances, transportation, and electronics. Focusing on transportation, tires are made of rubber, which also belongs to the group of plastics. Rubber can be classified as natural and synthetic, with the production of the latter being higher compared to the former as of 2016 reports (Kershaw, 2016; Kole *et al*., 2017). Synthetic rubbers are made up of polymers, with petroleum used as the raw material.

The contact of tires on the road surface results in wear and tear, and the amount of particles released depends on the vehicle speed, road surface, climatic conditions, and tire composition (Alexandrova *et al*., 2007). When the tire comes in contact with the road, it creates shear and heat, which liberates wear particles. The shear forces only emit large particles, but the accumulation of heat can form hotspots on the tire, and once the temperature reaches a level where the volatile content can vaporize, it results in the emission of micro-sized particles (Grigoratos and Martini, 2014; Kreider *et al*., 2010).Figure 3 showcased how vehicle release micro plastic to the environment.

Figure 3: Micro plastic from vehicle tires

Others

Microfibers can also be shed from fishing nets and synthetic polymer garments, although they do not have a direct application at present. These synthetic microfibers can be manufactured from nylon, polypropylene (PP), and polyethylene terephthalate (PET) (Gago *et al*., 2018). As synthetic microfibers are produced using chemicals, they are highly dangerous and can affect the food chain (Bal *et al*., 2019; Mohanty *et al*., 2018). In 1950, the annual production of synthetic fiber was 2.1 million tons, but it increased to 49.6 million tons in 2010 due to the growing demand (Essel *et al*., 2015).

Another source of microfiber deposition in water sources is landfills. Microfiber particles can leach from landfills located near water bodies, directly entering domestic drainage systems, oceans, and rivers (Cole *et al*., 2011). Landfills near water resources and the direct dumping of waste into the ocean contribute to plastic debris. The most commonly reported types of micro plastics include fragments, fibers, and pellets, as well as ropes, sponges, rubber, foams, microbeads, and films (Frias *et al*., 2018). Aquaculture, commercial fishing, and coastal tourism are additional sources of both primary and secondary microfibers that enter the marine environment directly (Cole *et al*., 2011). The growing demand for synthetic fibers in today's society will gradually result in increased global microfiber pollution (Lamichhane, 2018).

Environmental impact

The emerging microscopic microfiber pollution is a serious issue that not only pollutes the environment but also affects the food chain. Due to the lack of proper treatment techniques, food resources and water ways are concerned with these microscopic pollutants. Studies showed that around 1.4 trillion microfibers are present in the marine habitat and is causing various problems to our biodiversity (Halpern, 2018). As discussed above, the major sources of microfibers are from textile industries, laundering, landfills, wear and tear of tyres etc. The macroplastic wastes when discarded will undergo fragmentation and turns into micro fragments as a result of the exposure to ultraviolet rays, oxidative and thermal weathering (Weinstein *et al*., 2016). The different weather conditions such as temperature, wind speed, cyclones, humidity, precipitation and wind direction also holds an important role in determining the amount of micro plastics present in atmosphere (Kaya *et al*., 2018). The tiny fragmented pollutants can be carried by wind and water and ends up in different pollutions such as water, air and sometimes soil. Humans will be affected by the micro pollutants when they inhale air polluted with micro plastics. Likewise, aquatic organisms are also affected by ingesting those micro pollutants when they enter into the sea. Humans consuming those affected sea foods also will be victims of micro sized pollutants and thus micro pollutants enters in the food chain (Figure 4).

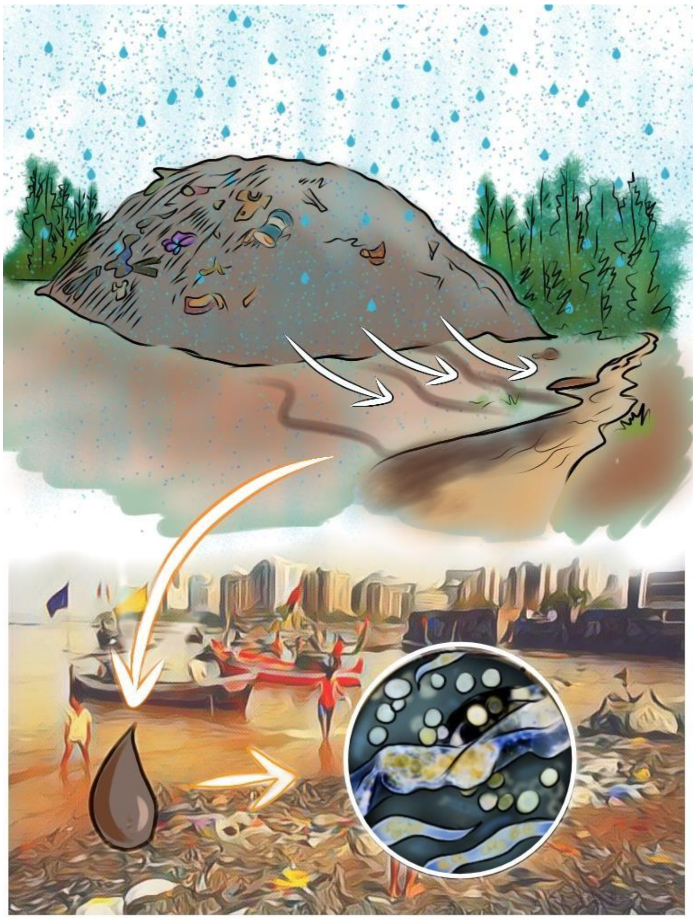

Figure 4: Adverse impact on environment due to micro plastic deposition

Threat to Marine Habitat

Microfiber pollution has affected almost every part of the planet, including Polar Regions. Due to their small size and density, microfibers can float on the water surface, impacting both aquatic plants and animals. As these micro-particles can enter through gills and the gastrointestinal system, they can block the respiratory systems of aquatic organisms (Mishra *et al*., 2019). The human-made waste deposited in the aquatic environment can affect the growth, reproduction, and mortality of aquatic life. Even a small piece of plastic can be consumed by aquatic organisms.

Micro plastics can sometimes act as a vector, transporting different chemicals and contaminants into the marine habitat and organisms (Brennecke *et al*., 2016; Koelmans *et al*., 2016). Heavy metals, organic, and inorganic contaminants can adhere to or be adsorbed by micro plastics, and their toxicity to marine organisms has been investigated in several studies. Ingestion is the primary concern when it comes to aquatic life.

Aquatic animals, including plankton, mistakenly consume these microfibers as food. Smaller aquatic animals and fish that depend on plankton as their main food source will then consume the microfibers, passing these micro-pollutants up the food chain. Micro plastics have been found in the autopsied stomachs and intestines of whales, with polymers like rayon, polyester, acrylic, polypropylene, and other polyethylene groups identified (Lusher *et al*., 2013).

Microfibers release various toxic chemicals that are harmful to fish organs and ultimately contaminate the fish. These chemicals can disrupt the endocrine systems of fish, adversely affecting their reproductive processes (Zhao *et al*., 2014). Recent studies have reported that the consumption of such micropollutants can alter the endocrine systems of adult fish (Rochman *et al*., 2014).

Europe, the world's highest consumer of shellfish, is estimated to consume around 11,000 microfiber particles per year, while countries with lower shellfish consumption rates report around 1,800 microfiber particles consumed annually (Duis and Coors, 2016). Approximately 175 microfiber particles were estimated to be consumed per individual per year just from shrimp. Microfibers have been commonly found in two varieties of mussels, Mytilus galloprovincialis and Mytilus edulis, gathered from parts of Europe (Van Cauwenberghe and Janssen, 2014). Studies have shown that about 9% of microfibers were present in the gastrointestinal tracts of fish sold in the USA markets, and 28% in seafood sold in Indonesian markets (Rochman *et al*., 2015).

Microfibers have the ability to leach toxic chemicals, such as plasticizers, fabric pieces, or adsorbed organic compounds, into the tissues of fish and other aquatic organisms. These chemicals and microfiber pollutants can reduce feeding rates in fish, cause physical damage to various organs, immune function, digestive tract, stomach lining, and ultimately affect the entire ecosystem, including soil quality (Tutton, 2018).

Air Pollution

Microfibers can be flammable if they belong to polyester or cellulose fabrics, and upon burning, they can emit toxic gases. When fabrics made of aromatic compounds (PET - Polyethylene terephthalate, PS - Polystyrene, ABS - Acrylonitrile Butadiene Styrene) or treated with azo dyes and halogenated flame retardants are burned, the emission of toxic gases is high (Braun and Levin, 1986). It is a well-established fact that the toxicity of micro plastics increases as their size decreases. Although micro plastics are considered toxic pollutants, there is a lack of standardized approaches for sorting, sampling, extraction, purification, and identification.

As clothing requirements and styles change seasonally, the amount of microfibers present in the environment also escalates. It is confirmed that micro plastics can exist in the air we breathe, drinks, and our food items (Kaya *et al*., 2018). The clothes we hang out to dry can also act as a source of airborne microplastic fibers in the environment. Sewage sludge used as fertilizers can also contain micro plastics, which can be transferred into the atmosphere via wind after periodic drying. Furthermore, the polyethylene foils used in the agricultural sector can be a contributor to microplastic pollution, as they can disintegrate due to the catalytic activity of cobalt or other metal salts in the soil after exposure to the environment (Liebezeit and Liebezeit, 2014).

Some researchers have discovered the presence of airborne micro plastics released from clothes in their work environments, using blanks and open Petri dishes for sampling.

Flowering plants are also victims of microplastic contamination, likely due to atmospheric fallout. Micro plastics have even been found in honey (Prata and Mühlschlegel, 2017).
Focusing on airborne microplastic pollutants, humans are highly exposed in their occupational areas, and these contaminants can adversely affect human health. Factories working with large volumes of polymeric materials, with poor ventilation and inadequate conditions, can result in chronic exposure to airborne micro plastics (Prata, 2018). It is also reported that micro plastics exist in particulate matter. Atmospheric particulate matter comprises a combination of natural airborne liquids and solids, or human-made sources such as the sea, soil, biosphere, and combustion (Perrino, 2010). The public is exposed to a significant amount of pollutant particles in their airways, even at low levels of pollution, which may affect susceptible individuals by causing diseases (Brauer, 2000). Particulate matter can also affect the climate by interfering with cloud formation and scattering solar radiation (Perrino, 2010).

Adverse effects in human health

The microfibers and associated chemicals passing through the food chain can severely impact human health. These micropollutants contain phthalates, which can cause breast cancer, damage to the kidneys, intestines, and liver, as well as reduced oxidative stress molecules in the liver and blood infections in humans. The phthalates present in microfibers have been assessed for their harmful effects on humans, resulting in reproductive and genital defects, reduced sperm count, early onset of puberty, and impaired hormone system function.
Another chemical present in microfibers is Bisphenol A (BPA), which can affect female reproductive hormones. Other dangerous chemicals can disrupt proteins and DNA when they enter the human body (Meeker *et al*., 2009).
Airborne micro plastics can cause occupational diseases in industrial workers who are exposed to high concentrations of these pollutants daily (Figure 5). Industries that can demonstrate the effects of airborne micro plastics include the synthetic fabric industry (Pimentel *et al*., 1975), vinyl chloride and polyvinyl chloride industries (Xu *et al*., 2004), and the flock industry (Atis *et al*., 2005). In humans, the reaction to inhaled particles may vary based on individual metabolism and susceptibility, and can result in interalveolar septal lesions, asthma-like bronchial reactions, and inflammatory and chronic bronchitis (Pimentel *et al*., 1975; Beckett, 2000).
In 1998, before the term "microplastic" was coined, a group of cancer researchers described bioresistant cellulosic and plastic-type pollutants as the primary causative agents leading to a high risk of lung cancer (Pauly *et al*., 1998). In 1961, Simonin reported that workers in nylon factories experienced mucous membrane irritation, burns, bronchial asthma, and hypersensitivity dermatitis due to frequent and prolonged contact with nylon. Inhalation of nylon dust has also been linked to cases of pneumoconiosis due to organic dusts, resulting in fibrotic nodules in the lungs. In 1967, Abe and Ishikawa administered various categories of dust, including synthetics, to the trachea of experimental animals and found that samples containing nylon formed alveolar-type foci in the lungs (Pimentel *et al*., 1975).
Microbes can quickly colonize micro plastics in the environment, forming biofilms that can harbor harmful human pathogens like Vibrio species. When such pathogens enter the human body, the additional substrates present in the lungs or gastrointestinal tract may promote their growth, leading to alterations that can affect the functions and structure of the microbiomes in the lungs and gastrointestinal tract, ultimately impacting human health (Wright and Kelly,

2017). There is no doubt that these micro pollutants are affecting not only the marine habitat but also human beings.

Figure5: Adverse effect of micro plastic on human health

How to overcome?

Microfiber pollution is a man-made problem that requires immediate solutions. There are some existing technologies to reduce the level of pollution, but they have limitations. One such technology is the membrane reactor, which can remove microfibers using cross-flow filtration, but the high energy consumption is a major drawback. Another method is centrifugation and density separation, but it is not successful in filtering large sample volumes. These technologies are not practical due to their high operational costs and expenses. However, by applying some strategies, we can overcome microfiber pollution to an extent. Washing clothes at lower temperatures can help control the shedding of fibers from clothes. A recent finding to address this problem is washing clothes in a separate bag. Using a Guppy bag or Cora ball in the washing machine can help collect the microfibers shedding from clothes during washing. Adding a Cora ball with clothes in each wash can filter microfibers and prevent their release into drainage systems. It is claimed that a Cora ball can remove about 26% of microfibers from machine washes. The reusability of this product and the ease of separating the entrapped microfibers are its biggest advantages. Another similar product is the Guppy bag, a synthetic bag designed to trap microfibers from fleece during machine washing. This idea was raised from a campaign called "STOP! MICRO WASTE" by a group of German scientists. Another way to control microfiber release is by fully loading the washing machine. A fully loaded machine can reduce the friction between clothes, as they cannot rub against each other as much. However, clothes dry quickly at high spin speeds, which can cause more synthetic fibers to shed. Washing clothes at a low spin speed using cold water can help reduce microfiber shedding. Tumble drying of clothes is more dangerous than air drying, as it can cause more fibers to shed from the clothes. Using a front-loading washing machine is more suitable than a top-loader, as studies have shown that top-loading machines are likely to release more fibers. The major source of microfibers is from fleece. Using woolen fleece rather than polyester fleece can reduce the amount of microfibers shed. Clothes also shed more micro plastics during the first few washes, so using high-quality, longer-lasting garments can help minimize the issue (Mishra *et al*., 2019).

Conclusion

Plastics are an inevitable source of pollution contributed by humanity. The size of pollutants can vary from larger debris to micro-sized plastics, but the effect remains the same: environmental pollution and health problems in humans. Microfibers, a subcategory of micro plastics, are the tiniest plastic pollutant particles and pose a significant threat to the atmosphere. Marine life as well as humans are suffering due to this micro-sized pollutant.

Microfibers are present in the air and water resources due to their lightweight and low density. These pollutants contain toxic chemicals, and once they enter the sea, the chances of aquatic life consuming them increase. Gradually, these chemicals can enter the food chain and cause health problems in humans through seafood consumption. Micro plastics can also reduce the photosynthesis rate in aquatic plants, affecting their growth.

The changing lifestyle of people, driven by an increased demand for synthetic textiles due to their irreplaceable features, has led to the expanded use of microfibers. Microfibers also play an important role in the hospital sector, construction applications, and cleaning purposes. While microfibers hold a promising future with many areas to explore, it is necessary for our environment to find a more eco-friendly way to dispose of and decrease the shedding of these fibers.

When it comes to laundry, there are ways to decrease the shedding levels of microfibers from garments. Using washing machines at a low spin speed with cold water can reduce the shedding level of fibers to an extent. Labeling the speed of the machine spin, the type of water for washing, detergents, etc. on the microfiber-based fabric can also help reduce fiber shedding.

By following good manufacturing practices (GMP) and ensuring proper ventilation in industries manufacturing microfibers, we can reduce occupational diseases in workers caused by microfibers. Conducting awareness programs about the severity of microfiber pollution will also help mitigate the problem. Organizing seminars and performing street plays are effective ways to educate the public about the seriousness of microfiber pollution, as some people are still unaware of the consequences of increased microfiber use.

While producing fabrics from microfibers, producers must be more concerned about choosing the best knitting methods to minimize fiber loss. As individuals aware of the impact of microfiber pollution, it is our duty to protect the environment by air-drying clothes instead of washing them after a single use.

The emergence of microfibers has opened up a new path in almost every sector, and it is now time to invent new disposal methods for microfiber waste. Ongoing research in this field has expanded the scientific opportunities to address this environmental challenge.

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