

**DO MICRO- AND NANO-PLASTIC PARTICLES INTERACT WITH  
NANOPARTICLES/MATERIALS? AN OVERVIEW**

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**ABSTRACT**

Micro and nano plastic particles along with nanomaterials are the two intensely associated with man and his anthropogenic innovations. Both of these products are in use in almost all spheres of life, from kitchen to research laboratories and from clothing to domestic and industrial use; above all, these are durable, economical and intended to meet human needs. Both of these groups of materials present in our atmosphere influencing each and every component of environment over the globe. Both groups of these behave like necessary evils. Their production and waste products have increased unprecedentedly. Micro and nano plastic particles come across various molecules in the environment which are toxic, contaminants, having different chemical nature and composition, properties and show varied degree of reactivities. These get adsorbed on their surface in accordance to the surface properties and enter the biosystem and consequently leave very derogative impacts on the components of environment. The mechanism involved is ambiguous. The investigation in this direction indicates that their interactive behaviour with biosystem is in accordance to conditions like pH, ionic state, type, valence, concentration of salt, shape, size, and type of the polymer and physiological status of the biosystem they encounter. This presentation is an effort to evaluate these interactions and the mechanism (probable) involved.

**KEYWORDS:** carbon nano-particles, cracking, ecotoxicity, flexibility, graphene, hydrolysis, liposomes, plastics, micro and nano-plastic particles, pH, polydispersity-index, surface properties, up-take of plastic particles, viscosity.

**RECAPITULATION**

Plastics and their waste (may be degraded and discarded) products have become ubiquitous in all components of environment i.e., water, soil and air. Plastics are the polymers and product of anthropogenic activities. First, Thompson and group phrased the term microplastic for micro and nano plastics particles present in environment.<sup>[1]</sup> These particles measure upper limits as 5 mm for microplastic particles and below 1  $\mu\text{m}$  for nanoplastic particles. The plastic materials have light weights, highly adaptable, long lasting, most of the plastics are resistant to corrosion and temperature. These

materials provide products which are easier to procure, relatively safer to use, long lasting and affordable. For entrepreneurs, these plastics are economical, profitable and relatively easy to manufacture and economically significant as these products have good margin of profit. Further, because of their popularity, ease to use and being economically beneficial commodity, they are being used by one and all rich and poor individuals. Their production has increased beyond the expectations and as a result tones of such products are unproportionally being manufactured; (only in Europe, up to 368 Mt in the recent past<sup>[2]</sup> and their production on large scale is still in

process. The huge amount of plastic waste is being released unprecedentedly, unplanned and irresponsibly in the environment either in open unattended or burnt haphazardly. This mode is one of the primary causes of uncontrollable pollution affecting biota and physicochemical aspects of air, water and soil.

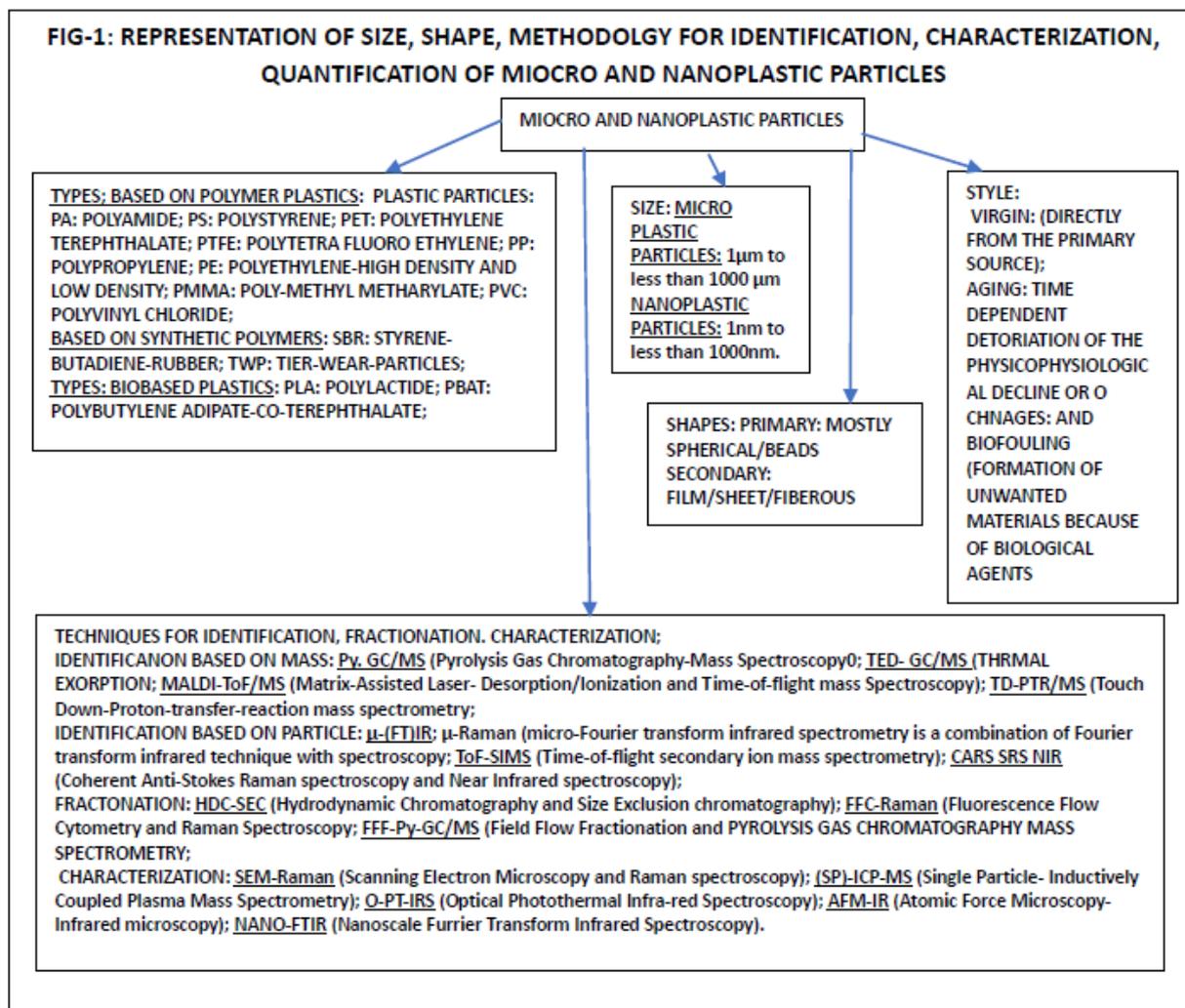
The main sources of these materials are polymers organic chemicals like polyethylene (PE): it is of two types, high density and low-density PE i.e., high-density polyethylene (HDPE) and low-density polyethylene (LDPE), propylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET). Polymeric organic compound, polypropylene is one of the most preferred sources for manufacturing plastic goods. The other polymers are polystyrene (PS) PVC and PET are also the preferred sources in decreasing order.<sup>[3]</sup> The polymers like poly-methyl methacrylate (PMMA), polyamide (PA) and polyurethane (PUR) are also some bioplastics and are also act as the sources for manufacturing plastic products Bioplastics can be broken down with the help of biological agents as they are biobased plastic materials. The biobased plastics such as polylactide (PLA), polybutylene adipate-co-terephthalate (PBAT) are commonly used for packaging food and agriculture products. The synthetic polymers like styrene-butadiene-rubber (SBR), paint particles and surface coating materials along with tire-wear-particles (TWP) are also the sources of micro plastic particles as waste. These polymers are complex or multicomponent aggregates and are in use as binders, pigments, fillers, and additives. These forms surface coating for various purposes. These are polyester (PES), alkyds, epoxy and urethane resins etc. Acryl and vinyl-(co)-polymers act as a component of physically drying system.<sup>[4,5]</sup>

Most of the plastic polymers sources have specific applications based on their approximate size variations in aqueous bodies which are reported in various investigations and are summarised as:

1. Polyamide (PA) source of synthetic fibers utilized in clothing (nylon). Size variations of microplastic particles 22.7  $\mu\text{m}$  to 180.5  $\mu\text{m}$ .
2. Polyester (PES) used in sports and casual clothing and domestic textiles. Size not reported.
3. Polyethylene terephthalate (PET) source for packaging material (food, edible, drinks); Size variations of microplastic particles are between 5 $\mu\text{m}$  to 350  $\mu\text{m}$ .
4. Polypropylene (PP) primary sources for manufacturing materials to packing materials and used in making disposable utensils, fibers, for masking, hygiene and medical products like syringes and goods of common utility in medical field. Size variations of microplastic particles 5 $\mu\text{m}$  to 380  $\mu\text{m}$ .
5. Viscose (CV) (Biopolymer) regenerated or synthetic fibers from cellulose specifically to be used in textiles and wipes;
6. Polyethylene (PE) primary source for making plastic bags, packaging films/sheets, bottles, micro-beads to be used in cosmetics and detergents. Size variations of microplastic particles less than 15 $\mu\text{m}$ .
7. Polystyrene (PS) acts as building materials for manufacturing disposable packaging materials, making insulations and foam materials fragmentation. Size variations of microplastic particles 5 $\mu\text{m}$  to 400  $\mu\text{m}$ .
8. Polyvinyl chloride (PVC) used in manufacturing building materials, pipes, plumbing materials. Size variations of microplastic particles 5 $\mu\text{m}$  to 10  $\mu\text{m}$ .
9. Polyacrylonitrile (PAN) materials for fabrics like fleece, filters, ropes etc.;
10. Ethylene vinyl acetate (EVA) used in making soles of shoes, toys, mats, sports goods;
11. Polybrominated biphenyl (PBB) flame resistant polymer.
12. Poly-methyl methacrylate (PMMA) used for packing food and agricultural products. Size variations of microplastic particles are 5 $\mu\text{m}$  to 10  $\mu\text{m}$ .

Although, there are good numbers of varieties of man-made plastic polymers but polymers like polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC), seems to be mostly used as source for synthesis of plastic polymers. Which in turn are used for manufacturing the respective products. Most commonly, the debris and waste are from PE, PP, PS and PVCs in decreasing order.<sup>[6,7]</sup>

Source (1-Koelmans et al., 2019,2-Hela,2017, GESAMP, 2019,9,62-Zafri, 2019).



The plastic and their waste are categorized on the bases of their structure, mode of polymerization, response to heat, physicochemical properties like texture, softness, rigidity, density, elasticity (in comparison to rubber). The products made of such polymers are applicable in buildings, construction work, healthcare, sports, aeronautics, storing, medical field, transportation, beverages, food and packaging industries and other products of day-to-day use. These plastic materials are also useful as fillers, stabilizers, pigments, foaming agents, lubricants, flame retarders, plasticizers etc. Some products are utilized in place of metallic goods like pans, bars, wheels. These products are durable, rust and corrosion resistant, take long duration for their degradation or decomposition and most important, these products are economical for a common man and commercially beneficial to the industrial personnel. One of the major portions of the waste from these products is used as landfill (this aspect amounts to around 49% of the total plastic waste) and one of the prime sources of micro and nano plastic particles and pollution which acts as health and ecological hazard materials.

Micro and nano plastic particles face variety of molecules in the environment which are toxic,

contaminants, having different chemical nature, composition, properties and varying degree of reactivities. These chemicals are inorganic (metal and nonmetals), polycyclic aromatic hydrocarbons (PAHs), pesticides, organohalogenes and other nanomaterials etc. During the plastic manufacturing process many chemicals like initiators, catalyst, flame-retardants, stabilizers, plasticizers, fillers, colorants, specific additives and many others are used. These additives are also released along with plastic waste. These interactions are synergistic, additive and antagonistic in nature. All such interactions play major roles in elevating the degree of pollution in water, soil, and air.<sup>[8]</sup> These micro and nano plastic particles exhibit multifaceted interactions involving enzymes too. In all probability, good number of these interactions do induce ecotoxic and degrading impacts. Investigations on enzymes like, carbonic anhydrous and esterase enzyme reflect on the 'existing lacunae' in the information about the interactions between micro and nano plastic particles.<sup>[9]</sup>

Interactions of micro and nano plastic particles with plants and plant tissues are interesting and worth considering to know their overall impacts on plants. The plants are an important component of ecosystem, mostly

considered as producers. It has been noticed that these minute end products of polymers compounds accumulate and distribute themselves in plants as a whole. Their entry in various parts of plants involves specific uptake, special transport mechanism, endocytosis, apoplasmic transport, crack-entry mode. Other factors that influence their entry in plants, are size, type, surface-charge, mechanical and chemical properties and more importantly, the physiological behavior of plant and environmental conditions prevailing. The translocation of micro and nano plastic particles reflects on the insight in to their movement-path in plants. This phenomenon also proves the functional role of plants in the regulation of plastic pollution. The recent investigations ensure various translocation paths of micro and nano plastic particles; these pollutants enter plants through roots, vascular system, foliar absorption (stomatal entry). After gaining entry in plant body, these distribute themselves in parts like leaves, stem and branches, floral components and fruits (seed). This indicates possibility of potential risks through crops and fodder to herbivores.<sup>[10]</sup>

As a result of their interactions with natural and synthetic matter like nano particles, polymeric compounds, sewages, mostly, form aggregates. These aggregates may be homoaggregates and heteroaggregates in physical form and have potent to pose difficulties in their investigations. These interactions are in accordance to conditions like pH, ionic type and valence, concentration of salt, shape, size, and type of the polymer used in the formation of micro and nano plastic particles. There is greater need to investigate various types of micro- and nano plastic particles so that relevant phytological remedial options can be envisaged.<sup>[11]</sup>

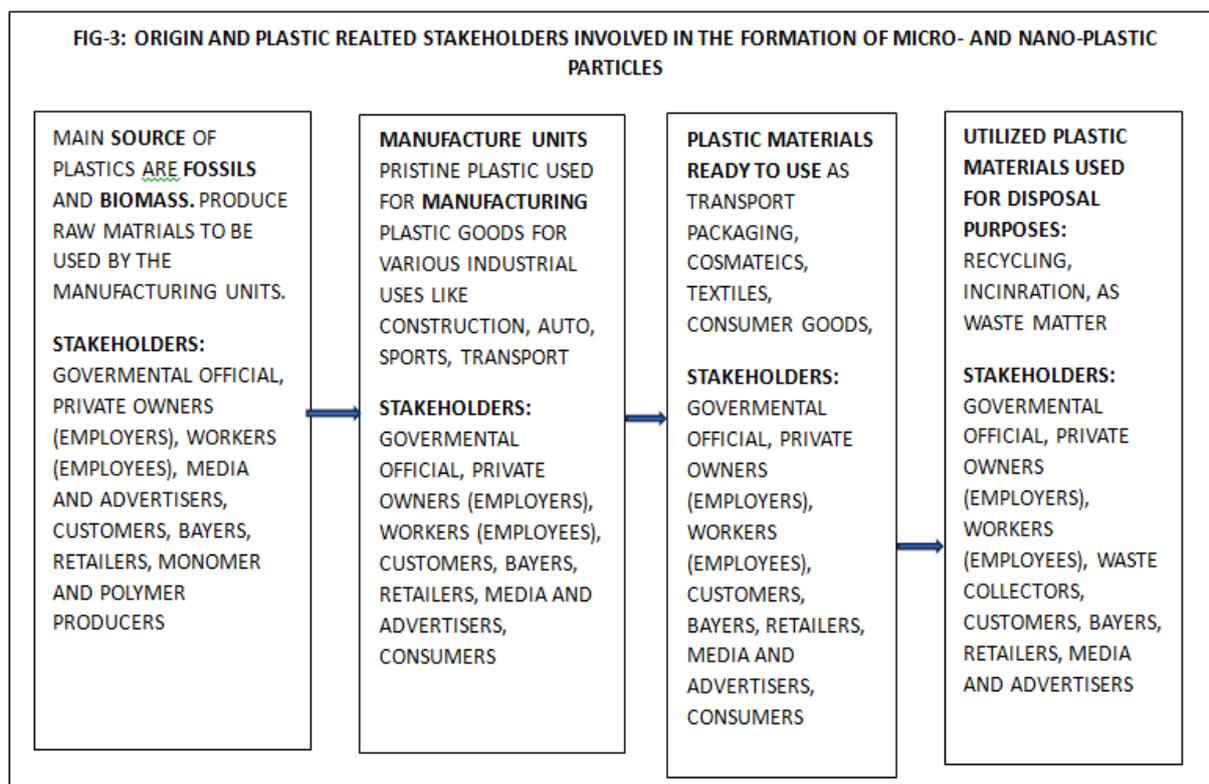
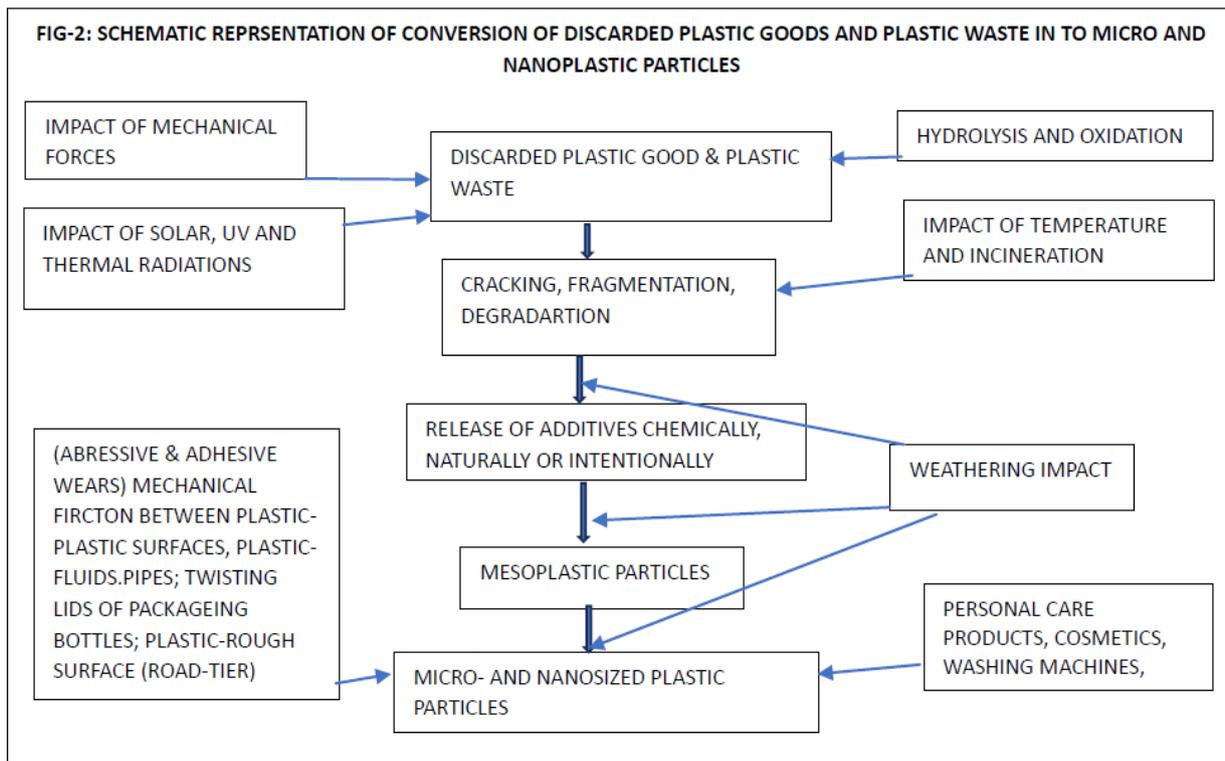
All animals, along with human-beings and members of plant kingdom are the compositional and functional units of the environment on earth and are under the influence of any change affecting the tendency to strive and survive. These animals are the part of consumer unit in the 'food' and 'energy pyramids/trophic level' of the ecosystem. When the ecosystem is highly contaminated with the micro and nano plastic particles vesting their influence. The micro and nano plastic particles are present in the aquatic bodies (fresh water, marine, estuarine) areal and terrestrial habitats. Micro- and nano plastic particles find easy entry in the tissues of the animals either via ingestion, respiration during feeding and respiration. On examination, fragments and plastic particles are observed in the systems of fish study samples<sup>[12]</sup> at pelagic, mesopelagic and demersal strata of water bodies. The micro- and nanoplastic fibers of PA, PE, and PET plastic polymers are seen in variable amounts in aquatic invertebrates and vertebrates. In short, these micro- and nano plastic particles find easy entry in the food-chain of ecosystem and reach the organisms of all the levels of food chain pyramid and reach its apex level.<sup>[13,14,15,16]</sup> Nano plastic particles invade body fluid like milk, blood and meat of the

livestock, and sensitive organ like spleen, body fluid and interfere with physiocytological aspects<sup>[17,18]</sup>, and placenta and liver, understandably, disrupting the normal functionalities living and in livestock.<sup>[12,16,19,20,21]</sup>

Why and how plastics?

Tendency of looking for alternatives to quench his tendency of new adventures. Man has developed polymers for their multiple applications based on their varied physical and chemical properties. These products have been extensively exploited. Polymers are the products of one of the major anthropogenic endeavour that man has endured. Basically, the polymers are the resultant products of crude oil, natural gas and coal and or petroleum products. These polymers exhibit great affinity to mingle chemically with others and forming resultant products which are useful as fillers, heat stabilizers, ultraviolet stabilizers, colorations, flame-resistant agents etc. Some of the most significant features are, durability, cost saving and low density. These polymers are produced in bulk quantity and do not involve complex mechanism. These lighter in weight and are mostly weather resistant (tolerant to sun-light, minimum impact of atmospheric temperature), rust proof and withstand the transportation stress. These polymers interact with variety of compounds forming products of multifaceted utility. These products meet the requirements of most of the industries and domestic requirements such as fillers, heat stabilizers, ultraviolet stabilizers, colorations, flame-resistant agents etc. The most common feature of these polymer products is their durability, reusability, diminished rate of disintegration prolonged durability. These features are beneficial as well as troublesome too.<sup>[22]</sup> Since, plastics are used in almost every field of life, their waste is also produced in huge amount. This plastic waste matters in due course of time act as primary source of micro and nano plastic particles.

According to one estimation there are 25 trillion macro and 51 trillion microplastic particles are present as litter in oceans. This is about 500 times the estimated number of stars in the Milky way.<sup>[23]</sup> This number and types are ever increasing in quality and quantity elevating the overall plastic additives-organic pollutants in the aquatic component of the environment. This tendency is totally ignored by the plastic industry as whole without realizing the derogative impacts caused on the environment. These effects are seen at three levels: (i) these added plastic particles inflict physical influence and also displace the nutrients available for the biota, (ii) micro and nano-plastic particles undergo sorption involving organic and metallic contaminants present in the vicinity, (iii) the monomers and the additive chemicals which are incorporated in the plastic particles undergo sorption. Environment is like a huge universal natural laboratory where each and every interaction proceeds in the natural conditions which are quite different than those of existing in the man-made laboratories.<sup>[24]</sup>



**GENERAL PHYSICOCHEMICAL PROPERTIES OF POLYMERS**

The physicochemical features of polymers play basic role in the structural aspects and the functionality of the polymers.<sup>[25]</sup> Following are the most common properties in brief.

Sr. No.	PROPERTY	BRIEF DESCRIPTION
1	DEGREE OF POLYMERIZATION AND MOLECULAR WEIGHT (Mol. Wt.) AND	DEGREE OF POLYMERIZATION DENOTES THE NUMBERS OF REPEATING UNITS IN THE POLYMER CHAIN; REPEATING UNITS MAY BE IDENTICAL OR NON-IDENTICAL. MOLECULAR WEIGHT IS THE PRODUCT OF DEGREE OF POLYMERIZATION AND THE MOLECULAR WEIGHT OF THE REPEATING UNITS. MOL. WT. CONCERNES WITH THE MECHANICAL STRENGTH AND THE THERMAL STABILITY OF POLYMER. IT RELATES WITH THE NUMBERS OF REPEATING UNITS IN A POLYMER CHAIN FORMING POLYMER MOLECULE.
2	DENSITY	IT AFFECTS THE WEIGHT AND THE STRENGTH OF A POLYMER. IT CHANGE ACCORDING TO THE STRUCTURE AND COMPOSITION OF SPECIFIC POLYMER
3	CRYSTALLINITY	IT RELATES WITH THE PHYSICAL FEATURES LIKE TRANSPARENCY, TOUGHNESS AND BRITTLINESS OF THE POLYMER. POLYMER CAN BE CRYSTALLINE, AMORPHOUS OR COMBINATION OF THESE TWO FORMS. CRYSTALLINITY HAS LAMELLAR, AMORPHOUS PATTERNS. IN LAMELLAR PATTERN THE POLYMER CHAINS ARE ARRANGED IN LAYERS FORM AND AMORPHOUS PATTERN POLYMER CHAINS ARE IRREGULAR FORM. POLYETHYLENE AND PET COME UNDER CRYSTALLINE POLYMER; POLYSTYRENE AND POLYMETHYL METHACRYLATE COME UNDER AMORPHOUS GROUP OF POLYMERS.
4	TENSILE STRENGTH (ELONGATION), THERMAL STABILITY, THERMAL EXPANSION	THIS FEATURE REPRESENTS THE ABILITY OF POLYMER (POLYMER CHAIN) TO WITHSTAND THE TENSION OR STRETCHING STRESS WITHOUT BREAKING. POLYMERS HAVING LINEAR SYMMETRY/PATTERN EXHIBIT HIGHER DEGREE OF TENSILE STRENGTH IN COMPARISON TO THOSE HAVING BRANCH/CROSS-LINKS PATTERN. THERMAL STABILITY REFLECTS ON THE ABILITY OF POLYMER TO WITHSTAND THE DEGREE OF HEAT/TEMPERATURE WITHOUT BEAKING OR DEGRADING. POLYMERS HAVING CROSS-LINKED POLYMERIC CHAINS SHOW HIGHER LEVEL OF THERMAL STABILITY. THERMAL EXPANSION CORRELATES WITH THE ABILITY OF POLYMER TO EITHER EXPAND OR CONTRACT IN RESPECT TO CHANGE OF TEMPERATURE. GENERALLY, POLYMERS HAVE ABILITY TO EXPAND WITH DIFFERENT DEGREE OF RESPONSE W.R.T. CHANGE IN TEMPERATURE. THIS RESPONSE IN DIFFERENT DIRECTIONS.
5	VISCOSITY	THIS FEATURE OF POLYMERS REFLECTS ON THE DEGREE OF EASE OF THE POLYMER TO UNDERGO THE MODE OF PROCESSING AND TO MOULDING PROCESS. VISCOSITY OF POLYMER DEPENDS ON THE TEMPERATURE AND MOL.WT. OF THE POLYMER.
6	FLEXIBILITY	AMONG POLYMERS THIS FEATURE IS COMMON. IT INDICATES THE PATTERN OF ARRANGEMENT OF POLYMER CHAINS AND ALSO EXISTENCE OF CROSS-LINK OR SIDE BRANCH IN A GIVEN POLYMER SAMPLE. POLYMERS WITH CROSS-LINKS CHAINS HAVE HIGHER DEGREE OF FLEXIBILITY AS COMPARED TO THE ONE WHICH HAVE NO CROSS-LINKS.
7	POLYDISPERSITY INDEX	THIS PARAMETER OF POLYMER INDICATES THE DISTRIBUTION OF MOLECULAR MASS IN GIVEN SAMPLE OF POLYMER AND ALSO INDICATES UNIFORMITY OF THE POLYMER CHAINS.

#### GENERAL PHYSICOCHEMICAL FEATURES OF MICRO- AND NANO-PLASTIC PARTICLES

Each and every particle present in the universe possess general properties and behave and leave impact/s in the ecosystem. The physical size of a particle is very

essential parameter and the particle may appear different in comparison to their source material.<sup>[25]</sup>

Some of the general physicochemical properties of micro and nanoplastic particles are as follow:

Sr. No.	PROPERTY	MICROPLASTIC PARTICLES AND PRIME FUNCTIONALITY	NANOPLASTIC PARTICLES AND PRIME FUNCTIONALITY
1	SIZE	5 mm TO 1 $\mu$ m; THIS PARAMETER FACILITATES THE MOBILITY AND THE RESPECTIVE MOLECULAR BHAVIOR WITHIN BIOSYSTEM.	SMALLER THAN 1 $\mu$ m; THIS PARAMETER FACILITATES THE MOBILITY AND THE RESPECTIVE MOLECULAR BHAVIOR WITHIN BIOSYSTEM.
2	SHAPE	(MOSTLY TWO DIEMNTIOANAL), SPHERICAL, RECTANGULAR, SHEAT/FILM LIKE, CUBICAL, RECTANGUKAR; THE SHAPES MAY VARY BUT THESE PATICLES HAVE HIGH MOL. WT. AND ARE BIOCHEMICALLY STABLE	(MOSTLY UNIDIMENSIONAL) SPHERICAL, CUBICLE, RECTANGULAR, SHEAT/FILM LIKE, IRREGULAR; THE SHAPES MAY VARY BUT THESE PATICLES HAVE HIGH MOL. WT. AND ARE BIOCHEMICALLY STABLE
3	CHEMICAL COMPOSITION, SURACE PROPERTIES, ADDITIVES, SURFACE CHARGE	CHEMICAL COMPOSITION DEPENDS ON THE CHEMICAL COMPOSITION OF THE PARENT MATERIAL, THE ADDITIVE INVOLVED WILL ALSO HAVE AFFECT,	CHEMICAL COMPOSITION DEPENDS ON THE CHEMICAL COMPOSITION OF THE PARENT MATERIAL, THE ADDITIVE INVOLVED WILL ALSO HAVE AFFECT,
4	WEATHERING IMPACT	THIS FEATURE REFLECTS ON THE IMPACT OF PROCESSES LIKE DEGRADATION, DISTINTEGRATION, OTHER PHYSICOCHEMICAL FEATURES AND THEIR INTRERATIONS AND UPTAKE BY BIOSYSTEM	THIS FEATURE REFLECTS ON THE IMPACT OF PROCESSES LIKE DEGRADATION, DISTINTEGRATION, OTHER PHYSICOCHEMICAL FEATURES AND THEIR INTRERATIONS AND UPTAKE BY BIOSYSTEM

#### BASIC DIFFERNCES BETWEEN MICRO plastic particles (MICRO PPs) AND NANO PLASTIC PARTICLES (Nano PPs).<sup>[26]</sup>

1. Generally, Micro PPs change into Nano PPs as a result of mechanical wear, aging processes and impacts of environmental factors.
2. Micro PPs exhibit size variations between 100 nm to 5mm and Nano PPs are below 100 nm.
3. Micro PPs show sedimentary tendencies with respect to the buoyancy and nano PPs remain highly suspended.
4. The specific surface area is less in micro-PPs than nano-PPs.
5. The specific surface area of micro-PPs has lesser molecules and functional groups while nano-PPs have more of molecules and functional groups. As a result, micro-PPs have relatively lesser interaction with other pollutants and nano-PPs have higher interaction with other reactants.
6. The micro-PPs have lower degree of bioactivity while nano-PPs have higher bioactivity.
7. Sedimentation rates of micro-PPs and Nano-PPs varies in pure water than in humic acid, a mixture of humic acid and NaCl and high concentration of NaCl; pure humic acid it is practically zero percent; the sedimentation rate increases as the concentration increases while micro-PPs do not settle.

8. Micro-PPs when ingested in aquatic animals, mostly, pass through alimentary canal and egested along with feces while nano-PPs distribute themselves throughout the body (these nanoparticles can move through biological barrier) and (increase anti ROS level to combat ROS formed due to nano-PPs).
9. Micro PPs having size 45  $\mu$ m, elevate mucin secretion, D-lactate and diamine oxidase level in gut (diamine oxidase breaks down dietary histamine declining the level of histamine. Low levels of histamine results in headache, skin reaction and digestive issues in human).
10. Micro-PPs cause major changes in the gut microbiomes but nano-PPs result in minor or no changes in the gut microbiomes.

#### THE SURFACE PROPERTIES OF BULK PLASTIC MATERIALS AND MICRO-AND NANO-PLASTIC PARTICLES AND THEIR SIGNIFICANCE

The basic surface properties play an effective role during the interactions between plastic materials and other organic and inorganic materials. The for examples feature like, size, contact angle, surface-energy, surface tension, buoyancy etc., have their own significances. These properties regulate the physicochemical interactions between plastic particles and other

interacting molecules of materials. These features regulate the degree of adhesion, wetting behavior, coating, printing, and performance of the final products, for example, contact-angle indicates the degree of interaction between the surface and the fluid/liquid, wettability and secure binding between the plastic products. The contact-angle also reflects on the selection of suitable adhesive materials, surface coatings, and the age of the bond formed between the surface and the molecules of the materials involved.<sup>[27]</sup>

Generally, the surface properties of bulk plastic undergo drastic changes or modifications at micro and nano-sized particles resulting in highly enhanced degree of interaction between plastic particles and the interacting molecules. This is because of the size, shape and changes in physicochemical properties. These properties of micro and nanoplastic particle impact biosystems and the tissues too. These modifications enable their intense interference with physiological and biochemical pathways of the biosystem. In micro and nanoscale-plastic particles the 'area to volume' ratio changes drastically and render them 'multifaceted disturbers' which cause changes in the physiological and endocrinological mechanisms in a biosystem. Thus, the micro and nano sized plastic particles act as a necessary evil. It becomes imperative to investigate such fluctuations and find some remedial options. Such investigations along with their impacts on the interactions between these micros and nanoplastic particles and the environment. Some of the techniques such as atomic force microscopy, scanning electron microscopy, Raman spectroscopy, help to investigate the morpho-chemical aspects on these crucial particles involving suitable test animal.<sup>[28]</sup> The surface and physicochemical properties play very significant role during their interactions between micro and nano-plastic particles. Quite often, some of these parameters change the environmental conditions and physiological environment within organisms. Thus, possibly, these parameters and properties like surface charge, density, dispersion, overall size, contaminants, molecules adsorbed, cellular interaction and electrophoretic characteristics can change. The micro and nano plastic particles adsorb organic pollutant along with the sorbed molecules, pesticides, phenanthrene etc., become internalized in aquatic organisms, as a result, micro and nano and the adsorbed molecules undergo processes such as bioavailability, biodistribution, bioaccumulated, in the bodies of members various trophic levels, energy levels in the given ecosystem. All these events cause bioaggregation, biomagnification in food-webs. The related investigations based on mathematical, computational, methodology; under the concept of time and length concept.<sup>[22,29,30]</sup>

#### **IMPACTS OF MICRO AND NANO PLASTIC PARTICLES ON VERTEBRATES AND HUMANS**

Procuring and disposing plastic waste is subjected to either recycling or degradation in natural conditions. During these processes the bigger pieces are converted in

to micro and nano plastic particles. These are rendered as pollutants in areal, aquatic media and in soil. These are the dominantly very reactive toxicants and along with their adsorbed molecules/microbes are potential sources of health risks in an environment. These micro and nano sized particles primarily enter the biosystem via digestive and respiratory systems (ingestion, respiration) and thereafter, well protected vital body parts, like brain etc. These particles have ability to move across the biological barriers, thus, nanoplastic particles have access to all the body parts while micro plastic particles mostly remain within gut. This parameter of the micro and nano plastic particles is size dependent. They have relatively easy entry to 'gut-brain axis' of the biosystem. The observations on related investigations involving cell culture and the animal test animals have been extrapolated in higher vertebrates and humans. The nano plastic particles internalize in the cells of gut and the cerebral cells result in viability induction and cause histophysiological destruction like, oxidative-mediated stress response while micro plastic bring about dysbiosis as response in alimentary canal. As these micro and nano plastic particles act as carriers for other toxins (organic and inorganic, and microbes) affecting the behavior of the animals initially and finally, physiological disruptions. These reach other vital organs of animals and via their easy passage through various biological barriers. There are confirmed reports in case of aquatic test animals. These nano plastic particles readily reach other internal organs, like spleen, kidneys, gonads; this distribution is in proportional to the surface modifications of nano plastic particles, more so if the surface has a negative charge. The impact of micro and nano plastic particles (45 $\mu$ m and 50nm respectively) include selective accumulation of these particles in gut, nano plastic particles elevate the antioxidative enzyme activity like superoxide dismutase, catalase in the tissues of alimentary canal, apoptosis and breaks in DNA. The micro plastic particles are more effective in dysbiosis in gut while most of the nano plastic particles involve in disrupting redox balance.<sup>[31,32]</sup>

These micro and nano plastic particles induce the production of reactive oxygen species (ROS), molecular oxygen and ROS can act as toxic molecules. Oxygen is under the control of antioxidant system which in turn is regulated by enzymatic and non-enzymatic mechanisms. These processes involve hydrophilic compounds like uric acid, vitamin-C, bilirubin and glutathione, and hydrophobic molecules like vitamin-E; other enzymes that relate directly with metabolism of ROS (superoxide dismutase and catalase) or maintain the supply of reduced ROS i.e., glutathione reductase.<sup>[33]</sup>

The nano plastic particles cause dysbiosis among intestinal biota within lumen of gut thereby, resulting in imbalance of microbes in intestine. Nano plastic particles after reaching gut interact with the cells of intestinal barrier (epithelial cellular lining) causing declined cytological integrity, uncontrolled high permeability and

reduction in the secretion of mucin. These particles reach blood circulation from gut. These influence the vagus nerve and the afferent nerve fibres and send message to brain while in blood circulation. The complex network of neurons embedded within wall of the gut and functions independently to central nervous system and is also called 'Enteric nervous system' or 'second brain'; the nano plastic particles also impact this enteric nervous system. The nano plastic particles impact brain and activates the 'hypothalamus-pituitary-adrenal axis' which in turn influence kidney and gut. Brain also affects vagus nerve and efferent nerve fibers which in turn also affects gut and kidney. The nano plastic particles while in circulation affects the short chain fatty acids metabolism.<sup>[26,34,35]</sup>

#### PROBABLE MODES OF INTERACTIONS BETWEEN MICRO- AND NANO-PLASTIC PARTICLES AND METAL AND METALOXIDE NANOPARTICLES

The study relating interactions between metal and metal oxide nano-particles and micro and nano-plastic particles opens a vast horizon for researchers. These interactions can be useful and of practical and remedial utilities. The properties of these two categories of materials add to the resultant matrices and enhance their utilities. Metal and metallic oxides nanoparticles get incorporated with micro- and nano-particles forming 'nanocomposites' on the bases of thermoplastic matrices concept. The amalgamation (plastic) of metal and metallic oxide nanoparticles and micro- and nano-plastic particles impacts some of their properties like, mechanical, thermal and antimicrobial capabilities. The resultant products (matrices) show relatively more suitable range of temperature and mechanical resistance, thereby, increasing range of their applications. The combination of antimicrobial metal and metallic oxide nanoparticles and micro- and nano-plastic particles also result in antimicrobial products which make them suitable to be used in medical, biochemical, biomolecular and health care fields. These products are also applicable for the uses as food-packaging materials.<sup>[36,37,38,39]</sup>

The physicochemical properties like size, charge and surface area of particles of these two categories increase their surface area to increase the degree of sorption and increase in reactivity which helps to enhance their catalytic efficacies. As a result, the resultant nanocomposite polymers have higher degree of adsorption and can be useful to separate the inorganic and organic contaminants from the wastewater. Mostly, metal ions, dyes, organic and inorganic pollutants are present in the industrial effluents and this waste needs effective treatment so that one can prevent the deterioration of quality ground water, to elevate effectivity of process of water purification and reduce the impacts of the toxins present in it. The polymers nanocomposites play an effective role in the treatment of such wastewater; these composites have much higher surface area and higher degree of adsorption and/or degrading

efficacy. These features facilitate the quality of wastewater treatment and render the water reusable. These polymer nanocomposites are readily applicable in the medicine, electronics, sensors, coating industries, aerospace, drug delivery, food industry and remediation of environment. Thus, one can make of wastewater reusable using specific polymer nanocomposites.<sup>[40]</sup>

Good numbers of metal and metal oxide nanoparticles exhibit and behave like good sorbents, catalysts, sensors, reducing agents and bactericides. As they have high surface to volume ratio, these show faster rates of kinetics and elevated capacity to sorption. But these particles have a tendency to aggregate and when these flow through a system under high pressure, they lose their specific reactivity and their mechanical strength and becomes weak; as a result, their 'real-life reactivity' declines. Whereas the biopolymers and functionalized polymers are robust, stable chemically and can be chemically modified in accordance to the intended needs. Functionalized polymers and biopolymers are synthetic/semisynthetic functionalized materials. These polymeric materials can be micro- and or nano-sized plastic particles. These are completely a different class of organic materials because they are robust, chemically stable and amenable to chemical modifications depending on the intended applications. Such materials are known as 'reactive polymers', ion-exchangers. These are exploited in the fields of mining, microelectronics, deionization to decontamination, synthesis, sensing, desalination and drug-delivery systems. The interaction between the specific polymeric micro- and nano-plastic particles and metal and metallic oxide nanoparticles can maintain their respective degree of stability and functionality. The metal and metallic oxide nanoparticles show aggregation, thereby, their size alters and functionality gets affected. The polymeric particles play significant role in reducing the degree of aggregation of these nanoparticles and help in maintaining the respective size. Thus, the high surface area and functionality of the metal and metallic oxide nanoparticle do not change. This stability of these nanoparticles facilitates their applications in reactivity, catalytic and sensing efficacies. 'Polymer-supported metal and metal oxide nanoparticles' constitute a separate class of materials which have properties different than polymer-molecules/materials and inorganic nanoparticles as individuals. Hence, this class of materials are under 'polymer-supported-nanoparticles' (for convenience sake). The metal oxide and metal nanoparticles are dispersed in the matrix/phase of the polymer materials. This dispersion depends on the mode of their formation i.e., *ex-situ* or *in-situ* processes. The physical configuration of polymeric materials may change from rounded beads, granular, membranous, fibrous, etc., but metallic and metal oxide particles are always as nanosized. The intrinsic features of nanoparticles remain unchanged while those of polymeric materials may change. Thus, there is practically no hindrance in the

overall intended applications of the polymer-supported-nanoparticles.<sup>[41,42,43]</sup>

The probable successful applications to incorporate micro and nanoplastic particles with metal and metal-oxide nanoparticles include preparation of antimicrobial coatings. These coatings are helpful in the use of medical and food packaging and the related products. These coatings reduce the risk of contamination and check the growth of microbes. The 'polymer-nanocomposites' enriched with metal and metal oxide nanoparticles exhibit proficiency to adsorb pollutants from the wastewater, thus, these products enhance environmental clean-up processes. These polymer-nanocomposites act as are good sensors and detectors for contaminants. The best aspect of these polymeric nanocomposites is these can be synthesized for a desired intentions to meet the specific needs.<sup>[40]</sup>

### INTERACTIONS BETWEEN MICRO AND NANO PLASTIC PARTICLES AND CARBON NANOPARTICLES

Carbon nano particles like, graphene, graphene oxide, carbon nanotubes, metal modified carbon, fly ash and activated carbon or carbon biochar exhibit exceptional conformational features. These properties elevate the degree of efficacy of extracting micro and nano plastic particles from the aqueous waste. This separation ability is in congruence with the exceptional structural aspects and adjustable surface properties of carbon nano particles and also the micro and nanoplastic particles. This is the reflection of the applicability of carbon-based adsorbents which highlights the intensity of functionalization and analytical interactivity between both of these categories of nano materials. Looking at the extent of water pollution, it is imperative to find better and efficient performers in water purification to solve the global water crises.

Generally, micro and nano plastic particles are extracted from aqueous medium using biochar. There exist chemical bonding and chemical attraction among these plastic particles in test samples. These particles potentially affect physicochemical features like pH, EC (electric conductivity), TEC (total organic matter), CES (cation exchange capacity), of the soil. The microbial activities and greenhouse gases emission get affected in the presence of micro and nano plastic particles in soil. Biochar acts as an agent that elevates the biological properties like maintenance of alkaline pH, porosity, aggregation of micelle, water holding capacity, bioavailability of soil nutrients, and growth of soil-microbes even if the soil contaminated with micro and nano-plastic particles and metalloids. The role of biochar is significant in maintaining biomass, soil-respiration and microbial and micro-rhizoidal diversity.<sup>[44,45,46]</sup> Biochar has potentials to synergistic amendment of physicochemical and biological specifications as per the need and also to establish persistent efficacy of functional aspects of ecosystem that facilitates the

sustenance of biodata and non-biotic factors.<sup>[47,48,49]</sup> The biochar is one of the most suitable to promote remedial environmental prospectus of soil. The polluted and contaminated soil can regain its natural optimum physicochemicobiological identity.<sup>[50]</sup> The physicochemical aspects of particles of biochar like, its pH, electrical conductivity, cation exchange capacity etc., and biological efficiency of biochar maintains the soil fertility.<sup>[51,52]</sup>

The prime features of carbon nanoparticles like act like an absorbent. This feature of carbon nano particles relates with their physicochemical features like, particle size, carbon contents, pore-size and available surface area. Further, other properties such as hydrophobic interaction between these two, van der Waals forces and their interaction,  $\pi$ - $\pi$  interactions along with electrostatic interactions are the key-factors involved during the interaction between carbon nanoparticles and micro and nano plastic particles. The degree of interactions between micro and nano plastic particles and the carbon nanoparticles along with biochar basically relates with the carbon contents and the degree of porosity of active carbon and biochar but the modified carbon nanoparticles exhibit high degree of adsorption of micro and nano particles. There is a need to review the importance of understanding the relationship between surface characteristics and adsorption efficiency to develop optimized adsorbents for microplastic particles removal from wastewater. However, challenges such as the lack of standardized testing methods, variability in biochar performance, and the high cost of regenerating carbon adsorbents remain to be delved into. Future research should focus on developing cost-effective production methods, optimizing biochar production, and exploring advanced modifications to broaden the application of carbon adsorbents. Integrating advanced adsorbents into existing water treatment systems could further enhance the microplastic removal efficiency. Addressing these challenges can improve the effectiveness and scalability of carbon-based adsorbents, significantly contributing to the mitigation of microplastic pollution in wastewater.

Each of the carbon nanoparticle has some specific feature which facilitates their respective ability to interact with the toxins and other obnoxious matter for their extraction from aqueous media. Activated carbon is most suitable in its fine powdered form and so is the biochar. Biochar has an array of woody-bio-mass source like, pea-nut hulls and various diary manure (agricultural waste) and its lower production cost effectiveness at higher scale in comparison to the activated carbon for bulk use. These forms of carbon are also preferred for other processes like carbon sequestering, enhancement of soil fertility and enhancement of environment. Graphene is made of single layer of a 2D-hexagonal carbon network; graphene oxide and reduced graphene oxide offer a highly specialized zone. The magnetically carbon nanotubes are good agents to isolate on polyethylene

(PE), polyethylene terephthalate (PET), and polyamide (PA) and all the MPs/M–CNTs composites were readily separated from aqueous solutions by magnetic force.<sup>[53,54,55,56,57]</sup>

### INTERACTION BETWEEN MICRO AND NANO PLASTIC PARTICLES AND LIPOSOMES

Generally, pristine and processed plastic particles are grouped based on their surface chemistry, zeta-potential, and elementary composition.<sup>[58]</sup> There seems to be relatively less data concerning plastic particles and their interaction with liposomes; hence, there is a need to investigate this aspect. During the study involving biological fluids i.e., artificial lysosomal fluids and Gamble's solution for 2 to 80 h, different toxic endpoints like, effects on potential on the membrane of mitochondria, proteins, lactate dehydrogenase activity, along with antioxidant state effects of micro and nano plastic particles (both pristine and processed; as found in nature) and the A549-lung carcinoma cells. These plastic particles induced toxicological impacts in relation to their chemical features and the reactive groups actively present on their surface.

In general, the impacts of the aged/weathered/treated/pristine plastic particles are different than the impacts of pristine micro and nano plastic particles.<sup>[59]</sup> Further, the overall toxic behavior, bio-accessibility, bio-durability and the biological impacts of micro and nano particles may differ *in vivo* and *in vitro* simulated conditions.<sup>[60]</sup> There is possibility that basic and surface physicochemical of micro and nano plastic particles and their tendency of formation of biofilm may show overall different behaviour in simulated biological environment in comparison to natural and controlled conditions.<sup>[61]</sup> The combined effect of micro and nano plastic particles and antibodies may provide a protective layer. The interactions between micro and nano plastic particles and antibodies indicate mitigation of the toxicity of antibiotics and ability to moderate the impacts of pollution. But the related investigations reflect on the synergic impact rather than the impact of individual reactants; thus, the combined effect of these reactions is balancing the derogative effects of both. It is essential to investigate further to understand the mechanism involved. These studies will elucidate the remedial and mitigatory responses relating pollution caused by micro and nano plastic particles, pesticides and antibiotics.<sup>[62]</sup>

### MICRO AND NANOPLASTIC PARTICLES AND THEIR ROLE IN THE DAY-TO-DAY LIFE OF HUMANS

Invention, production, existence, decomposition, infiltration of micro and nanoplastic particles, and transformation of plastic goods, all are anthropogenic undertakings to meet the personal, social, industrial, domestic needs and to hasten the day-to-day life activities keeping economical and utility preference. Plastic goods are in use in every aspect of life such as construction materials, goods of domestic utility,

biomedical tools, agriculture, personal-care materials etc. To meet such huge demands their production has increased up to 460 million metric tonnes in the year 2023 and is likely to elevate much higher in the future.<sup>[63]</sup>

Some of the plastic polymers which are most needed such as polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polyurethane (PU), polyethylene terephthalate (PET), polyethylene (PE), polyester (PES), polystyrene (PS), and polyamide (PA). They have been manufactured to the tune of 8.7% annually and at a higher rate to meet the demands.<sup>[64]</sup> Of these plastic product polyethylene terephthalate PET is in demand, hence, its production is relatively higher. Recently, the intentional chemical recycling of PET is on the increase. The polyethylene terephthalate can be readily degraded chemically. This product is hydrolysed into ethylene glycol, this in turn is catalytically changed into glycolic acid. This practice is adopted to degrade the waste material from PET. The challenges and hurdles in this direction which are being tackled. Phoenix started a project which intends to convert PET waste in to glycolic acid and along with it produces propanol.<sup>[65]</sup>

Plastics have unique 'organic decompositional capability' and because of this feature these are big threat to the ecosystem. The end products of these plastics distribute themselves in the three components of natural environment i.e., aquatic, aerial, soil and food chain.<sup>[65]</sup> The end products of these plastic materials are not managed appropriately and exposed to lower rate of reduction, recycling, reusing and recovering, (R.R.R.R.) resulting in the accumulation of waste, end products and micro and nanoplastic particles which gets added to all the components of the environment.<sup>[66]</sup> The International Union of Pure and Applied Chemistry classify plastics as a 'polymeric material' having various additives that activate and elevate their performance and cost-effectiveness.<sup>[67]</sup> This practice along with seemingly social and federal negligence, the plastic waste has become a serious 'global issue'. The waste from plastic goods undergoes decomposition, biodegradation, impacts of ultraviolet radiation (natural and man-made sources) resulting in the formation of macro, meso-, micro and nano plastic particles. In all probabilities, the fragments are not entering further break-down processes and these products do not enter any biological cycle like the end products of other biomaterials but remain untreated in all the three major components of environment and pose a threat to entire environment and globe. These micro- and nano plastic particles are less than 1 $\mu$ m (SI units) forming major chunk of plastic litter. These are present as hetero- and/or homeo-aggregates with size rang 1 to 1000 nm and exhibit colloidal behavior.<sup>[68,69,70]</sup> In all probabilities, the constituents of plastic litter undergo a process called 'total-mineralization'; this process is very slow and time-consuming.<sup>[71]</sup> This duration allows these man-made products enough time to induct serious environmental threat and risk to the health of biota and

ecosystem. Technically, in soil science technology, oxidation plays main role in mineralization to convert nutrients into organic matter and soluble inorganic form which become available to plants as minerals.<sup>[72,73]</sup> Thus, mineralization enhances the bioavailability of nutrients present in organic matter to the plants in relation to their respective quantity present in organic matter. Nutrients like nitrogen, phosphorous, sulfur etc., are also present in a specific ratio to carbon, in the organic compound. The mineralization occurs only if the quantity of specific nutrient (element) is more than the requirements of the decomposer for either storage or biosynthesis.<sup>[74]</sup>

The micro and nano plastic particles exhibit specific behaviour and undergo sedimentation under the influence of buoyancy.<sup>[68]</sup> In most of the cases, micro and nano plastic particles show colloidal behavior and appear as particulate matter. There is a physical change in these particles and behave like colloidal particles and can undergo chemical partitioning showing sorption mechanism. Because of these reasons they adopt specific toxic features and impact the inorganic and organic components of environment.<sup>[75]</sup> All internal organs have epithelial cellular lining which readily up-takes these micro-and nano plastic particles depending on their sizes and later translocate into the lumen of digestive system. These also move to the other organs of a biosystems.<sup>[64,76]</sup> The nano plastic particles have higher ability for effective translocation through biological membranes in comparison to the micro plastic particles.<sup>[77]</sup> The micro and nanoplastic particles also behave as vectors and carriers for the toxic metals, hydrophobic organic molecules because of their surface chemistry that adversely affect the variety of biota.<sup>[78]</sup> The agricultural soil is better repositior agent than the soil in aquatic media or ecosystem.<sup>[79]</sup> Although micro and nano plastic particles are produced as a result of varied industrial processes and from different sources but these particles can enter the various biota and the ecological food chains along with their loads of toxicants. This phenomenon makes them agents that cause the derogative health issues in the members of various biological systems.<sup>[80]</sup>

Basically, nanosized plastic particle have primary and secondary origin. Primary nano plastic particles are manufactured from virgin plastic materials such as 'pallets' and used for goods used for industrial applications. These goods are small, big, and various shapes suitable for industrial purposes/needs. The 'nano and micro-beads' are preferred for the manufacture of personal care materials, cosmetics, domestic and industrial cleaners, creams. The secondary micro- and nanoparticles are the products of fibers and particles from nylon, PA, PES formed as result of physical processes like pulverising, disintegrating, degradation, fracturing, splitting, abrasion, mechanical wear and tear, impacts of UV radiation, biological degradation etc., of the plastic debris, or plastic to be recycled and any goods containing plastic. Micro as well as nano plastic particles

get distributed in each and every nook and corners of the globe, deep down substrata of sea-sediments and the snow-covered mountains and all of the geographical zones of globe irrespective of climate, temperature condition prevailing on earth.<sup>[81,83,83,84,85,86,87]</sup>

The micro and nano plastic particles show high tendency of leaching and also have potential to inflict toxic influence on the biota of the ecosystem. These derogative impacts may be carcinogenic nature and disrupt the endocrine functionality of the biosystem.<sup>[84,87,88,89]</sup> The plastic debris undergo oxidative photodegradation process resulting in the formation or release of deleterious and detrimental by-product called 'volatile organic compounds' (VOC, like acrolein, benzene etc.); these products affect biota and the ecosystem.<sup>[90]</sup> The micro plastic particles have surface properties and chemical structural aspect and because of these features, the micro and nanoparticles interact with toxic metals, behaves like vectors for the microorganisms which are antibiotic resistant and even the pathogens.<sup>[91,92]</sup> The interactions between micro and nano plastic particles exhibit quite contradicting observations; some the reports indicate negative, lethal impacts, while some researchers report on detoxification influence. Possibly, these variations relate with concentrations, duration of exposure and general health of a biosystem.<sup>[87,93]</sup> Micro and nano plastic particles also behave with biota of the environment and are able to move across blood brain barrier uninterrupted but there appears to be some ambiguity regarding concentration of micro and nano plastic particles within the experimental animals and the concentration of plastic particles in either ambient medium and the concentration existing in the test animals.<sup>[94]</sup> Thus, it is most essential to know the exact amount of these particles in and around the test animals and ambient environment.

Likewise, human population undoubtedly exposed to micro and nano plastic particles; this is possible as air, water and food along with other associated products are enriched in these particles and get 'up-taken' in human or animals via entry-ports such as dermal, pulmonary or experimentally administered. These observations encourage and compel to undertake intensive investigations.<sup>[95,96,97,98]</sup> There are ample proof of administration of micro and nano plastic particles via alimentary canal/digestive and respiratory systems. This indicates the uninterrupted movement of these particles through the barrier present in these systems, even vital organs like central nervous system specifically brain. During investigation the proportion of these particles, false-positive and false-negative observations and quantification of micro and nanoplastic particles play significant role in decision making about the deleterious, toxic and physiological impacts of these particles on biota, food chain, biodistribution, bioaccumulation and biomagnification in a given ecosystem; all these are likely to guide for the remedial aspects. The micro and nano particles are the product of specific polymer plastic

source, its applications, mode of utility, and the physicochemical properties of their sources and all these factors indicate the diversity of these particles. There is a basic need to establish a well organised programme that standardise the physical, chemical and biological attributes like size, density, hydrophilic or hydrophobic and surface features, behavior with the animals tissues and their metabolic status in biosystems along with the type of polymer.

## CONCLUSION

The ongoing discussion reveals that micro and nano plastic particles and nano materials have become the part and parcel of our ecosystem. Despite of the untiring efforts their total elimination from the ecosystem seems to not possible to eradicate them. Nano particles can provide some of the remedial options with regards to separate micro and nano plastic particles but there is a need to investigate more deeper in to the problem. Both groups of the materials exhibit specific properties depending on the size, nature, and their targeted purpose but leave behind the innumerable side and after effects which are disturbing the environment and its contents immensely.

There is a need to review the importance of understanding the relationship between surface characteristics and adsorption efficiency to develop optimized adsorbents for microplastic particles removal from wastewater. However, challenges such as the lack of standardized testing methods, variability in biochar performance, and the high cost of regenerating carbon adsorbents remain to be delved into.

One has to find a feasible mode of natural remedial approach of their end products. Total chemical degradation of plastic part may be possible but there is a need to study other types of plastic depending on their physicochemical nature and find some chemical mode to break down to other useful or inert noninterfering products. The physical break up may form the products which will be harmful or ecologically disturbing the environment. The whole scenario of current state of affair distinctly represents a prey entangled in invisible cob-web trying to free itself but in vain.

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