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Current research trends on micro- and nano-plastics as an emerging threat to global environment: A review

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ABSTRACT

Micro-and nano-plastics (MNPs) (size < 5 mm/<100 nm) epitomize one of the emergent environmental pollutants with its existence all around the globe. Their high persistence nature and release of chemicals/additives used in synthesis of plastics materials may pose cascading impacts on living organism across the globe. Natural connectivity of all the environmental compartments (terrestrial, aquatic, and atmospheric) leads to migration/dispersion of MNPs from one compartment to others. Nevertheless, the information on dispersion of MNPs across the environmental compartments and its possible impacts on living organisms are still missing. This review first acquaints with dispersion mechanisms of MNPs in the environment, its polymeric/oligomeric and chemical constituents and then emphasized its impacts on living organism. Based on the existing knowledge about the MNPs' constituent and its potential impacts on the viability, development, lifecycle, movements, and fertility of living organism via several potential mechanisms, such as irritation, oxidative damage, digestion impairment, tissue deposition, change in gut microbial communities' dynamics, impaired fatty acid metabolism, and molecular damage are emphasized. Finally, at the end, the review provided the challenges associated with remediation of plastics pollutions and desirable strategies, policies required along with substantial gaps in MNPs research were recommended for future studies.

1. Introduction

Generation, dispersion and accumulation of microplastics (MPs) are gaining attention all around the globe, similarly, their increasing environmental impacts become a challenge for researchers and policies makers (Kumar et al., 2020; Xu et al. 2020; Wu et al., 2019). Plastic fragments having size smaller than 5 mm are considered as MPs, which can show bioaccumulation and biomagnification potency (Li et al., 2018; Kumar et al., 2020). The polymeric constituents of MPs generally found in natural setting include polyvinylchloride (PVC), polyethylene terephthalate (PET) polypropylene (PP), polyethylene (PE), polystyrene (PS), Low-density polyethylene (LDPE), and high-density polyethylene (HDPE) (Bolan et al., 2020; Horton and Dixon, 2018; Kumar et al., 2020). In 2016, approximately 27.1 million metric tons (Mt) of plastic wastes were collected in the European Union (EU), of which 31.1%, 41.6%, and 27.3%, were recycled, reused (for energy production), and dumped again on the landfill site, respectively (Plastics Europe, 2018). The mismanagement and dumping of domestic and commercial plastic wastes is the major cause of pollution to natural setting (Fig. 1a). Natural environments are receiving MPs in the form of anthropogenic direct

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release as well as disintegrated and loose products of lager plastics via biological activities, mechanical abrasion, and UV radiation (Machado et al., 2018; Galafassi et al., 2019). Considering the persistent nature of MPs in the environment, this is an emergent issue of the forthcoming future (Bolan et al., 2020; Aslam et al., 2020).

MPs are now-a-days ubiquitously present in all the compartments of environment (lithosphere, hydrosphere, and atmosphere). There have been several recent reviews published, which discuss the fate, and occurrence of MPs in natural setting (Kumar et al., 2020; Xu et al. 2020; J. Wang et al., 2019; Wu et al., 2019). Marine MPs were investigated by

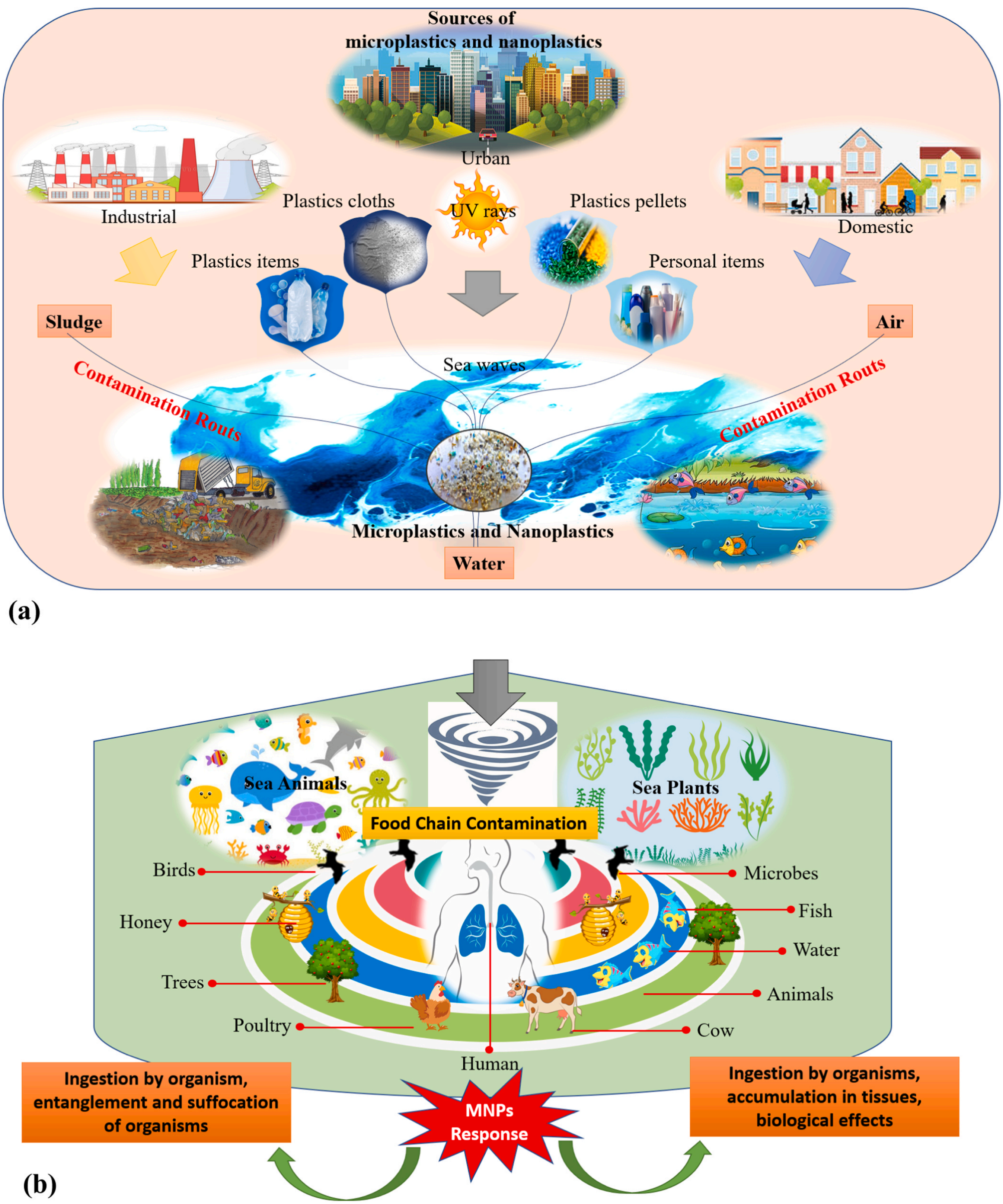

Fig. 1. (a) Sources and possible routes of micro plastics (MPs)/micro-nano plastics (MNPs) contamination and (b) impacts/responses.

a groups of researchers, and their presence has widely been demonstrated in the coastal environments (Aslam et al., 2020; Gallo et al. 2018; Kane and Clare, 2019; Wu et al. 2019). The fresh water system is also considered as potential sink of MPs (Wagner and Lambert, 2018; Strungaru et al., 2019; Prokić et al., 2019). Zbyszewski and Corcoran, (2011), reported for first time the existence of MPs in freshwater system during the shoreline survey of the Lake Huron, Canada. Recently C.R. Li et al. (2020) reported the diverse concentration of MPs in riverine system (surface runoff and sediments) in Australia, Asia, North America, and Europe.

Terrestrial ecosystem including agricultural soil is also gaining attention of MPs contamination recently, due to agricultural intensification and landfilling practices of plastics (J. Li et al. 2020; J. Wang et al. 2019; Xu et al. 2019; Pagano et al., 2019; Savoca et al., 2019b). Horton et al. (2017a), recently estimated and reported, occurrence of 4–23 time more MPs in terrestrial environment than marine environment. Terrestrial environments display different physico-chemical characteristics in comparison to aquatic environments. The occurrences of MPs in industrial soils (Rillig and Bonkowski, 2018; J. Li et al., 2020), agricultural soil (Liu et al., 2018), home garden soil (Lwanga et al., 2017), coastal soil (Zhou et al., 2018), and floodplain soil (Scheurer and Bigalke, 2018) were investigated, with a wide range of concentrations. Occurrence of MPs in terrestrial soils shows diverse toxicity and environmental effects on flora and faunas of the soils (Rillig et al., 2019; de Souza Machado et al., 2018). MPs polluted soil displayed negative impact on functioning of indigenous plants and soil microbial community (Guo et al., 2020; Xu et al., 2020). More crucially, uptake of MPs by plants (crops) has been noticed, thereby reaching to higher trophic level (biomagnification) and posing more adverse impact (Chae and An, 2020; Sun et al., 2020) (Fig. 1b).

Nanoplastics (NPs) are formed during the disintegration of bigger plastic waste materials (Gigault et al., 2018a, 2018b) or generated from impregnated/engineered nanomaterials (Ferreira et al., 2019). Recently, NPs, which are considered as the smaller-sized unit of MPs, have been gaining attention (Wagner and Reemtsma, 2019). The exact classification of NPs by scientific community is still under investigation. Few investigators established the maximum size limit up to 1000 nm (Cole and Galloway, 2015; Gigault et al., 2018a, 2018b), whereas others set the size range 1–100 nm, according to the definition given by universally acceptable nanomaterials society (Ferreira et al., 2019). NPs, imposed more potential risk in comparison to MPs as it can easily able to enter in cells/tissues. Complexity in separation and identification of NPs, its abundance in the environmental setting has been generally overlooked till date. Hence, the physical presence and health menace of NPs may be under rated. In this review we collectively used the term MNPs for MPs and NPs. This review mainly covers the occurrence, migration/dispersion mechanism of MNPs and its fate in overall compartments of the environment. The polymers/oligomers/ and chemicals/additives used in fabrication of MNPs and their health impact has also been discussed in detail. Furthermore, policies implications and challenges associated with MNPs pollution has been emphasized critically with prospects for future research opportunities.

2. A theoretical assessment of MNPs migration and fate in all compartments of the environment (terrestrial, aquatic, and atmospheric)

The environmental fate of the MNPs is significantly influenced by a wide range of transporting agents. Owing to low densities and inert properties, MNPs are transferred between the different components of an ecosystem such as long-distance travel with oceanic currents, flow among freshwater bodies, and wind-assisted dispersion (Horton and Dixon, 2018; Windsor et al., 2019; Wu et al., 2019). The dispersion mechanisms of MNPs across variable environmental matrices is well explained by Horton and Dixon (2018) and Du et al. (2020), which justifies their ubiquitous and widespread existence in every nook and corner of the world. Globally, this has posed an environmental menace. The migration processes of MNPs largely control its potential toxicity as it migrates from the source site to the sink which are the two key compartments of the environment. The production, consumption and dumping of plastic is mostly takes place in terrestrial environment which makes land, a prevalent MNPs source (Jambeck et al., 2015; Rochman, 2018). However, the sink for MNP accumulation was earlier believed to be the vast deep oceans but recent investigations have also added soil and fresh aquatic sediments to the possible sinks (Peng et al., 2020; Horton and Dixon, 2018; Rochman, 2018; Horton et al., 2017b). Due to the incessant anthropogenic input, mass conservation is not maintained in the "plastic cycle" unlike elemental cycles. Persistence and accumulation of MNPs in terrestrial as well as fresh water ecosystem for longer time justify the consideration of these two ecosystems as significant plastics sink.

2.1. *Migration via land to river (fresh water)*

As mentioned above, MNPs input dominance is on land ecosystems which arises from sources like agriculture, household, transport, and industries followed by their disposal in landfills and sewage treatment. Due to ineffective plastic waste management, 21–42% of the total production stays in the landfills increasing its import to the terrestrial system (Nizzetto et al., 2016b). Wastewater treatment plants (WWTPs) gain some attention in removal of MNPs (Blair et al., 2019; Mintenig et al., 2017) while a significant proportion still finds its way to fresh aquatic systems due to the large volume of wastewater and high amount of MNPs in effluent (Blair et al., 2019). According to a study by Li et al. (2018), MNPs are unable to separate out during the treatment of the waste water resulting higher MNPs concentration in the sludge of the WWTPs. A number of countries including North America, Europe, Australia, China and India utilize the WWTP sludge as an agricultural fertilizer, increasing the input of MNPs in land (Corradini et al., 2019; Nizzetto et al., 2016a). The removal and treatment of the waste water pollutants results in the abundance of MNPs in both land and fresh aquatic bodies (He et al., 2018; Yu et al., 2019).

The transportation of MNPs between land (dominant source) and freshwater bodies (dominant sink) is reported to be bidirectional involving various pathways. However, these keystone source and sink are impacted by diffuse inputs and point MNP pollution. Agricultural, urban, recreational, and industrial lands bring MNPs intensively through their runoffs to the receiving waters (Bondelind et al., 2019). In a theoretical assessment by Nizzetto et al. (2016b), the contribution of runoff to the MNPs input in soil is 62–84% approximately. MNPs associated with road and construction (terrestrial) make a significant contribution to the imports in European rivers through stormwater (Unice et al., 2019; Siegfried et al., 2017). MNPs are also detected in the sediments of the Thames River as a result of the downstream storm drainage which is an evidence of the runoff pathway (Dris et al., 2015). This MNPs load in fresh aquatic bodies can also return to the terrestrial environment through irrigation and flooding. As mentioned in the earlier section, WWTP is responsible to transport a huge proportion of MNPs from water to soil (Corradini et al., 2019; Nizzetto et al., 2016a). This land transport is additionally contributed by events like irrigation, flooding events and high tide (Blasing and Amelung, 2018; Xu et al., 2019; Horton et al. 2017a). Irrigating an agricultural field with treated and untreated wastewater can reduce the plastic inputs up to 125,000 and 627,000 plastic items m^{-3} respectively (Blasing and Amelung, 2018).

2.2. *Migration via river (fresh water) to ocean and deep ocean*

A prominent pathway for the movement of MNPs in the ecosystem is towards the ocean from the terrestrial land (Jambeck et al., 2015; Rochman, 2018). Terrestrial sources contribute 70–80% of the total marine plastic debris. Jambeck et al. (2015) showed an approximate plastic waste over surge of 4.8–12.7 million metric tons in 192 coastal countries which followed its way to the oceans. The transport of MNPs from the land to oceanic ecosystem is significantly achieved by rivers (Bondelind et al., 2019). Similar studies have demonstrated the MNPs load in the estuaries which revealed the extensive reach of plastic debris through river flows (Bondelind et al., 2019; Cohen et al., 2019). Hence, it is necessary to assess MNPs toxicity to study their holistic effects on the freshwater ecosystem. Following the input of MNPs in the oceanic system, they are dispersed swiftly with transporting currents, tides, and waves (Handyman et al., 2019). The oceanic transportation ensures the MNPs coverage over a long range of distance in consideration of its surface area (Hamid et al., 2018). Along with this fact, the movement of MNPs from surface to deep oceanic sediments and water is ensured by its vertical transport (Kane and Clare, 2019). Not much to our surprise, 71.1 items kg^{-1} dry weight MNPs abundance has been noticed in the sediments of the deepest ravine of the Pacific Ocean (Peng et al., 2020). In a systemized engineering analytical approach conducted by Koelmans et al. (2017) to assess the oceans for top-down transfer of plastic debris, it was found that since 1950, 99.8% of the plastic input is settled beneath the surface layer by 2016 which is increasing by 9.4 million tons every year. The transportation cycle of the plastic debris starting from the land to ocean, followed by the transfer to the deep ocean due to formation of the microbial biofilms and reaching to the bottom concludes the immense retention potential of the oceans as plastic sink (Wang et al., 2020b; Bolan et al., 2020).

2.3. Atmospheric migration

Along with oceanic transport, atmospheric transport is an additional pathway for worldwide distribution of MNPs. Airborne MNPs are directly distributed to the environment in the form of aerosols and particles emitted from traffic or industrial sectors. Furthermore, wind also act as a transporting agent for exposed MNPs on terrestrial surfaces like roads (Abbasi et al., 2019; Liu et al., 2019). In comparison to the aquatic transportation, the flexible airborne transportation of MNPs experience few topographic limitations and proceeds through multiple directions due to which it can pose threat to fragile areas. Owing to small size and low density, airborne MNPs exhibits extended persistence and easily transported with air currents (Liu et al., 2019), followed by their fallout deposition through dry or wet atmosphere deposition to further oceans, lands, and freshwater systems (Klein and Fischer, 2019). Dris et al. (2015) conducted a research in Greater Paris and stated an average MP fallout of 118 particles m^{-2} day^{-1}. In a similar study by Liu et al. (2018), transportation of 120.7 kg of suspended MPs annually is estimated through Shanghai air. Allen et al. (2019) reported daily counts of 44 fibers, 249 fragments and 73 films m^{-2} in the pristine French Pyrenees catchment deposited through wet and dry deposition. 218 MPs are moved over a distance of 95 km as assessed by the trajectory analysis (Allen et al., 2019). Similarly, Y. Zhang et al. (2019) revealed the presence of MPs in high elevated glaciers of the Tibetan Plateau. Recently, substantial concentration of MPs has been also estimated in Arctic snow ($0–14.4 \times 10^3$ N $liter^{-1}$) and European snow ($0.19 \times 10^3–154 \times 10^3$ N $liter^{-1}$) which were transported via atmosphere and deposited via wet deposition (Bergmann et al., 2019).

3. Chemical congeners/additives of MNPs

MNPs are mainly composed of hetro- and homo monomeric unit of plastics. They are every so often mixed with supplementary chemicals and additives such as, dioxins, polycyclic aromatic hydrocarbons (PAHs) and heavy metals as well (Chen et al. 2019a, 2019b; Hahladakis et al. 2018; Zhang et al. 2015). At the time of plastic synthesis and processing, these organic and inorganic constituents are practically used to expand utility of the final plastic products (Bolan et al., 2020; Hahladakis et al. 2018). After longer exposure to environmental setting, these groups of chemicals/additives are leached out in the environment via slow release or desorption and UV-degradation, triggering impacts on biological multiplicity and function. A limited investigation confirmed the plausible MPs transfer from soil to organisms such as Nematode, Earthworms etc (Kim et al., 2020a, 2020b; Jiang et al., 2020) whereas few specified the involvement of MNPs in triggering toxicity to the waste water sludge microbial flora or oceanic microbiota (Oliviero et al., 2019; Wei et al., 2019).

3.1. Endogenetic chemicals in plastic (monomers and additives)

The endogenetic chemical contaminants of MNPs includes monomers and additives used in manufacturing of plastics/plastic products. Chemicals such as Bis (2-ethylhexyl) phthalate (DEHP), polybrominated diphenyl ethers (PBDEs), bisphenol A (BPA), triclosan are used as plasticizer, flame retardant, precursors/stabilizer, and biocide respectively (Hahladakis et al., 2018). Plasticizers are extensively applied in plastic synthesis, and in which phthalates are often utilized (>60% of PVC plastic) (Teuten et al., 2009). Nonylphenol, and bisphenol A (BPA) are typically utilized as plastic packing stabilizing agent and antioxidants, and these chemicals are considered as endocrine disrupting chemicals (EDCs) (Groh et al., 2019; UNEP, 2017). Chen et al. (2019a) explored the EDCs leaching from marine particulate plastics and reported that estrogens were the primary EDCs, BPA is the second most often detected chemical (mean concentration 475 ± 882 μg kg^{-1}) afterword bisphenol S (BPS), octylphenol (OP) and nonylphenol. Mato et al. (2001), also detected and estimated the nonylphenol concentration 130–1600 μg kg^{-1} in PP-resin pellets sample collected from coastal sites of Japan and it was considered to be a disintegrated product/leachate of plastics (Mato et al., 2001). Because of their adverse effect on human being as EDCs, its existence in the natural environment has gained extensive consideration from past few years. Application of brominated flame retardants (BFRs) in fabrication of electric appliances is very well known. Almost 3% w/w plastics used in TV molding consisted BFRs also called PBDEs, along with others brominated organic compounds such as, polybrominated biphenyls (PBBs) (250 μg kg^{-1}), tetrabromobisphenol-A (TBBPA) (8100 μg kg^{-1}), and polybrominated phenols (PBPs) (4700 μg kg^{-1} (Choi et al., 2009).

3.2. Exogenetic organic contaminants

Hydrophobic organic contaminants (HOCs) are one of the most prominent and pervasive chemicals belongs to exogenetic organic contaminants of the MNPs. These contaminants are derived from terrestrial and aquatic environments and interact with MNPs deposited in these environments. Among this HOCs categories, polychlorinated biphenyls (PCBs) (Chen et al., 2018, 2019b), organochlorine pesticides (Zhang et al., 2015), and PAHs (Chen et al. 2019b; Zhang et al. 2015), are the widely documented. Their concentration in MNPs is mostly in the range of part per million (ppm). Zhang et al. (2015) reported the PAHs concentration (136.3–2384.2 μg kg^{-1}) in MPs collected from coastal area of northern China. Previously PAHs concentration 39–1200 μg kg^{-1} and up to 6298.8 μg kg^{-1} in MNPs was also reported by Rios et al. (2010) from North Pacific Gyre associated zones and open ocean areas respectively. Similarly, more recently, Chen et al. (2019b) reported considerable concentration of PAHs in the range of 1722.9–31764.8 μg kg^{-1} in the MNPs sample of marine environment. The concentration of PCB is usually < 1 ppm in soil; lower than the PAHs concentration found in MNPs sample. The lower concentration of PCB in comparison to PAHs is might be due to its lower abundance in the surrounding environment (Chen et al., 2019b). Along with PCB, polybrominated diphenyl ethers (PBDEs) (Chua et al. 2014), dichloro-diphenyl-trichloroethane (DDT), (Rios et al. 2007), dichloro diphenyl dichloroethylene (DDE) (Mato et al. 2001), endosulfan, aldrin, dieldrin, endrin chlordane, and heptachlor have likewise been often reported in MNPs (Zhang et al., 2015).

4. Mechanisms and impacts of MNPs pollutions

The mechanism and impacts of MNPs on living organisms and investigating the potential risk that are accompanying to chemicals/additives are emerged out recently (Jiang et al., 2020; Aŝmonaté and Carney Almroth, 2019; Rodríguez-Seijo et al., 2018). The submissive or accidental introduction of MNPs in biota, such as phytoplankton, zooplankton, marine organisms, terrestrial biotas, including humans, occurs globally (Bhagat et al., 2020; Kumar et al., 2020; Gallo et al., 2018; Smith et al., 2018). A developing colligation in the field of MNPs research propel us to recognize the key factors controlling the adverse impact of plastics pollution. Compared to larger size MPs fragments, MNP fragments displayed greater biological impacts (Fig. 2) (Aŝmonaté and Carney Almroth, 2019). Similarly, shape of the plastics fragment can be also a key parameter, like more irregularly fragments would be able to induce more physical impacts in comparison to round fragments (Aŝmonaté and Carney Almroth, 2019). Concentration, an essential parameter in toxicological studies, is still a challenging factor in impact assessments since most of the in-vivo and in-vitro investigations used higher plastics fragment concentrations than those persist in ambient environments (Miao et al., 2019). The shape, and size associated impact of MNPs, demands additional consideration and is not covered in this review. The difference in the physicals and chemicals characteristics of MNPs importantly affected their capability to penetrate cells and persuade adverse impacts. The impacts assessment related researches of MNPs fragments and chemicals/additives, still in infancy stage, which are covered comprehensively in the following section.

4.1. Impacts of MNPs polymers/oligomers

The impacts of MNPs fragments on all the components of environments including fresh water (Meng et al., 2020; Kögel et al., 2020),

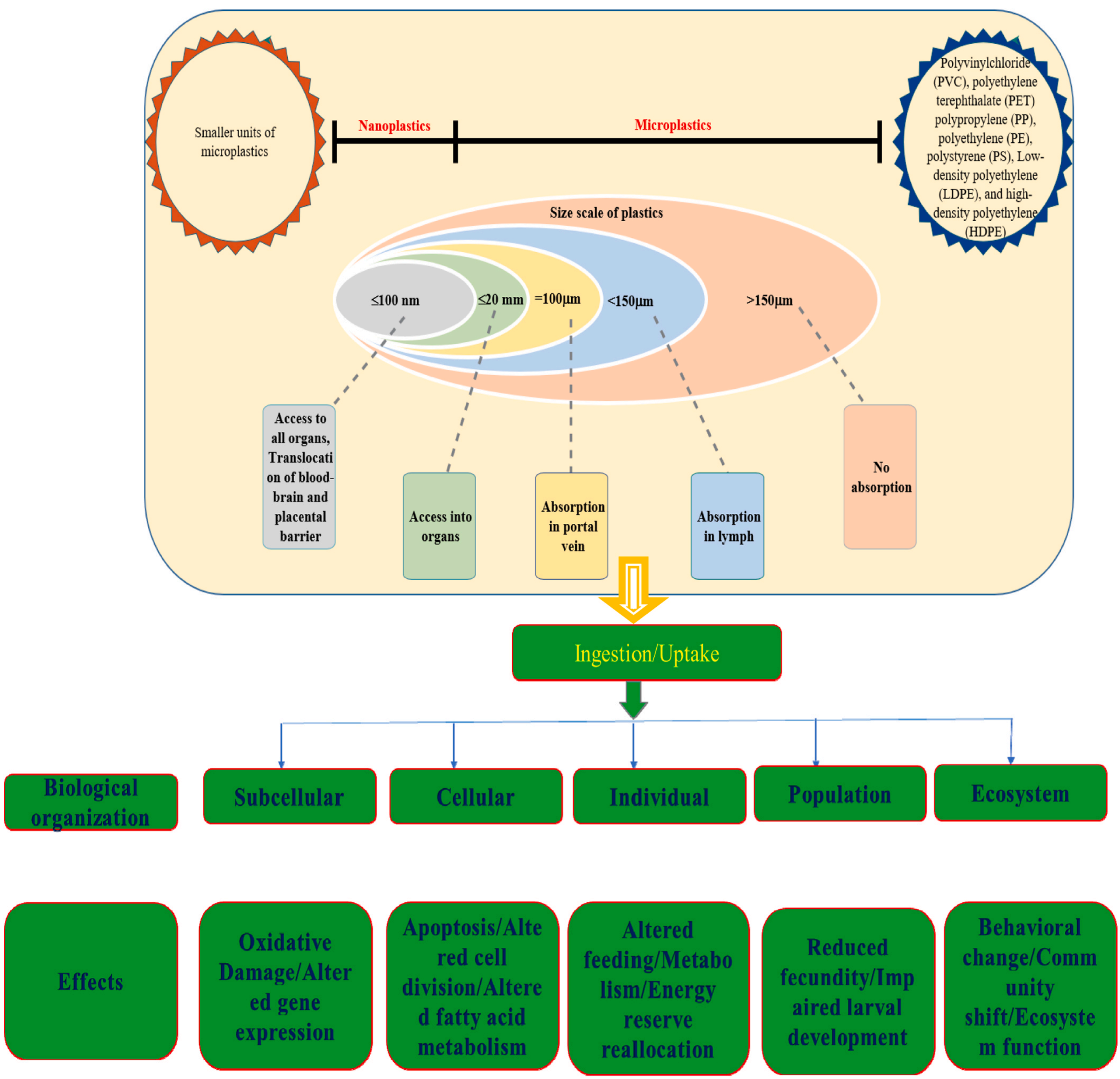

Fig. 2. Potential impacts of micro-nano plastics particles at successive levels of biological organization.

marine water (Nelms et al., 2018; Alimba and Faggio, 2019), terrestrial land (Song et al., 2019) and agroclimatic zone (van Weert et al., 2019; Ng et al., 2018) have been investigated recently. Investigations have revealed that the nano-scale PS dots (100 nm) displayed noticeable negative impacts on the biofilm's formation plausibly through oxidative stress generated by plastics additives in aquatic environment (He et al., 2018; Miao et al., 2019). The MNPs hardly ever causes death of living organism, it does diminish physical development rates, delay cellular transformation, and lower down the organ regeneration capacity. Miao et al. (2019) has expressed only PS dot plastics (100 nm) influenced on the secretion of β-glucosidase and leucine aminopeptidase and antacid phosphatase, and these three chemicals shown diverse reactions to the PS dots at various concentrations.

In human, Inhalation and ingestion are possible exposure routs of MNPs (Fig. 3). Inhalation of MNP-contaminated aerosols and the entry of MNPs into the blood vessels enable this pollutant to distribute all over the human cells (Lim et al., 2019). Research investigation has exhibited that atmospheric fallout is a key source of MNPs (Prata, 2018), but still there is no substantial data available related to the concentration of atmospheric MNPs. Previously, Wright and Kelly (2017) specified, sea salt aerosols, atmospheric dispersion of MNPs from sludge solids, generation of MNPs from polyester clothes, and the degradation plastic mulch used in from agricultural field are plausible sources of MNPs in the atmosphere. Size of MNPs and quantity regulate the noxiousness of the atmospheric MNPs, and more investigations should scrutinize the significant health risks accompanying with inhalation of MNPs. Ingestion of contaminated food and water is probably the major exposure pathway of MNPs. The gastrointestinal tract, having larger surface area (≈ 32 m^2) (Wang et al., 2020a), is the prime site for the absorption of MNPs. Gopinath et al. (2019) confirmed the, entry of MNPs in blood vessel and formation of protein corona complex (protein-plastic complex) after crossing the intestinal villi. This key mechanism, decide the toxicity of MNPs in living organisms (Lehner et al., 2019). *In vitro* investigation of human blood cell revealed that, protein-coated MNPs can generate higher genotoxicity and cytotoxicity than virgin MNPs (Gopinath et al., 2019). This is possibly due to the formation of protein corona complex on the exterior surface of MNPs, which helps them to escape from the human defense system, resulting protracted occurrence in the circulatory system. The formation mechanism of protein corona complex with MNP is still not well investigated, but recently Gopinath et al. (2019) and Wang et al. (2020a) reported that, Van der Waals force, π- π interaction, hydrogen bond could be responsible for this mechanism. A few numbers of in vivo and in vitro studies in rodent and human being respectively established the adverse impacts of MNPs on the defense system. Adverse impact of MNPs on human being includes induced apoptosis (Inkielewicz-Stepniak et al., 2018), influenced up-regulation

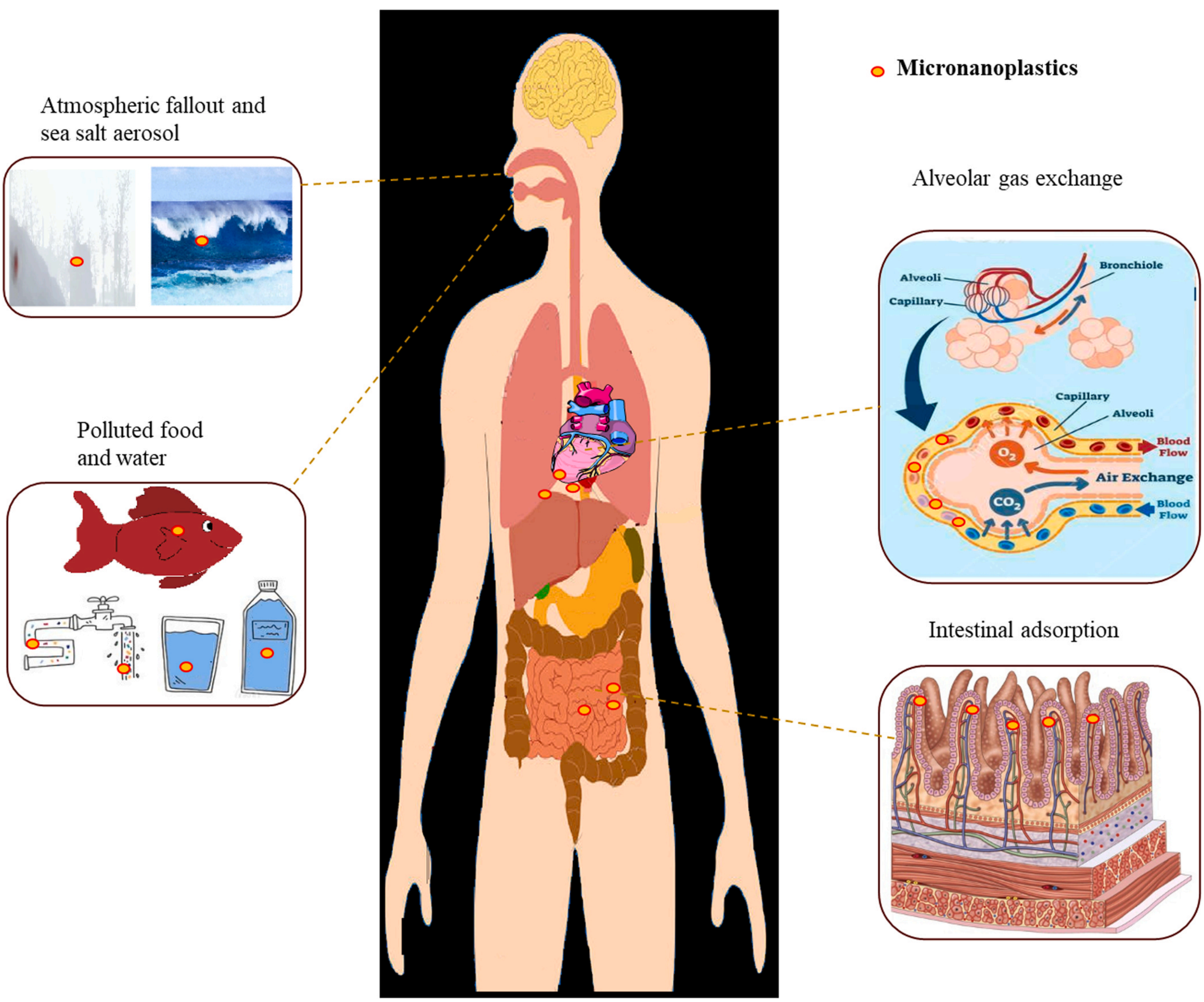

Fig. 3. Human exposure routs of micro-nano plastics (MNPs).

of cytokines (Forte et al., 2016), induced endoplasmic reticulum (ER) stress (Chiu et al., 2015), hampered iron transport (Mahler et al., 2012), and induced oxidative stress (Ruenraroengsak and Tetley, 2015). In human cerebral and epithelial cells, high concentrations of PS-NPs introduction initiated oxidative stress in vitro, showing its potential cytotoxicity impact (Pedersen et al., 2020).

MNPs exposure can initiate several vital reactions such as oxidative stress, repressed development, irritation, dysregulation metabolism, and endocrine disturbance in *Caenorhabditis elegans,* Zebrafish etc. (Table 1). The investigation of Pedersen et al. (2020) revealed that introduction of PS-NPs to zebrafish can initiate dose-dependent impacts on neuro-behavior, as well as potential hepatic, cardiovascular, gastrointestinal, epigenetic, and metabolic breakdown, based on transcriptomic results obtained in NP-exposed zebrafish. NPs are known for their capacity to initiate benign and incendiary reactions as well as producing reactive oxygen species (ROSs). Whereas a few researches have addressed the immunotoxicity of NPs based on in vitro and in vivo studies in fish after intraperitoneal infusion (Elizalde-Velázquez et al., 2020; Smith et al., 2018; Lu et al., 2018). Elizalde-Velázquez et al. (2020), found the NPs within the liver and kidney of fathead minnow (FHM) after assimilation of polluted *Daphnia*, which supports the transfer of NPs constituent via food chain and may translocate from the intestine to other organs. After 48 h of treatment, PS NPs altogether influence the intrinsic resistant framework of FHM, along with hampering the formation and function of neutrophils, macrophages, vital hematopoietic tissues (Elizalde-Velázquez et al., 2020).

Root uptake of MPs by plants isn't reported. The high atomic weight or larger particle size may restrict their infiltration through the ligno-cellulosic plant cell wall (Patil et al., 2019). In comparison to MPs, NPs undoubtedly have been appeared to enter plant cells. Investigators have illustrated the uptake of 20 and 40 nm nanopolystyrene (nPS) dots by tobacco BY-2 cells in cell culture through endocytosis, whereas 100 nm globules were forbidden (Bandmann et al., 2012; Machado et al., 2018). Fabricated carbon nanoparticle similar to particulate plastics in size, shape, organic functional groups can be applied supposedly to identify plant and NPs interactions and their bioavailability (Wang et al., 2016). Specially in plants, such fabricated nanomaterials are being used as facilitators to transport agrochemicals to plant cells or to study the histology of plants (Morales-Díaz et al., 2017). Uptake of these carbonaceous nanoparticles has been demonstrated for different plant species such as *Arabidopsis thaliana*, *Oryza sativa*, *Zea mays*, and *Glycine max* (Ng et al., 2018; Zhao et al., 2017). On the basis of above investigation, the projected entry routs of carbon nonmaterial in the plants, depends on the material properties, plant species and mechanism like endocytosis along with soil organic carbon or root exudate.

On the other hand, to recognize impacts of MNP particles, van Weert et al. (2019) performed dose-response bioassays utilizing the macrophytes *Myriophyllum spicatum* (Eurasian water milfoil) and *Elodea* sp. (water weed). A number of commonly connected parameters were monitored to estimate the impacts that include root and shoot dry weight (DW), relative development rate (RDR), shoot to root proportion (S: R), fundamental shoot length and side shoot length. MPs did not cause steady dose-effect at the end of the experiment, but the fundamental shoot length was decreased for *M. spicatum* with increasing MP concentration. NP altogether diminished S: R for both macrophytes as a result of enhanced root biomass compared to shoot biomass. NP also caused a decrease in fundamental shoot length of *M. spicatum*; however, shoot biomass was not influenced (van Weert et al., 2019).

4.2. Impacts of additives/chemicals

The detrimental effects of MNPs at various level of biological organization is accompanied by the leaching out of the constitutes (monomers/oligomers) and several additives/chemicals (Groh et al., 2019). Because of their high molecular weight, the monomers/oligomers are not easily cross the cell barriers and considered as less impactful comparatively (Ašmonaté and Carney Almroth, 2019). As discussed in Section 3, the plastic products contain diverse range of chemicals, which may leach out during the weathering of MNPs in the environment, thereby having significant impacts on the living organisms (Nelms et al., 2018) (Table 2). Groh et al. (2019) recently reported 906 substances that can be used in plastics packaging. The authors screened and identified 7 persistent, bioaccumulative, and toxic (PBT) compounds along with 15 EDCs. Recent UNEP (United Nations Environment Programme) identified and reported 34 potential EDCs out of 906 chemicals (UNEP, 2017).

Additives applied in manufacturing and processing of plastics may also behave like mutagen and carcinogen, and display detrimental impacts on animal reproductive cycle (Lithner et al., 2011; Rillig and Bonkowski, 2018). Such characterization of additives was mainly based on their toxicological impacts on human with majorly focused on certain groups such BPA and DEHP (Thompson et al., 2009). Now present days, ecotoxicological impacts of these chemicals are gaining greater attentions. Higher concentration of phthalates such as diethyl phthalate (DEP), dibutyl phthalate (DBP), DEHP and their metabolic intermediates were detected in aquatic organisms such as turtles (Savoca et al., 2018), sharks (Fossi et al., 2014) and whales (Fossi et al., 2012). These finding suggested, widespread occurrence of the plastics leachate in aquatic ecosystem. Field reports, also identified presence of chemicals/additives in the digestive system of the organisms resulting mainly from the ingestion of MNPs by organisms (Savoca et al., 2018). With the current available information, it remains difficult to demonstrate that additives and chemicals are released in the environment as a consequence of plastic products ingestion only and not via some other exposure routs. Simulation and modeling investigations of MPs, reveal that the accumulation of certain additives such as nonylphenol, BPA via only ingestion rout in organisms is nominal (Koelmans et al., 2014). Whereas Koelmans et al. (2016) investigation revealed that plastic associated additives can dissociate from the plastic products and potentially accumulate into biotas (Koelmans et al., 2016). Additives associated with plastic products have the inherent characteristics like leachability, which may facilitate the release of chemical compounds into biotas (Koelmans et al., 2016; Rillig and Bonkowski, 2018). Recent investigations suggest substantial variances in toxicological influence among additive-free plastics versus additive-enriched plastics (Baztan et al., 2018; Zimmermann and Wagner, 2018). These obtained results indicate that foremost toxicological apprehensions are related with the chemical/additives associated with plastics. Plastic products constituted with certain polymers like PVC may comprise up to 60% additives w/w, expressively snowballing the toxicity level of such products (Lithner et al., 2011). Thaysen et al. (2018) performed the investigation to evaluate the toxicity potency of marketable packaging plastic, and experimental results showed higher mortality of targeted organism when exposed to plastics leachate. Similarly, a recent research established disturbed prey-predator interactions due to release of plastics chemicals (Seuront, 2018). Previously, Li et al. (2016) also, demonstrated a decrease in larval growth and weakling in the survival potency of barnacle species exposed to recyclable plastics leachate.

Plastic chemicals/additives are well known to induce hormonal (estrogen/androgen) activities at molecular level, which was confirmed by in vitro testing (Burgos-Aceves et al., 2018; Savoca et al., 2019a; Schirinzi et al., 2020; Wooten and Smith, 2013). Clearly, biochemically active constituents of leached substances from recycle plastic wastes or new plastic products showed significant impact at various levels of biological organization. The inherent chemical characteristics, such as duration, degradation rate, genesis and environmental fate of the polymers can regulate their key leaching pathways (Gewert et al., 2018; Jahnke et al., 2017). Nevertheless, potential impacts and toxicity of the released chemicals from aged MNPs are undetermined and still under investigation (Jahnke et al., 2017). Inclusively, additives exposures allied with plastic-derived materials are imperative when discoursing the ecotoxicological impacts of MNPs. Owing to the intrinsic miscellany of plastic products, important chemistry and their ecotoxicity potency are

Table 1
Impacts of various types of micro-nano plastics on the living flora and fauna.

Organism	Soil Type/Media	MNPs type and Size	Dose/quantity	Duration	Impacts	Reference
Eisenia fetida	Agricultural soil	PET, HDPE, PVC; < 2 mm	0.5% w/w	9 months	Insignificant	Judy et al. (2019)
E. fetida	Agricultural soil	PS:10 nm, 1300 nm	1000 μg kg^{-1}	14 days	Increased mortality, reduced weight	Jiang et al. (2020)
E. fetida	Agricultural soil	LDPE: 0.25 μm–1 mm, 5 mm	180–200 particles kg^{-1} (0.25^{-1}mm), 16 particles kg^{-1} (5 mm)	14 days	no mortality, display escaping behavior	Rodríguez-Seijo et al. (2019)
E. fetida	Agricultural soil	LDPE < 400 μm	1.5 g kg^{-1}	28 days	Induced oxidative stress and neurotoxicity, skin damage	Chen et al. (2020)
E. fetida	Orchard soil	PS: 50 μm	1–2% w/w	30 days	Enhanced mortality, reduced growth	Cao et al. (2017)
E. fetida	Agricultural soil	LDPE: 250–1000 μm	1000 m /kg^{-1}	28 days	Increased hormonal secretions	Rodríguez-Seijo et al. (2018)
Aporrectodea rosea	Sandy clay loam soil	HDPE: 0.48–316 μm	1 g kg^{-1}	30 days	Reduced body weight	Boots et al. (2019)
Metaphire californica	Farmland soil	PVC	2000 mg kg^{-1}	28 days	Decrease in gut microbial diversities	H.T. Wang et al. (2019)
Folsomia candida	Plaster of Paris with activated charcoal	PVC: 80–250 μm	5000 particles	7 days	Modify the soil physical properties	Zhu et al. (2018a, 2018b)
F. candida	Loamy clay soil	PVC: 80–250 μm	1 g kg^{-1}	56 days	Reduced rate of reproduction and growth, increased microbial diversity in gut	Zhu et al. (2018a, 2018b)
F. candida	Artificial soil	PE beads: < 500 μm	1% w/w	28 days	Created avoidance behavior, reduced reproduction and intestinal bacterial diversity	Ju et al. (2019)
Achatina fulica	Agriculturalsoil	PET: 76.3 μm	0.71 g kg^{-1}	28 days	Reduced food intake, reduced absorption	Song et al. (2019)
Hypoaspis aculeifer	Plaster of Paris with activated charcoal	PVC: 80–250 μm	5000 particles	7 days	Modify the soil physical properties	Zhu et al. (2018a, 2018b)
Myriophyllum spicatum	Sediment	PS: 50–190 nm, 20–500 μm	3% and 10% w/w	0–24 h	Inhibited shoot growth	van Weert et al. (2019)
A. fulica	Standard soil	PS: 20 nm	10 mg kg^{-1} w/w, 10 mg kg^{-1} w/w	14 days	Reduced growth, feeding and foraging	Chae and An (2020)
Caenorhabditis elegans	Growth media	PS: 100, 500 nm, 1.0, 2.0, 5.0 μm	1.0 m /L^{-1}	3 days	Reduced survival rate, Lifespan, induced neurotoxicity	Lei et al. (2018)
C. elegans	Growth media	PS: 100 nm	10, 100, 1000, 10,000 μg L^{-1}	24 h	Feebler motor actions, reduced offspring size	Zhao et al. (2017)
C. elegans	Growth media	PS: 1 μm	100 μg L^{-1}	3 days	Intestinal damage, Engulfment of PS	Yu et al. (2020)
C. elegans	Growth media	PS: 50 nm, 200 nm	17.3 mg L^{-1}, 86.8 mg L^{-1}	24 h	Hampered metabolism, movement and reproduction	Kim et al. (2019)
Chlorella pyrenoidosa and Microcystis	Growth media	PP and PVC: 0.1 and 0.5 μm	5–500 mg L^{-1}	0–72 h	Reduced growth and chlorophyll a content	Wu et al. (2019)
Chlorella pyrenoidosa	Growth media	PS: 0.1 and 1.0 μm	10 and 50 mg L^{-1}		Growth inhibition and reduced photosynthetic activity	Mao et al. (2018)
Tetraselmis chuii	Growth media	MPs: 1–5 μm	4 mg L^{-1}	96 h	Reduction in average specific growth rate	Davarpanah and Guilhermino, (2019)
Skeletonema costatum	Growth media	PVC: 1 μm	50 mg L^{-1}	96 h	Growth inhibition and photosynthesis inhibition	Zhang et al. (2017)
Lemna minor	Growth media	PE: 4–12 mm	100 mg L^{-1}	48 h	significantly affect the root growth	Kalcikova et al. (2017)
Paracentrotus lividus	Artificial seawater	PVC: ≤ 20 μm	0.3–30 mg L^{-1}	24 h	Impaired of larval growth	Oliviero et al. (2019)
Daphnia magna	Aquatic media	PS: 50–100 nm	10 mg L^{-1}	48 h	Oxidative damage to gut	P. Zhang et al. (2019)
Pocillopora damicornis	Natural seawater	PS: 1.0 μm	50 mg L^{-1}	6–24 h	Increased oxidative stress, repress detoxification and immune system	Tang et al. (2018)
Zebrafish	Aquatic media	PS: 5 μm, 70 nm	20 mg L^{-1}	0–7 days	Inflammation and lipid accumulation in liver, increased oxidative stress	
Periphytic biofilms	Aquatic media	PS beads:100 nm	100 mg L^{-1}	72–96 h	Excessive generation of reactive oxygen species (ROS), hampered biofilm formation	Miao et al. (2019)
Vicia faba	Aquatic media/ emulsion solutions	PS: 5 μm and 100 nm	10–100 mg L^{-1}	48 h	Induced genotoxic and oxidative damage, significant decrease of growth at higher concentration	Jiang et al. (2019a)
Lepidium sativum	Plant tissue culture media	Polymer Microspheres: 50, 500, and 4800 nm	10^3–10^7 particles mL^{-1}	8, 24, 48, 72 h	Delayed germination and root growth,	
Triticum aestivum	Sandy soil	HDPE: 50, 500, 4800 nm	1% (w/w)	24, 48, 72 h	Hampered the growth of both above-ground and below-ground plant parts	
Lactuca sativa	Plant tissue culture media	PS: 0.2 μm and 1.0 μm	–	0–30 days	Accumulated in edible part	Li et al. (2019)

MNPs- **micro-nano plastics.**

Table 2
Impacts of various types of micro-nano plastics additives (organic constituents) on the living organisms.

Organism	MNP type	MNP size	MNP concentration	Additive	Impacts	Reference
Microcystis aeruginosa	Amino-modifiedPS	200 nm	3–20 mg L^{-1}	Glyphosate	Inhibit photosynthetic capacity	Zhang et al. (2018)
D. rerio	PS	45	10 mg L^{-1}	PAHs	Impair mitochondrial energy production, decreased developmental deformities and impaired vascular development	Trevisan et al. (2019)
Gammarusroeseli	Polyamid	40–63 µm	–	Phenanthrene	Neurotoxicity and locomotor toxicity	Bartonitz et al. (2020)
Lates calcarifer	PS	97 µm	–	Pyrene	Neurotoxicity and locomotor toxicity	Guven et al. (2018)
Enchytraeus crypticus	PS	50–100 nm	1000 mg kg^{-1}	Tetracycline	Increased in number of antibiotic resistant gene	Ma et al. (2020)
Daphnia magna	PS	50 nm	2.5–14.5 mg L^{-1}	Phenanthrene	Physical damage, lethal	Ma et al. (2016)
M. edulis	PE	10–– 90 µm	–	Fluoranthene	Alteration in oxidative stressbiomarkers	Magara et al. (2018)
D. magna	PS	100 nm	1–75 mg L^{-1}	PCBs	At 1 mg L^{-1} MNP concentration reduced lethality, while at 75 mg L^{-1} increased lethality	Lin et al. (2019)
M. edulis	PE, polyhydroxybutyrate (PHB)	10–90 µm	–	Fluoranthene	Reduced enzymatic activities	Magara et al. (2019)
Mytilus galloprovincialis	LDPE	20–25 µm	–	Benzo[a]pyrene	Alteration in immune system, oxidative status, neurotoxicity, and genotoxicity	Pittura et al. (2018)
Perinereis aibuhitensis	PS	568 nm	0.4 mg L^{-1}	PAHs	NPs at environment relevant concentrations (0.4 mg L^{-1}) contributed little to bioaccumulation of PAHs	Jiang et al. (2019b)
D. magna	PS	100 nm	2–20 mg L^{-1}	PCBs	Enhance the accumulation of PCBs by 1.4–2.6 folds	Jiang et al. (2018)
D. magna	PE,PET	1–10 µm,	–	Glyphosate	Increased mortality	Zocchi and Sommaruga, (2019)
Chlorella pyrenoidosa	PS	0.1–5 µm	–	Dibutyl phthalate	Increased toxicity	Li et al. (2020)
Brachionus koreanus	PS	50 nm	10 mg L^{-1}	2,2′,4,4′-tetrabromodiphenyl ether, triclosan	Inhibit the activities of multidrug resistance proteins and P-glycoproteins, generate oxidative stress	Jeong et al. (2018)
D. magna	Polyamid	15–20 µm	–	BPA	Decreased immobilization	Rehse et al. (2018)
Mus musculus	PE, PS	0.5–1.0 µm	–	Organophosphorus flame retardants	induced higher oxidative stress, neurotoxicity, and disrupted amino acid and energy metabolism	Deng et al. (2018)
D. rerio	PS	65 nm, 20 µm	–	Butylated hydroxyanisole (BHA)	Impaired larval growth	Zhao et al. (2020)
D. rerio	PS	50 nm	1 mg L^{-1}	BPA	Enhance the accumulation of BPA in head and viscera by 2.2, 2.6 folds respectively, neurotoxic	Chen et al. (2017)

mysterious (Groh et al., 2019).

5. The challenges of forecasting plastic pollution

The MNP existence within the environment is perceived as a global challenge (Egessa et al., 2020). There are various challenges within the methodological forms of sampling, identification and evaluation of MNPs in several natural matrices (Silva et al., 2018). Trestrail et al. (2020) have demonstrated numerous illustrations of MNPs ingestion posturing an oxidative challenge to invertebrates, which required upregulation of antioxidant framework components. In any case, the need of precise tests precluded us from clearly distinguishing which properties of MNPs caused these reactions. In expansion, one of the current most prominent challenges in MNPs inquire about is to distinguish exceptionally little polymeric particles (e.g. NPs). There are several analytical technics used recently, which empower the characterization and quantification of environmental MNPs (Table 3). Atomic force microscopy (AFM) combined with either Raman spectroscopy (RS) or Infrared spectroscopy (IR) may empower analysts to carry out MNP investigation. The dissemination and maintenance of MNPs within the freshwater bodies are still not completely understood, primarily due to the need of research data on the distribution of MNPs. The challenge of collecting and handling such tests for MNPs investigation, not to say the time assets required, may be a reason for this (Meng et al., 2020). Right now, the concentrations of MNPs used for ecotoxicity studies are significantly higher than those observed in natural lattices. Hence, a few of the potential impacts of these materials as of now depicted may be not realistic. In expansion, the types of polymers regularly used to estimate their ecotoxicological impacts are restricted to one or two (Silva et al., 2018). The conservation of the biological equilibrium, the security of life quality for all living beings and the turning away of an obscure threat are required for logical objectives around the world. In this manner, the collection of MNPs must be maintained a strategic distance by a transition into a circular economy. The most obligation for fundamental and connected inquire about pointing at the appraisal of poisonous quality and for connected science pointing at anticipation and preservation ought to be laid by the terrific makers of plastic and plastic waste. Here, strategy makers, funders and researchers all over the world are called upon to handle this challenge (Machado et al., 2018; Klingelhöfer et al., 2020). Furthermore, when working on the spatial and transient

Table 3
Mechanism, advantages and limitations of analytical methods of micro-nano plastics.

Analytical method	MNPs size (diameter)	Elucidation	Advantages	Limitations	Reference
Fourier-Transform Infrared Spectroscopy (FT-IR)	Bulk size	Functional groups	Rapid, easy to operate	Unable to characterize smaller MNPs	Hernandez et al. (2019)
X-ray Photoelectron Spectroscopy (XPS)	Bulk size	Surface chemical characterization	Easy to operate	Unable to characterize smaller MNPs	Hernandez et al. (2019)
Raman Micro spectroscopy (RM)	> 100 nm	Identify the shape and size, chemical characterization	Better resolution than FT-IR, examine the size, shape and chemical properties concurrently	Qualitative instead of quantitative, the diffraction limit of the laser spot hinders the imaging of smaller MNPs	Sobhani et al. (2020)
Scanning Electron Microscopy (SEM)	Any range	Examine the surface morphology along with shape and size	High resolution of images	Expensive, quantification is difficult	Oriekhova and Stoll, (2018)
Transmission Electron Microscopy (TEM)	Any range	Examine the internal constituents of MNPs as well as the shape and size	High resolution of images	Expensive, quantification is difficult	Gigault et al. (2018a, 2018b)
Energy-dispersive X-ray Spectrometry (EDS)	Any range	Elemental composition	Easily coupled with SEM and TEM	Unable to identified some elements precisely like carbon	Gniadek and Dąbrowska, (2019)
Dynamic Light Scattering (DLS)	1−3000 nm	Analyze size using fluctuation due Brownian motion	Easy to operate, fast, in-situ	Does not provide any chemical information	Oriekhova and Stoll,(2018)
Electrophoretic Light Scattering (ELS)	1−3000 nm	Estimate the surface charge by measuring the variation caused by MNPs movement in the electric field	Rapid, easy to operate, onsite	Sensitive towards environmental variables	Oriekhova and Stoll, (2018)
Multiangle Laser Scattering (MALS)	10−1000 nm	Examine particle size through scattered laser light at several angles	Easily coupled with separation methods	Sensitive towards environmental variables	Gigault et al. (2017)
Laser Diffraction (LD)	10 nm−10 mm	Examine particle size on the basis on the Fraunhofer diffraction principle	Large size range, easy to operate, fast	Unable to quantify MNPs	Xu (2015)
Nanoparticle Tracking Analysis (NTA)	10−1000 nm	Examine particle size on the basis of the Brownian motion theory with digital camera and microscope	Imagining the motion of MNPs	Unable to quantify MNPs	Lambert and Wagner (2016)
Pyrolysis Gas Chromatography MassSpectrometry (Py-GC-MS)	Not applicable	Chemical identification	Easily coupled to separation methods	High-quality standard is required	Mintenig et al. (2018)

dissemination of MNP, timelines inside well-known situations can give data on the long-term improvement of MNP dispersions. This makes a way to measurable examination of MNP dispersions and the recognizable proof of sources, sinks and potential risks. However, current confinements still are a need in steady testing and explanatory strategies. Future challenges in this manner are the advancement of such common methods related to separation and estimation of MNPs (Metz et al., 2020). The inquiries about hotspots and future patterns of MNPs were distinguished based on clusters of catchphrases and Altimetric Consideration Score. Moreover, the MNPs contamination status, challenges and most importantly its risk assessment needs methodically investigations to formulate the strategies and policies related to mitigation of MNPs (Zhang et al., 2020; Wang et al., 2020a).

To realize the risk related to MNPs, a DPSIR (drivers – pressures – states – impacts – responses) chassis can be implemented (Fig. 4). Increasing population growth and global economy resulting, higher demands of plastics/plastic products and generation of huge quantity of plastic waste (driving forces) (Wang et al., 2020a). This triggers the release of MNPs in the environment from terrestrial and aquatic sources of plastic waste input (pressures). Once MNPs enters in the environment, they experience aging, aggregation and dispersion mechanism (Horton and Dixon, 2018; Du et al., 2020) In terrestrial environments, soil is considered as major sink of MNPs (He et al., 2018; Kumar et al., 2020), whereas a greater quantity of plastic waste enters in the aquatic environments and accumulated in lake/river sediments (fresh water) (Wagner and Lambert, 2018), or in the oceanic sediments (marine water) (Kane and Clare, 2019) (state). The occurrence of MNPs in the terrestrial and aquatic environment may pose potential risks to living organisms. MNPs may also affect the human health by its transfer via the food chain, or via direct inhalation (Wang et al., 2020a) (impacts). Therefore, it is obligatory to pursue the risk mitigation approaches in response to MNP pollution including the deployment of innovative remediation strategies, formation and implementation of new policies, and heightening the environmental awareness among the people (responses).

6. Context specific requirements for initiatives, policies and strategies

Different kinds of policies and regulations related to MNPs towards soil and water environment have been applied at different levels (international, regional and national). While, most of the environmental laws have not an explicit definition of MNPs as a kind of pollutant, as well as did not provide associated management method. In recent years, some policies aimed at the reduction of plastic usage were approved in EU and US, which all achieved the goal by regulatory instruments, economic instruments (increase related taxes on consumers, retailers, and suppliers) or a combination of both (UNEP, 2018). As increasing plastic pollution, governments and policy makers are considering MNPs as priority environmental issue, more and more related policies will be promulgated and implemented in the recent years.

Source control is the most effective strategy to reduce or even solve plastic pollution. Recent years, the production and usage of plastic products is increasing steadily because of its versatility. Governments and policy makers should legislate and formulate related policies to limit the production of plastics products which could potentially cause plastic pollution. For example, the legislative ban of plastic micro-beads used in rinse-off personal care products in some countries like the USA in 2015 and the UK in 2018 has been very effective in reducing their input to the aquatic environment (Auta et al., 2017). Additionally, government

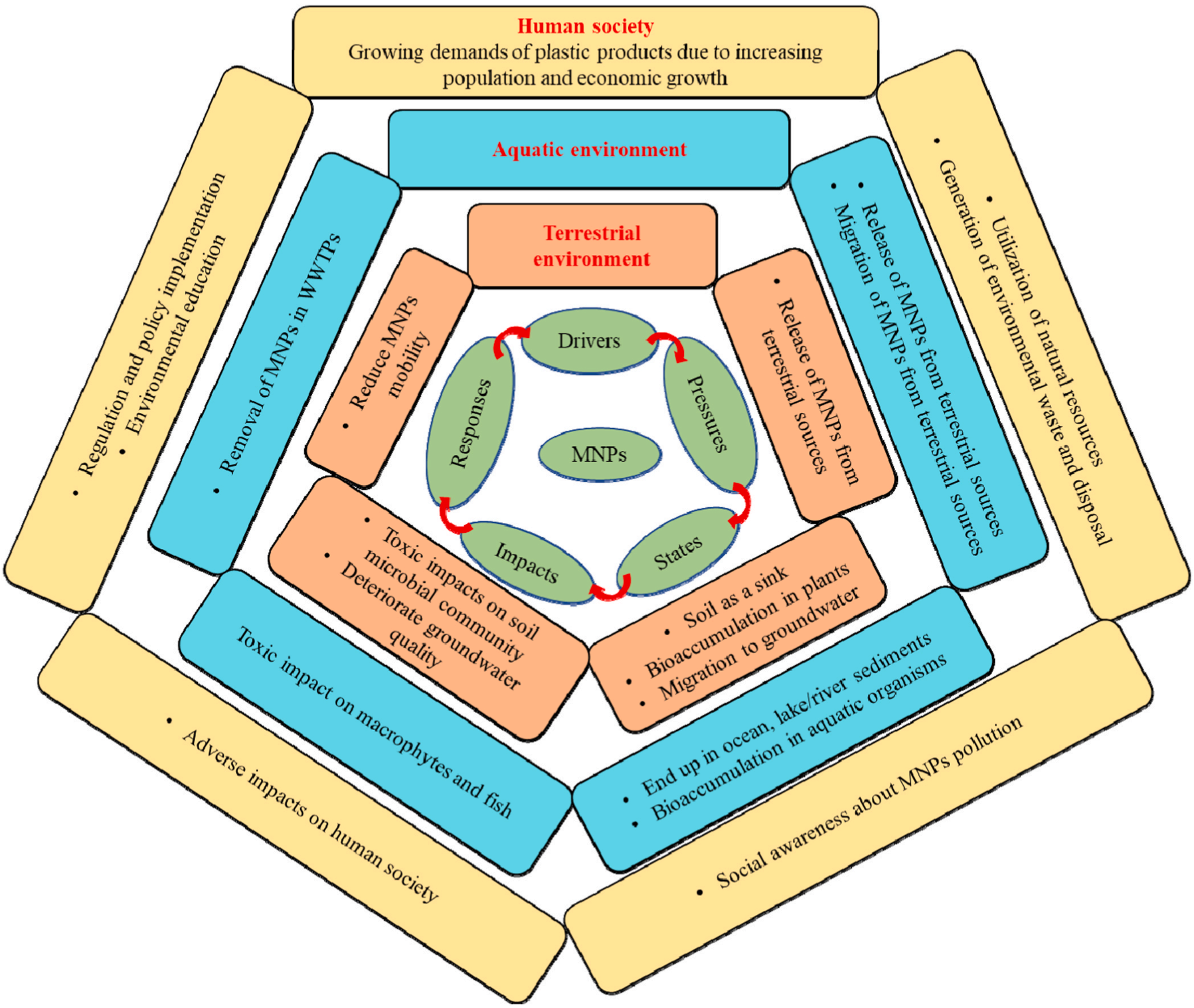

Fig. 4. A DPSIR chassis for the risk assessment of micro-nano plastics (MNPs).

should further enhance public awareness of environmental protection, strengthen publicity on the hazards of plastic pollution, and call for a reduction of use and indiscriminate disposal of plastic products.

Under the premise of reducing the production and usage of plastic products, improving the recycling of plastic waste is one of the most important solution to reduce the plastic waste pollution. Sewage sludge is identified as the primary plastic source to terrestrial environment, around 90% of plastic would finally accumulate in sludge (Nizetto et al., 2016). Meanwhile, most of the collected plastic waste is incinerated or landfilled to achieve reduction, harmless and resource recovery among them, about 50% of plastic waste is directly processed by landfill. Thus, it is important to improve recycling technology, increase the invest in waste management infrastructure. Increase investment in scientific and technological research is required and alternative products to plastic are promoted. The best strategy of reducing plastic waste is to find a harmless substance to replace it. More research should be encouraged to explore this filed. However, given the truth that it is impossible to make a breakthrough immediately, biodegradable plastic can be a replacement to non-degradable plastic. Biodegradable plastics can be degraded by environmental microorganisms after being discarded, which can prevent plastic pollution, realize harmless. While, the cost of degradable plastic is much higher than normal one, and the degradation efficiency is also not fast enough at present, which need to be further study.

7. Conclusion and perspective for future studies

This article reviewed the current research on the migration and fate of MNPs in different environment (terrestrial, aquatic, and atmospheric); meanwhile, it explained the mechanisms of potential impacts of MNPs polymers and chemicals/additives on flora and fauna, as well as provided the further challenges and opportunities on MNPs waste management. The research of MNPs pollution has received worldwide attention, some progress has been made in some aspects. While, as an emerging pollutant, there are still many issues need to be studied in the future.

- Establish standard MNPs measurement methods. As an emerging pollution, there is no unified standard technology for MNPs analysis at present. Given the diversity of plastic types, shape, and diameters, as well as widely distributed in different environments, the methods used in current studies are quite different from the sampling to analysis. This deeply influences the comparability between researches. Thus, standard protocols need to be formed to better study the MNPs pollution in the future.

- The distribution and impact of MNPs in terrestrial and atmospheric environment need to be further studied in the future. As mentioned above, MNPs are widely distributed in various environments, and MNPs in various environments migrate to each other, so as to more accurately estimate the impact of MNPs pollution on environment, MNPs research must be global and each environment needs to be studied accordingly.
- There have been many researches on the effect of MNPs to aquatic environment and inside organisms, while much more studies are required to evaluate the MNPs pollution in soil and atmosphere. More quantitative data is necessary to assess the exact hazards of MNPs in various organisms and the impact of these hazards on the ecosystem.
- MNPs transfer mechanisms from lower trophic level to higher trophic levels deserves certain attention. MNPs introduction to lower trophic level may transfer and magnify to higher trophic levels via food chain, finally posing detrimental effects on humans. Several MNPs have been noticed in human fiscal, signifying that MNPs certainly enter human bodies. However, only few investigations reported its biomagnification tendency. More studies are desirable to comprehend the mechanism of biomagnification potency of MNPs.
- Co-contamination impacts of MNPs along with several other environmental pollutants deserve to be examined. MNPs enable to absorb contaminates such as heavy metals, organic pollutants and therefore transform their toxicity and bioavailability, imposing collective toxic effects on living organism. Other emerging pollutants, such as, perfluorinated and chlorinated compounds, flame retardants, antibiotics, pharmaceuticals, nanomaterials etc. are also existing in the global environment. Hence, there is a high possibility of commutative association of plastic fragments with other contaminants in all the environmental compartments. Additionally, weathering of MNPs leads to the release of various chemicals and additives which may generate indefinite impacts on living organisms. More studies are required to explicate the co-pollutants impacts of MNPs and several other contaminants.
- At last, the usage of plastic has brought inevitable harmful impact to earth, it should be noticed that the production, use, and recycling of plastic waste still remains many fundamental problems need to be solved in near future.

CRediT authorship contribution statement

Dr. Manish Kumar (Ph.D. in micro-plastic) Scientist: He has written original draft this article and revised also. **Mr. Hongyu Chen** (Ph.D. student and working in micro-plastic): He has written some part of this manuscript. **Dr. Surendra Sarsaiya** (Ph.D. in microbiology) Associate Professor: He has written some part of this manuscript. **Mr. Shiyi Qin** (master's student): He has help to draw some figure of this manuscript. **Miss. Huimin Liu** (master's student): He has help to draw some figure of this manuscript. **Dr. Mukesh Kumar Awasthi** (Ph.D. in microbiology) Associate Professor: He has Conceptualization, Design and Supervision of review and also Writing - original draft this article. In addition, Funding acquisition, Project administration. **Dr. Sunil Kumar** (Ph.D. in environmental engineering) Principal Scientist: He help Supervision, Validation, Visualization, as well as very help to improve the manuscript quality and English. **Dr. Lal Singh** (Ph.D. in microbiology) Senior Scientist: He help Supervision, Validation, Visualization, as well as very help to improve the manuscript quality and English. **Prof. Zengqiang Zhang** (Ph.D. in organic Chemistry): He help Supervision, Validation, Visualization, as well as very help to improve the manuscript quality and English. **Prof. Nanthi S Bolan** (Ph.D. in environmental chemistry): He help Supervision, Validation, Visualization, as well as very help to improve the manuscript quality and English. **Prof. Ashok Pandey** (Ph.D. in microbiology): Prof. Pandey has Conceptualization, Design and Supervision of review and also Writing - original draft this article. **Dr. Sunita Varjani** (Ph.D. in microbiology): She help Supervision, Validation, Visualization, as well as very help to improve the manuscript quality and English. **Prof. Mohammad J. Taherzadeh** (Ph.D. in resource recovery): He has Conceptualization, Design and Supervision of review and also Writing - original draft this article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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