RECENT INSIGHTS ON NANOMATERIALS FOR MICROPLASTIC DEGRADATION

Hari Kamalasree[1,2], A. ArchanaDevi[1,2], R. Padmanaban[1] and K.Venkatramanan[1,*]
[1]Department of Physics, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Kanchipuram, Tamilnadu – 631561
[2]Department of Humanities and Sciences, Malla Reddy College of Engineering and Technology, Hyderabad, Telangana – 500100
E-mail: kv@kanchiuniv.ac.in

ABSTRACT

Micro plastics are one of the most alarming environmental and worldwide challenges of the past few decades, given the ever-increasing production of plastic and micro plastics particles, their inherent toxicity, and their potential for transportation by natural forces (such as wind, water streams, etc.).The diverse types of plastics, along with their additives and potential contaminants, create a major obstacle in the effective degradation of micro plastic particles, rather than just breaking them down into smaller pieces. Recent studies and research have concentrated on methods such as biodegradation, thermal degradation, pyrolysis, and nanoparticle-mediated micro plastic degradation as significant approaches to address the degradation process .Nanotechnology-driven approaches have been shown to be essential in the treatment of water and wastewater, effectively addressing a range of challenging micro and nano-pollutants (MNPs) with significant efficiency. The primary methods through which nanomaterials contribute to the remediation of MNP contamination include adsorption, photo catalysis, and membrane filtration. Finally, the review outlines the forthcoming challenges and perspectives in the development of nanomaterials for MP degradation.

Keywords: Environmental pollution, Microplastics, Nano Plastics, Polypropylene, Polyvinyl Chloride, Polyethylene Terephthalate

I. INTRODUCTION

The pervasive presence of microplastics in diverse ecosystems has prompted significant concern regarding their environmental and health implications. As these minute plastic particles accumulate in soil, water, and organisms, they pose severe threats to biodiversity and human health. The challenges posed by micro plastic degradation are amplified by their resilience against conventional decomposition methods [1]. In light of this pressing issue, innovative solutions are required, leading researchers to explore the potential of nanomaterials as effective agents for microplastic degradation. Nanomaterials, due to their unique physical and chemical properties, offer enhanced catalytic capabilities that may significantly accelerate the breakdown of microplastic resources [2, 3]. This review seeks to elucidate the advances in nanomaterial technologies designed to mitigate microplastic pollution, addressing their mechanisms of action, effectiveness, and potential applications [4]. By synthesizing current research, this essay aims to provide a comprehensive understanding of how nanomaterials can contribute to the degradation of microplastics, paving the way for future environmental solutions [5].

To improve their degrading efficiency, nano/micro structured metal oxides like TiO_2, ZnO, NiO, Cu_2O/CuO, perovskite-like Bi_2WO_6, Fe_3O_4, and bismuth oxyhalides (BiOX) have been modified [6]. The synthesis and characterization of ZnO NPs using *P. longum* leaf extract revealed their structural and functional properties, as well as their potential application in environmental remediation, particularly in microplastic degradation [7]. The most prevalent microplastics, such as high-density polyethylene, polypropylene, polyvinyl chloride, polystyrene, and polyethylene terephthalate, were effectively removed by hydrophilic bare Fe_3O_4 nano aggregates.

II. LITERATURE REVIEW

Microplastics, defined as plastic particles smaller than five millimeters, have emerged as significant pollutants with far-reaching environmental consequences [8]. Their ubiquitous presence in marine and freshwater ecosystems disrupts habitats and poses threats to aquatic life through ingestion and entanglement. Research indicates that microplastics can also harbor hazardous chemicals that leach into surrounding waters, further exacerbating their detrimental effects on marine organisms and food web dynamics [9]. Notably, the Southern Ocean, previously thought to be relatively unscathed, has shown signs of microplastic contamination in both deep-sea sediments and surface waters. Recent findings reveal microplastics being detected near research stations, prompting a reevaluation of their potential local sources, such as maritime activities and scientific research Understanding these dynamics is crucial for developing effective degradation strategies, making it imperative to explore the role of nanoparticles in mitigating the environmental impacts of microplastics [10].

a) MICROPLASTICS AND THEIR ENVIRONMENTAL IMPACT

The emergence of microplastics has become a critical environmental concern, as these small plastic fragments infiltrate ecosystems worldwide. Originally defined nearly two decades ago, microplastics have since been discovered in various habitats, including oceans, soil, and even within the lungs of humans and animals [11]. Their persistent nature exacerbates environmental pollution, contributing millions of metric tons of waste to ecosystems. Such widespread contamination poses significant risks to both marine life and human health, disrupting food chains and entering the human diet through seafood consumption. Research suggests that green microbiology may offer sustainable solutions for mitigating microplastic pollution, utilizing microorganisms that can degrade these particles effectively [12].

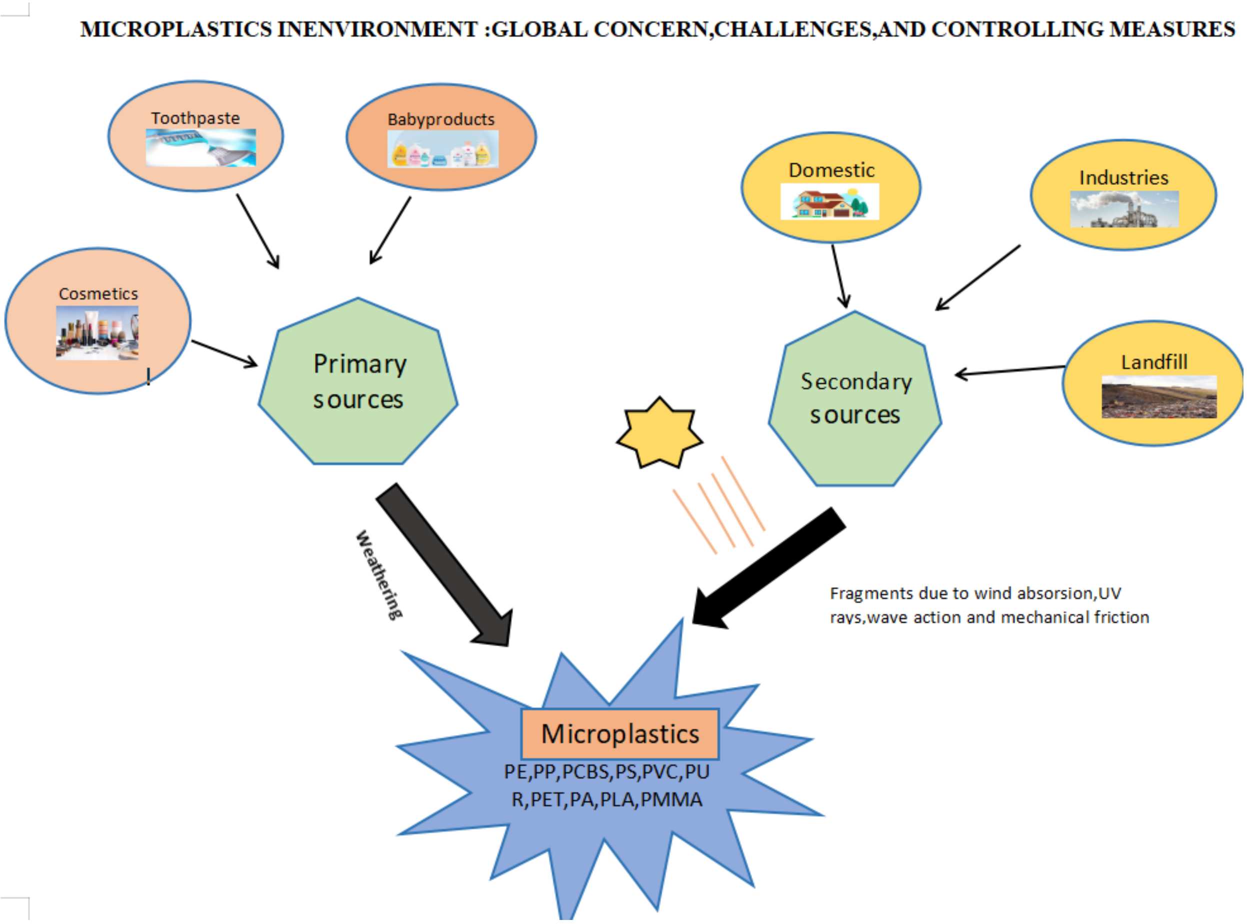

Fig 1. Types, sources, and the way of formation of primary and secondary MPs [13]

b) PROPERTIES OF NANOMATERIALS

The unique properties of nanomaterials render them particularly effective for addressing environmental challenges, such as the degradation of microplastics. Characterized by their high surface area to volume ratio, nanomaterials exhibit enhanced reactivity, making them suitable candidates for catalytic applications [14]. This reactivity enables the breakdown of complex microplastic structures into less harmful components, thus facilitating their removal from ecosystems. Furthermore, the versatility of nanomaterials, which includes carbon-based forms such as graphene and various metal oxides, allows for tailored approaches to microplastic mitigation, amplifying their efficacy in diverse environmental conditions. A significant body of research highlights the urgency of addressing microplastic pollution due to its detrimental effects on food safety, particularly in horticulture, where the contamination poses risks to both crops and human health .By harnessing the distinctive characteristics of nanomaterials, innovative strategies can be developed to combat the pervasive challenge of micro plastic pollution from fig 2.

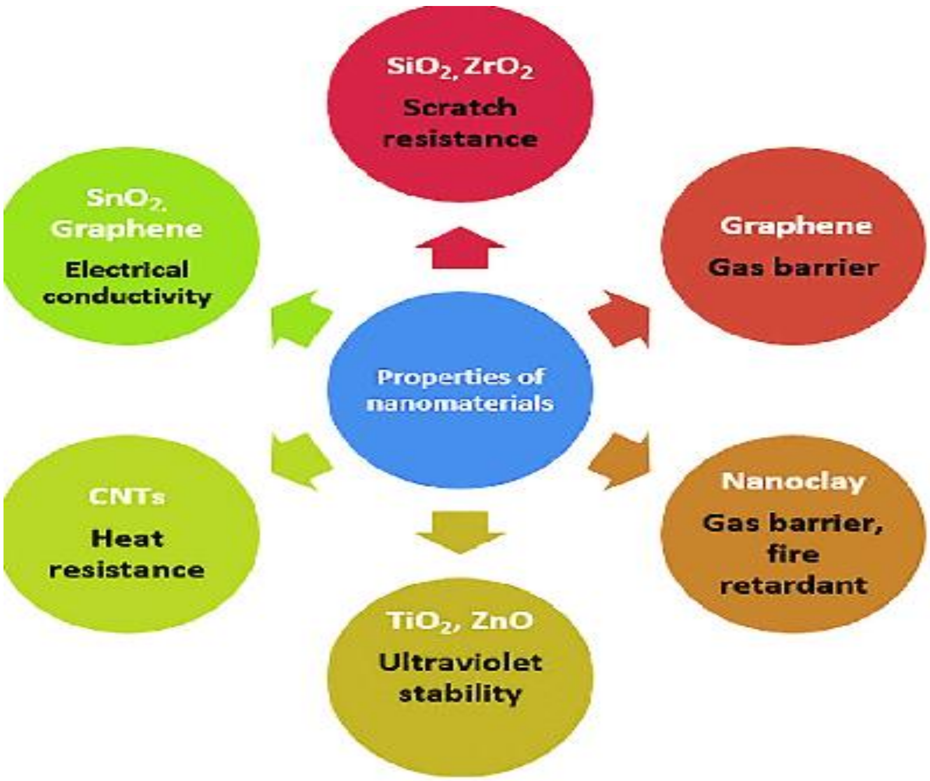

Fig 2. Nano properties [15]

c) UNIQUE CHARACTERISTICS THAT ENHANCE DEGRADATION CAPABILITIES

The unique characteristics of certain nanomaterials have significantly enhanced their capabilities in microplastic degradation, primarily due to their high surface area and reactive properties. Crustacean nano chitosan, derived from the biopolymer chitosan, exemplifies a promising material in this context. Its ability to adsorb and bind microplastics stems from the presence of functional groups that facilitate interactions with various contaminants, thereby immobilizing them effectively. Studies identify that these properties allow for superior contamination reduction compared to traditional methods, addressing the urgent need for sustainable solutions in combating microplastic pollution .Additionally, the scalability and cost-effectiveness of using nanochitosan in water treatment systems remain pivotal challenges; however, optimizing parameters such as pH and contact time offers potential avenues to enhance these degradation capabilities [16]. By focusing on these unique characteristics, researchers can contribute to developing sustainable strategies aimed at mitigating the pervasive issue of microplastic contamination.

d) **MECHANISMS OF MICROPLASTIC DEGRADATION**

The degradation of microplastics is a complex process influenced by various environmental factors and biological mechanisms. Microplastics, due to their persistent nature, pose significant challenges in ecological systems, as they are capable of accumulating in soils and water bodies, leading to harmful effects on aquatic and terrestrial organisms. Recent studies highlight the role of nanomaterials in catalyzing the degradation of these pollutants, effectively breaking them down into less harmful substances [17]. Agricultural practices, such as the application of certain nanomaterials, have shown promise in enhancing the degradation rates of microplastics within soil ecosystems, with impacts on plant uptake and physiological responses [18]. Additionally, the interaction of microplastic-associated biofilms with microbial communities can further contribute to the degradation process, underscoring the importance of understanding these mechanisms to mitigate microplastic pollution effectively. Continued research is crucial for developing innovative strategies to fight this pervasive environmental issue [19].

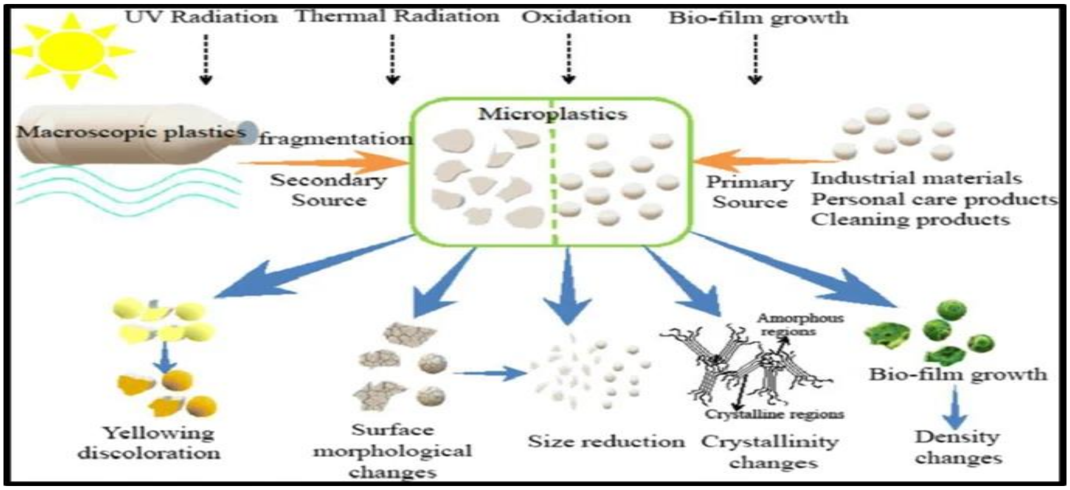

Fig 3. Degradation of micro plastic [20]

III. RESULTS AND DISCUSSION

How nanomaterials facilitate the breakdown of microplastics is increasing prevalence of microplastics in various ecosystems has prompted a need for effective remediation strategies. Nanomaterials, due to their unique physicochemical properties, have emerged as promising tools in facilitating the degradation of microplastics. These materials can interact with microplastic particles at the molecular level, enhancing their breakdown through processes such as photocatalysis and enzymatic degradation. For example, certain nanomaterials can absorb sunlight and generate reactive oxygen species that promote the oxidative degradation of the microplastics, ultimately leading to their mineralization. Moreover, the larger surface area-to-volume ratio of nanomaterials can improve their efficacy in adsorbing environmental contaminants, creating microplastic-associated biofilms that aid in subsequent breakdown [21]. Additionally, recent studies underscore the significance of nano plastics in the agricultural sector, emphasizing their potential to interact with plant systems and the implications for microplastic transport and degradation within soil environments. Here some of the nano particles used for micro micro-plastics degradation [22].

Table 1: Inorganic nanoparticle-enzyme/microorganism complexes for degradation of microplastics

Inorganic NPs	Enzyme / Microorganism	Microplastics	Complexes	Mechanism	Biodegradation Operating Conditions
Titanium Dioxide (TiO_2)	Lipase	BS	Polymer / nanoparticle composite incubated with enzyme	Creation of Photogenerated radicals to oxidize polymer by photocatalytic Oxidation during Enzymatic Reaction	Nanoparticle concentration: 5 wt.% Nanoparticle size: 7.0 (ST-01) and 30nm (P-25) Media : phosphate buffer saline Temperature : 27°C pH : 6.8 RPM : 1000 Light source : UV radiation
Nano Barium Titanate (NBT)	Micro bacterium species strain MK3, Pseudomonas Putida strain MK4 Bacterium and Te68R strain PN12	LDP	Nanoparticle incubated with polymer and microorganism	Accelerated growth of bacterial consortia used in biodegradation Inclusion of hydroxyl residues into hydrocarbon chain that increases solubility	Nanoparticle concentration: 0.01% Nanoparticle size: 38.0 nm Media: Davis minimal broth Temperature: 37° C RPM: 150
Superparamagnetic Iron Oxide Nanoparticles (SPION)	Micro bacterium species strain MK3, Pseudomonas Putida strain MK4 and Bacterium Te68R strain PN12	LDPE	Nanoparticle Incubated with polymer and microorganism	Accelerated growth of bacterial consortia used in biodegradation Inclusion of hydroxyl residues into hydrocarbon	Nanoparticle concentration: 0.01% Nanoparticle size : 10.6, 20.0 and 37.8 nm Media : Davis minimal broth Temperature : 37° C RPM : 150
Titanium dioxide (TiO_2)	α-amylase from	PLA	Polymer / nanoparticle	Presence of chain that increases solubility.	Nanoparticle concentration: 0.5, 1, 2, 5 and 10 wt.% Nanoparticle size: 21 nm Media: α- amylase solution Temperature: 37° C

CONCLUSION

Now a days plastics are part and parcel of human life. Problems are arising because of over usage and over production. If we started degradation of micro plastic many of them failed to degrade, it won`t reaches to the sustainable goals and large scale implementation pattern / but these MP`s can be degraded by nano materials or nano particles reaches these. Accumulation of microplastics in water and soil, gives a severe threat to many aquatic animals and humans. When nanoparticles created from different plant sources were tried to debase polymers, the outcomes gotten were positive and empowering. This certain an inexhaustible asset for nanomaterials with a debasing limit, to handle enormous scope issues. The results of these responses were additionally climate friendly, as the nanomaterials can be recuperated for the following pattern of debasement. Low-density polyethylene (LDPE) films are added to bacterial consortia that have been infused with nanoparticles, and the breakdown of the It was inevitable to use LDPE films. The suggested plastic substitutes must be on par with or better than plastics because, as a species, we have reached a point of no return where we would not accept anything less than plastics to meet all of our needs. It is enough to say that researchers from all over the world have taken on this enormous task. There will undoubtedly be creative solutions, and biopolymers and nanomaterials are unquestionably leading contenders in the competition to replace plastics.so nano particles are degrading MPs easily and reaches to the sustainable development goals and Environment friendly.

REFERENCES

1. M. Golmohammadi, S. Fatemeh Musavi, M. Habibi, R. Maleki, M. Golgoli, M. Zargar, L. F. Dumée, S. Baroutian and A. Razmjou, Molecular mechanisms of microplastics degradation: A review, Separation and Purification Technology, Volume 309, 2023, pp 122906, https://doi.org/10.1016/j.seppur.2022.122906.

2. A. Cholewinski, E. Dadzie, C. Sherlock, W. A. Anderson, T. C. Charles, K. Habib, S. B. Young and B. Zhao, A critical review of microplastic degradation and material flow

analysis towards a circular economy, Environmental Pollution, Volume 315, 2022, pp 120334, https://doi.org/10.1016/j.envpol.2022.120334.

3. V. C. S. Theja, V. Karthikeyan, D. S. Assi, H. Huang, K. Venkatramanan, Y. Chen, C. H. Shek, and V. A. L. Roy, 2D MXene Interface Engineered Bismuth Telluride Thermoelectric Module with Improved Efficiency for Waste Heat Recovery, Advanced Materials Technologies, Volume 9(21), 2024, pp 2301722, https://doi.org/10.1002/admt.202301722.

4. S. Nikhar, P. Kumar and M. Chakraborty, A review on microplastics degradation with MOF: Mechanism and action, Next Nanotechnology, Volume 5, 2024, pp 100060, https://doi.org/10.1016/j.nxnano.2024.100060.

5. M. Ouda, F. Banat, S. W. Hasan and G. N. Karanikolos, Recent advances on nanotechnology-driven strategies for remediation of microplastics and nanoplastics from aqueous environments, Journal of Water Process Engineering, Volume 52, 2023, pp 103543, https://doi.org/10.1016/j.jwpe.2023.103543.

6. M. Z. Angew and J. Liu, Removal and Degradation of Microplastics Using the Magnetic and Nanozyme Activities of Bare Iron Oxide Nanoaggregates, Angewandte Chemie, Volume 61, Issue 47, 2022, pp e202212013, https://doi.org/10.1002/anie.202212013.

7. I. Azeem, M. Adeel, M. A. Ahmad, N. Shakoor, G. D. Jiangcuo, K. Azeem, M. Ishfaq, A. Shakoor, M. Ayaz, M. Xu and Y. Rui, Uptake and Accumulation of Nano/Microplastics in Plants: A Critical Review, Nanomaterials, Volume 11, Issue 11, 2021, pp 2935, https://doi.org/10.3390/nano11112935.

8. N. P. Gayathri, G. Prasad, V. Prabhakaran and V. Priya, Understanding the impact of microplastic contamination on soil quality and eco-toxicological risks in horticulture: A comprehensive review, Case Studies in Chemical and Environmental Engineering, Volume 9, 2024, pp 100633, https://doi.org/10.1016/j.cscee.2024.100633.

9. Y. Li, C. Liu, H. Yang, W. He, B. Li, X. Zhu, S. Liu, S. Jia, R. Li and K. H. D. Tang, Leaching of chemicals from microplastics: A review of chemical types, leaching mechanisms and influencing factors, Science of The Total Environment, Volume 906, 2024, pp 167666, https://doi.org/10.1016/j.scitotenv.2023.167666.

10. I. P. Omoregie, A. D. Osagie and O. O. Oritseweyinmi, Crustacean nanochitosan-based bioremediation of nanoplastic-polluted aquatic habitat: A review pursuant to SDG 6, Scientific African, Volume 21, 2023, pp e01881, https://doi.org/10.1016/j.sciaf.2023.e01881.

11. A. Akinsemolu and H. Onyeaka, Application of green microbiology for microplastic remediation: Current progress and future perspectives, Environmental Advances, Volume 17, 2024, pp 100569, https://doi.org/10.1016/j.envadv.2024.100569.

12. D. D. Snow, D. A. Cassada, S. Biswas, A. Malakar, M. D'Alessio, L. J. Carter, R. D. Johnson and J. B. Sallach, Detection, occurrence, and fate of emerging contaminants in

agricultural environments (2019), Water Environment Research, Volume 91, Issue 10, 2019, pp 1103-1113, https://doi.org/10.1002/wer.1204.

13. G. Lamichhane, A. Acharya, R. Marahatha, B. Modi, R. Paudel, A. Adhikari, B. K. Raut, S. Aryal and N. Parajuli, Microplastics in environment: global concern, challenges, and controlling measures, Int. J. Environ. Sci. Technol., Volume 20, 2023, pp 4673–4694, https://doi.org/10.1007/s13762-022-04261-1

14. R. R. Chandran, B. I. Thomson, A. J. Natishah, J. Mary and V. Nachiyar, Nanotechnology in plastic degradation, Biosciences Biotechnology Research Asia, Volume 20, Issue 1, 2023, pp 53-68, http://dx.doi.org/10.13005/bbra/3068

15. R. K. Mishra, A. K. Zachariah and S. Thomas, Chapter 12 - Energy-Dispersive X-ray Spectroscopy Techniques for Nanomaterial, Editor(s): Sabu Thomas, Raju Thomas, Ajesh K. Zachariah, Raghvendra Kumar Mishra, In Micro and Nano Technologies, Microscopy Methods in Nanomaterials Characterization, 2017, pp 383-405, https://doi.org/10.1016/B978-0-323-46141-2.00012-2.

16. K. H. Tang, S. S. Lock, P. S. Yap, K. W. Cheah, Y. H. Chan, C. L. Yiin, A. Z. Ku, A. C. Loy, B. L. Chin and Y. H. Chai, Immobilized enzyme/microorganism complexes for degradation of microplastics: A review of recent advances, feasibility and future prospects, Science of The Total Environment, Volume 832, 2022, pp 154868, https://doi.org/10.1016/j.scitotenv.2022.154868.

17. A. I. Gopalan, J. C. Lee, G. Saianand, K. P. Lee, W. Y. Chun, Y. I. Hou, K. Venkatramanan, S. S. Park and W. J. Kim, Cost-Effective Production of TiO_2 with 90-Fold Enhanced Photocatalytic Activity Via Facile Sequential Calcination and Ball Milling Post-Treatment Strategy, Materials, Volume 13, Issue 22, 2020, pp 5072, https://doi.org/10.3390/ma13225072.

18. C. L. Waller, H. J. Griffiths, C. M. Waluda, S. E. Thorpe, I. Loaiza, B. Moreno, C. O. Pacherres and K. A. Hughes, Microplastics in the Antarctic marine system: An emerging area of research, Science of The Total Environment, Volume 598, 2017, pp 220-227, https://doi.org/10.1016/j.scitotenv.2017.03.283.

19. N. V. Vas, S. K. Sundari and S. Jeyachandran, Degradation of Microplastics by Zinc Oxide Nanoparticles Synthesized Using Piper longum Leaf Extract, Cureus, Volume 16, Issue 9, 2024, pp e69876, doi: 10.7759/cureus.69876.

20. S. R. Mishra and Md. Ahmaruzzaman, Microplastics: Identification, Toxicity and Their Remediation from Aqueous Streams, Separation & purification reviews, Volume 52, 2023, pp 283-304, https://doi.org/10.1080/15422119.2022.2096071.

21. P. S. Goh, H. S. Kang, A. F. Ismail, W. H. Khor, L. K. Quen and D. Higgins, Nanomaterials for microplastic remediation from aquatic environment: Why nano matters?, Chemosphere, Volume 299, 2022, pp 134418, https://doi.org/10.1016/j.chemosphere.2022.134418.

22. G. Lamichhane, A. Acharya, R. Marahatha, B. Modi, R. Paudel, A. Adhikari, B. K. Raut, S. Aryal and N. Parajuli, Microplastics in environment: global concern, challenges, and controlling measures, Int. J. Environ. Sci. Technol., Volume 20, 2023, pp 4673–4694, https://doi.org/10.1007/s13762-022-04261-1.