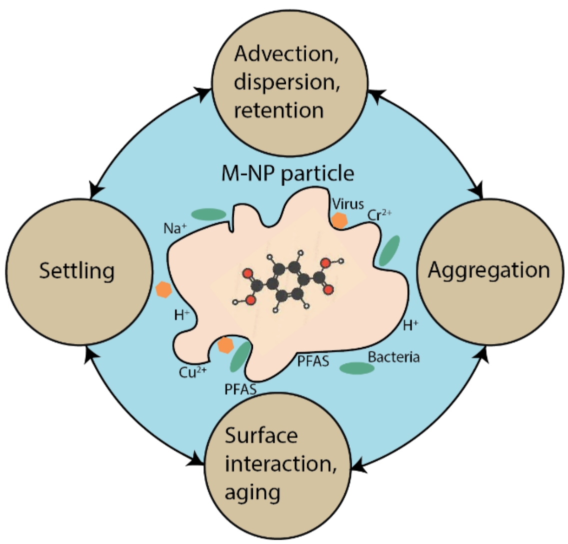
Experimental and modeling research project to study the co-transport of micro- and nano-plastics and dissolved contaminants in soil and water

Dr. Valentina Prigiobbe

Micro- and nano-plastics (M-NPs) are a diverse group of polymer-based particles, and they are considered contaminants of emerging concern because of their adverse impact on the environment and living organisms [1]. They are generated by the massive use of plastics in several products worldwide and enter the environment by their direct release into water or soil via wastewater treatment plant (WWTP) effluent discharge. Eventually, they can be ingested through water and food [2]. Upon release, plastic undergo unintentional degradation through physical, chemical, or biological processes forming micro-plastic particles (100 nm to 5 mm size) which can breakdown into particles of less than 100 nm size, nanoplastics [3,4].



Conceptual scheme of M-NP particle interactions with contaminants in an aqueous environment and the mechanisms of transport.

Recent studies have shown that M-NP particles can travel without retardation in soil and water [5,6,7] and accumulate other contaminants onto their surface and within their porous structure such as: heavy metals, persistent organic molecules, and pharmaceutical [8,9,10] behaving as contamination vectors around the planet [5,11]. The interaction of M-NPs with contaminants occurs through adsorption/desorption, attachment/detachment, and aggregation/disaggregation and it is facilitated by the large surface area, hydrophobicity, and porosity of the particles developed with aging [12].

Physico-chemical composition of the solution (e.g., pH, ionic strength, and temperature) and the biota affect the interaction between M-NPs and contaminants because they regulate the charge and enhance the aging of the particle surface. However, it is not clear to which extent those interactions respond to variable conditions in a complex environment. This is because experiments have been often performed under constant conditions and there are no models suitable to describe dynamic bio-physico-chemical systems. Therefore, there is the need to build a framework which couples governing equations of transport, aggregation, and settling of M-NPs under variable bio-physico-chemical conditions. The framework would allow us to explore the effect of system variability, predict the fate of M-NPs and adsorbed contaminants in the environment, and design remediation strategies.

In this three-year research project, experiments and modeling activities will be carried out to create a model of M-NPs transport coupled with biochemistry which will help to answer to the following research questions: 1) How do gradients of pH, temperature, and salinity affect the transport of M-NPs and their interaction with heavy metals or persistent organic contaminants such as PFAS? 2) Are transport mechanisms reversible? 3) Does the biota enhance M-NPs-contaminant interaction or help degradation?

Laboratory experiments using microfluidic and column-flood systems will be carried out on selected types of M-NP materials and under well-controlled laboratory conditions resembling the natural environment. Tests run using microfluidic systems will help formulating major mechanisms of interaction at the pore-scale while tests with column-flood systems will allow to validate the model. A recursive approach of modeling, experiments, and again modeling activities will be used.
Within the three years of the project, the Ph.D. student will gain an extraordinary background of experimental and modelling of reactive transport in porous media of solutes and suspensions. The student will have several opportunities of networking within academia by attending national and international conferences and by spending up to 6 months in an academic institution within Europe or the United States as a visiting scholar.

References

[1] Mammo, Amoah, Gani, Pillay, Ratha, Bux, and Kumari. Microplastics in the environment: Interactions with microbes and chemical contaminants. Science of The Total Environment, 743:140518, 2020.
[2] Nor, Kooi, Diepens, and Koelmans. Lifetime accumulation of microplastic in children and adults. Environmental Science & Technology, 55(8):5084–5096, 2021.
[3] Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Science of The Total Environment, 586:127–141, 2017.
[4] Granek, Brander, and Holland. Microplastics in aquatic organisms: Improving understanding and identifying research directions for the next decade. Limnology and Oceanography Letters, 5(1):1–4, 2020.
[5] Alimi, Budarz, Hernandez, and Tufenkji. Microplastics and nanoplastics in aquatic environments: Aggregation, deposition, and enhanced contaminant transport. Environmental Science & Technology, 52(4):1704–1724, 2018.
[6] Chu, Li, Li, Yan, and Shen. Transport of microplastic particles in saturated porous media. Water, 11(12), 2019.
[7] Keller, Jimenez-Martinez, and Mitrano. Transport of nano- and microplastic through unsaturated porous media from sewage sludge application. Environmental Science & Technology, 54(2):911–920, 2020.
[8] Santos, Rodrıguez-Mozaz, and Barcelo’. Microplastics as vectors of pharmaceuticals in aquatic organisms – an overview of their environmental implications. Case Studies in Chemical and Environmental Engineering, 3:100079, 2021.
[9] Joo, Liang, Kim, Byun, and Choi. Microplastics with adsorbed contaminants: Mechanisms and treatment. Environmental Challenges, 3:100042, 2021.
[10] Wang, Wong, Chen, Lu, Wang, and Zeng. Interaction of toxic chemicals with microplastics: A critical review. Water Research, 139:208–219, 2018.
[11] Santana-Viera, Montesdeoca-Esponda, Guedes-Alonso, Sosa-Ferrera, and Santana-Rodriguez. Organic pollutants adsorbed on microplastics: Analytical methodologies and occurrence in oceans. Trends in Environmental Analytical Chemistry, 29, 2021.
[12] Lu, Zhou, Sui, Zhou. Mechanism and characterization of microplastic aging process: A review. Front Environ Sci Eng. 2023;17(8):100.