TYPE Editorial
PUBLISHED 04 January 2024
DOI 10.3389/fenvs.2023.1355263

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OPEN ACCESS

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RECEIVED 13 December 2023
ACCEPTED 14 December 2023
PUBLISHED 04 January 2024

CITATION
Halsband C, Sørensen L, Khan FR, Herzke D and Wagner S (2024), Editorial: Environmental impacts and risks of car tire and styrene-butadiene rubber: microplastic pollution and contaminant transport.
Front. Environ. Sci. 11:1355263.
doi: 10.3389/fenvs.2023.1355263

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Editorial: Environmental impacts and risks of car tire and styrene-butadiene rubber: microplastic pollution and contaminant transport

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KEYWORDS

additives, risk governance framework, tire wear emissions, uptake, para-phenylenediamines, transformation product

Editorial on the Research Topic
Environmental impacts and risks of car tire and styrene-butadiene rubber: microplastic pollution and contaminant transport

Every year, almost 2 billion new vehicle tires are produced world-wide. At the same time >1 billion tires reach their end of life. During use, tire wear particles (TWPs) form through abrasion of the rubber material, and in contact with the road surface composites of both materials form tire and road wear particles (TRWPs). These emissions represent a large fraction of total microplastic pollution, and thus a pressing environmental challenge that cannot be counteracted by "green" urbanization through the electrification of car, truck, and airplane fleets. In fact, heavier electric cars may emit even more TWPs and increase the frequency of tire replacements. In addition to TWPs and TRWPs, crumb rubber (CR) produced from end-of-life tires has been a popular low-cost product as infill on artificial grass for outdoor sports pitches, where it has become a substitute for natural grass, sand, or gravel, but is prone to runoff into the surrounding environment.

TWPs and crumb rubber constitute their own class of nano- and microplastics in the size range of 10 nm to several millimeters, composed of a complex mixture of elastomers, mainly synthetic styrene-butadiene (SBR) and natural rubber (NR), and a range of chemicals. The magnitude of emissions and the complex composition of rubber and additive chemicals make these particles problematic, with soils, waterways, and eventually coastal and marine systems acting as the main environmental recipients. Both rubber particles and their leachates may induce toxic effects across a range of exposed habitats and species, and need to be better characterized, understood, and regulated.

Until now, TWP and CR have been largely overlooked in environmental monitoring studies focusing on microplastics due to a lack of appropriate techniques to identify and quantify rubber particles in environmental matrices. The small size of tire rubber particles in the nano size range prevents detection by most analytical techniques otherwise used for polymer particles (e.g., FTIR and Raman spectroscopy). Although tire rubber nanoparticles likely constitute a large proportion of the mass of TWP generated and have the greatest potential for long-range transport with air and water from the primary emission sources in urban areas, knowledge about their distribution and impacts therefore remains elusive. Consequently, the lack of data describing measured concentrations in environmental compartments hinders appropriate environmental risk assessments of TWP and CR.

As tire rubber is particularly rich in chemical additives and their transformation products, it is important to delineate organismal responses and effects arising from the exposure to the rubber particles themselves, the chemicals leaching from these particles, or a combination of both. Additives that could serve as bioindicators of exposure to TWP would be valuable tools to assist with the detection of the environmental presence of TWPs and/or their leachates, while at the same time improving our understanding of interactions between TWPs and organisms. Understanding the behavior, effects and impacts of car tire rubber emissions is thus important to assess the implications for environmental and human health.

The present Research Topic of studies considers many of these issues and contributes to an advanced understanding of the factors driving tire rubber particle emissions and their subsequent transport in the environment. The Research Topic consists of six original research articles, addressing topics concerning the occurrence and abundance of TWP near roads, their behavior under different environmental conditions, and the fate of their additives in seawater and marine organisms. In addition, one paper evaluates in how far governance frameworks are ready to be applied to assess environmental and human health risks from tire wear nanoparticles.

Habib et al. shed important light on the properties and fate of TWPs and rubber particles originating from other rubbery car parts (e.g., mud flaps, door mats) directly following their formation. They quantified TWPs in road dust, soil along roadsides, storm water run-off, and seasonally desiccating creeks. They conclude that hot arid regions have different TWP emission dynamics compared to more humid habitats. High local summer temperatures at very low humidity increased breakdown of rubber materials, which became hard, brittle and broke into smaller pieces. Infrequent rain events prevent TWP losses away from the roads, such that TWP concentrations remain high locally near the emission sites.

Gao et al. focus on the spread of airborne TWPs and found that both traffic density and driving behavior influence the spread of TWPs, although most particles were deposited within a few meters distance from the pavement. The authors also provide insights into a suite of promising sampling and analytical techniques, such as adhesive tape sampling and ATR-FTIR. These approaches deserve more attention in future studies. Using single particle characterization by SEM-EDX airborne TWPs deposited on boron substrates can be identified applying a morphological, textural and chemical classification scheme.

Wilkinson et al. investigated how specific tire properties and the type of road surface both influence the abundance and morphology of tire and road wear particles (TRWPs). In a controlled experiment, using a road simulator, nine tire types representing three brands and three tire designs (i.e., summer tires, winter tires, and studded winter tires) were driven on a simulated road surface of asphalt and cement concrete. Through comprehensive physicochemical characterization, the authors demonstrated that the number of TRWPs generated varied with tire type and surface and also observed changes in the chemical and physical properties in relation to the original rubber material. Overall, these findings suggest that modifications to tire formulations could reduce the release of TRWPs.

Foscari et al. provide a thorough assessment of environmental factors, e.g., sunlight, driving the leaching of organic chemicals from model TWPs. They also consider how environmental processes may transform chemicals such as phenylguanidines through, e.g., oxidation, linking with observations from other studies showing that tire chemical transformation products can be more toxic than the intentionally added chemical itself. Importantly, they also demonstrate the diversity of unknown chemicals leaching from car tire rubber, several of which are yet to be structurally identified, demonstrating the need for more transparency and regulation of chemical use in tire production and considering transformation of chemicals within the tire during the tire production and use-phase of the tire.

Hägg et al. demonstrate that CR is ingested by marine fish and study the temporal dynamics and individual variability in the egestion dynamics of CR particles from the intestinal system post-exposure. In addition, they show the transfer of several potentially toxic chemicals from CR to blood, confirming ingestion as an important exposure route of both tire rubber particles and associated chemicals to marine organisms. They identify a group of additives, *para*-phenylenediamines (PDs), commonly used as anti-ozonants in tire material, as promising biomarkers for TWPs and/or leachate exposure, providing an alternative, minimal-invasive method to determine recent TWP exposure other than through the detection of the TW particles themselves. They conclude that the uptake of tire additives into vertebrate blood provides potential to also detect and monitor human CR exposure.

Finally, Van Broekhuizen et al. attempt to apply a nano risk governance framework (NRGF) to the case of TWP nanoparticles. They performed a risk and concern assessment of manufactured nanomaterials used in tire rubber tread and the environmental release of TWP. The assessment focused on the release and hazards of nano-TWPs. As a result of this study, it was concluded that an exclusive risk assessment of nano-TWPs is not reliable yet. A key consideration from their work was that the lack of either environmental exposure or health hazard data currently hinders the risk assessment of such emissions.

Within this Research Topic we are beginning to see crucial datasets that study realistic pathways of these specialized microplastics from roads to ecosystems, while at the same time refining and optimizing targeted analytical methods for these particles. These methods are a prerequisite to increase the availability of comprehensive data needed to map environmental TWP and CR concentration gradients. Validated and harmonized TWP/CR analysis methodologies will enable a synthesis of available data in the future. Although we provide first experimental evidence for the uptake of both rubber particles and a few selected additives (*para*-phenylenediamines) more information on biological responses to TWPs, TRWPs and CR is needed for appropriate risk assessments of tire rubber particles in the environment. However, several knowledge gaps remain including a better understanding of toxic effects of additive chemicals and their transformation products. Existing studies reported severe impacts of PDs on anadromous fish and other species, while closely related taxa appear tolerant to the same chemicals. The physiological mechanisms and species-specificity of the toxicity are thus insufficiently understood. Further work on understanding the effects and impacts of the multitude of chemicals present in and leaching from tire particles is necessary. In addition to dose-responses to CR and TWPs, cocktail effects of additives and multi-stress impacts in combination with other environmental stressors (e.g., from climate change) must be considered in future studies. Effect and toxicity studies will not only help to quantify environmental risks from already emitted TWPs and CR, but can also contribute to evaluating alternative additives that provide similar desirable tire properties, but induce less toxicity. Improved risk assessments leaning on such studies will reduce uncertainty, and thus better guide manufacturer decisions and policy demands.

Author contributions

CH: Writing–original draft, Writing–review and editing. LS: Writing–original draft, Writing–review and editing. FK: Writing–review and editing, Writing–original draft. DH: Writing–review and editing. SW: Writing–review and editing.

Conflict of interest

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The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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