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Microplastics Concentrations in Soil Along a Racetrack

Demmelash Mengistu · Vegard Nilsen ·
Claire Coutris · Helena Marie Amdal ·
Arve Heistad

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Abstract Motorsport is known for its high tire wear due to speed, cornering, and high acceleration/deceleration activities. However, studies on the generation of microplastics from racetracks are rare. This study aimed at quantifying microplastics concentrations in topsoil (0–5 cm) along a racetrack. The results showed that rubber materials (RM) and tire reinforcement microplastics (TRMP) were deposited in the soil along the racetrack. Concentrations of the two microplastics were affected by the distance from the edge of the racetrack (highest concentrations within 20 cm from the track) and track alignment (highest concentrations at the start/finish area). In addition, a weak correlation was observed between the concentrations of the two microplastics, suggesting the effect of track alignment on the type of microplastics abraded. The results also showed that coarser microplastics (1000–5000 µm) dominate the size distribution of microplastics along a racetrack. The findings of this study may provide racetrack managers with basic information for designing microplastic-controlling solutions. While additional studies are required to map environmental effects and policy measures, our initial results suggest that motorsport is of concern in terms of microplastics release to the environment.

Keywords Tire · Microplastics · Topsoil · Rubber

1 Introduction

Motorsport started in the early twentieth century, after the invention of the automobile. It occupies a highly important place in popular and sporting culture in the world (Dingle, 2009). There are about 130 local clubs and over 400 motorsport facilities registered in Norway alone (The Royal Norwegian Ministry of Culture & Equality, 2022). According to Michelin's engineers (Formula 1, 2021b), tire is an essential part of a racecar for safety and performance. Abrasion of tires is an inherent consequence of their use for all kinds of vehicles (Jekel, 2019). This process, at the interface of tires and road pavements, creates tire wear particles (TWP) (Wagner et al., 2018), which, in combination with other road particles, form tire and road wear particles (TRWP) (Panko et al., 2013). TWP generation is affected by multiple factors, like tire characteristics (size, tread depth, construction, tire pressure, and temperature, contact patch area, chemical composition, accumulated mileage, wheel alignment) and vehicle operation (speed, linear and radial acceleration, frequency and extent of braking and cornering) (Grigoratos & Martini, 2014; Gustafsson et al., 2008;

D. Mengistu (✉) · V. Nilsen · H. M. Amdal · A. Heistad
Faculty of Science and Technology, Norwegian University of Life Sciences (NMBU), Ås, Norway
e-mail: demmelash.mengistu@nmbu.no

C. Coutris
Division of Environment and Natural Resources, Norwegian Institute of Bioeconomy Research (NIBIO), Ås, Norway

Jekel, 2019). High speed, fast acceleration and retardation, and high cornering speeds lead to increased tire wear (Pohrt, 2019). Dahl et al. (2006) studied the effects of speed on tire wear generation in a laboratory road simulator and found the speed to be the main factor in particle generation, as it determines mechanical stress and treads temperature. In addition, the size of the TWP generated decreased linearly with increasing temperature (Dahl et al., 2006). Therefore, it is expected that motor racing would lead to high deposition of TWP in the soil along the racetrack.

Racecar tires are composed of, among others, natural rubber (NR), styrene-butadiene rubber (SBR), carbon black or silica, sulfur, zinc oxide, antioxidants, and antiozonants (Formula 1, 2021a). Similar components constitute road tires (Grigoratos & Martini, 2014; Wik & Dave, 2009). However, race tires and road tires are very different and probably generate different TWP as car tires are made to last 40,000–50,000 km (Grigoratos & Martini, 2014; Parker-Jurd et al., 2019) while race tires, for example, Formula 1 tires, are designed to last for a maximum of 200 km (Formula 1, 2021b). Race tires are designed to withstand far larger forces than road car tires; for example, Formula 1 tires have to withstand massive forces of 6 *G* to decelerate and up to 5 *G* at cornering (Formula 1, 2021b), and potentially generate more TWP per vehicle kilometer compared to passenger cars. However, we are unaware of any prior studies on TWP concentrations in racetrack soils, the only related study being on the deposition of tire fragments from an ice racetrack (Ilgasheva et al., 2020).

This study aims to quantify the amount of TWP deposited in soils adjacent to the Rudskogen racetrack in Norway and assess whether track alignment and distance from the edge of the track influence microplastics concentrations in soil.

2 Materials and Methods

2.1 Study Area

Rudskogen racetrack is located in Southeastern Norway (Rakkestad, 59.368 N, 11.262 E) and was selected as Norway's leading motorsport facility. The main track is a 3-km-long asphalt track used for both motor racing and traffic training. The racetrack was opened for the first time in 1990 and was expanded in 2011 to its current form. The driving direction is clockwise, and the track has a maximum elevation difference of 43 m. It has 14 corners and is 15–18 m wide. Verges along the track are made of grass-covered soil, gravel, or paved to the fence (Fig. 1). The width of the verge varies along the track, and at the selected sampling locations for this study, the width ranged from 2.8 m in the start/finish area to 40 m at the final corner. The track is swept after each race to remove tire debris.

2.2 Sampling

A total of four sampling locations were selected to represent different track alignments where TWP generation and transportation from the track surface to the verges was assumed to occur at different rates following linear speeding, radial acceleration, and braking. The sampling procedure was first described by Amdal (2021). The selected sampling locations (SF, LS, IC, and OC) are shown in Fig. 1, and the main wear-generating factors for these locations are indicated in Table 1.

At each sampling location, three sampling spots (A, B, and C) with an area of 20 × 20 cm each and center distances of 10, 110, and 270 cm from the edge of the track, respectively, were selected (Fig. 1). After collecting four topsoil (0–5 cm) samples from the corners of each sampling spot using a soil corer, a composite sample was prepared for each sampling spot. Samples were oven-dried at 105 °C overnight and homogenized using a not sharp-edged Kenwood kitchen blender KMM770 for 15 s. Bigger soil particles were removed by 5-mm mesh sieves before a sub-sample of 10 g was sieved sequentially with three different mesh sizes (1000 µm, 50 µm, and 25 µm) using a stainless-steel vibratory sieve shaker (Retac 3D, Retsch, Germany). After sieving, the three fractions (1000–5000 µm, 50–1000 µm, and 25–50 µm) were weighed using an analytical balance AT200 METTLER (Mettler-Toledo GmbH, Giessen, Germany) and the proportion of each size fraction was determined by dividing the mass of the specific size fraction by the total mass recovered after sieving. The majority (66.0%) of the soil sample was in the size fraction 50–1000 µm, while the size fractions 1000–5000 µm and 25–50 µm accounted for 23.4% and 2.8% by mass, respectively. Samples from the major size fraction (50–1000 µm) were analyzed in

Fig. 1 Overview of the Rudskogen racetrack with sampling locations; start/finish (SF), long straight drive (LS), inward curve (IC), and outward curve (OC). The large insert (picture) shows the three different sampling distances from the edge of the track (**A**, 0–20 cm; **B**, 100–120 cm; **C**, 260–280 cm), and the small insert (schematic) shows the four sub-samples of topsoil taken for each of the three distances

Table 1 Description of the sampling locations

Code	Location	Wear-generating factors
SF	Start/finish	Acceleration/deceleration, the track is straight
LS	Long straight	Speed, no cornering
IC	Inward corner	Cornering
OC	Outward corner	Cornering

triplicate, whereas only one replicate was analyzed from size fractions 1000–5000 µm and 25–50 µm because of budget limitations—a total of 60 samples.

2.3 Data Acquisition and Modeling

Decomposition of Fourier transform infrared (FTIR) data of environmental samples using a parallel factor analysis (PARAFAC) model provides a mechanism to detect and quantify rubber materials (RM) among many components (Mengistu et al., 2019). Thermogravimetric and FTIR spectral data of the samples were generated using a simultaneous thermal analyzer STA 449 F1 Jupiter, with carrier type S (Netzsch, Germany), and a Fourier transform infrared spectrometer Bruker Tensor 27 with external gas cell (Bruker, USA) using the procedure described in (Mengistu et al., 2021). The STA registered changes in mass while samples were heated from 40 to 800 °C and released gases to the FTIR. The FTIR scanned spectra of a wavenumber range between 4000 and 600 cm^{-1} for every batch of gas released from the STA with a resolution of 1.93 cm^{-1}, generating 1762 signal points. The FTIR data resulted in 666 spectra per sample, giving a total of 1.1 million data points per sample. The data was arranged in a trilinear multiway dataset as outlined in Mengistu et al. (2021) to suit PARAFAC (Baum et al., 2016). PARAFAC models with 2 to 5 components were then built using MATLAB (The MathWorks, Inc., R2018a, Natick, USA) and a PLS Toolbox for MATLAB version 9.0 (Eigenvector Research, Inc., Wenatchee, USA). The PARAFAC analysis steps and model validation are presented in Mengistu et al. (2021).

From a valid PARAFAC model, scores were used to calculate the concentration of components (rubber materials (RM) and tire-reinforcing microplastics (TRMP)) in samples using Eq. 1 (Mengistu et al., 2021). RM are core components of tires (Thorpe & Harrison, 2008) and are good TWP markers (Wagner et al., 2018). Score values ≤ 0 were set to 0 in calculating concentrations. The limit of detection of the method is 0.7 mg/g, and therefore not likely to be affected by laboratory contamination for tire components.

$$C_f = \left(ml \times a_{if}\right) / \left(m \times S_i\right) \tag{1}$$

where

C_f concentration of the f^{th} component (mg/g)

ml sample mass loss during heating (mg)

m initial sample dry mass (g)

a_{if} score of f^{th} component of sample i extracted from PARAFAC

S_{i} sum of the score of components of sample i

2.4 Statistical Analysis

Differences in concentrations (in soil fraction 50–1000 μm) between racetrack locations and between distances from the edge of the racetrack were tested using two-way analysis of variance (ANOVA), followed by a Tukey pairwise comparison test to identify differing locations and distances. The level of significance was set to 0.05.

3 Results and Discussion

3.1 Identifying Microplastics in Samples from the Racetrack

Microplastics along the racetrack were identified by analyzing the FTIR and pyrolysis temperature (mass loss) profiles of the components from the PARAFAC model. The PARAFAC model decomposed the data into three components, with 95% of the variation in the data captured by the variation in these components. The model showed 93% core consistency (Fig. 2a) and similarity of 71% in split-half analysis (Fig. 2b). Models with similar figures of merit are considered valid (Bro & Kiers, 2003; Murphy et al., 2013). However, the model fit and unique fit % showed differences in components 1 and 2, indicating overlap/data sharing between the two (Fig. 2c).

The FTIR spectra and pyrolysis temperature profiles of the three components are shown in Fig. 3a and b. Component 1 showed FTIR peaks typical for hydrocarbons (2927 and 2850 cm^{-1}). Other peaks (ca. 1500 and 700 cm^{-1}) were also visible. Pyrolysis temperature of component 1 showed the highest degradation at 456 °C. Another broad peak was observed at 610 °C (range 500–700 °C). Component 1 might have originated from the decomposition of other microplastics such as polyester or nylon, as they are common reinforcement synthetic fabrics in the tire industry, fitted under the tread (Tian et al., 2019). The presence of polyester or nylon is plausible because of the observed removal of pieces of rubber of different sizes and shapes shredded from tires, which might have exposed the underlying reinforcement materials. Although determining the component's identity with sufficient certainty is difficult, component 1 showed similar FTIR and pyrolysis temperature peaks to polyester (Bautista et al., 2017) than nylon (Charles et al., 2009). However, further study using gas chromatography–mass spectrometry (GC–MS) may help in achieving a more precise identification. This study uses tire-reinforcing microplastics (TRMP) to refer to this component. Component 2 mimicked the properties of RM, which is a typical marker for tires reported

Fig. 2 Figures of merit of the model: (**a**) core consistency, (**b**) similarity of split-half analysis, and (**c**) model fit and unique fit

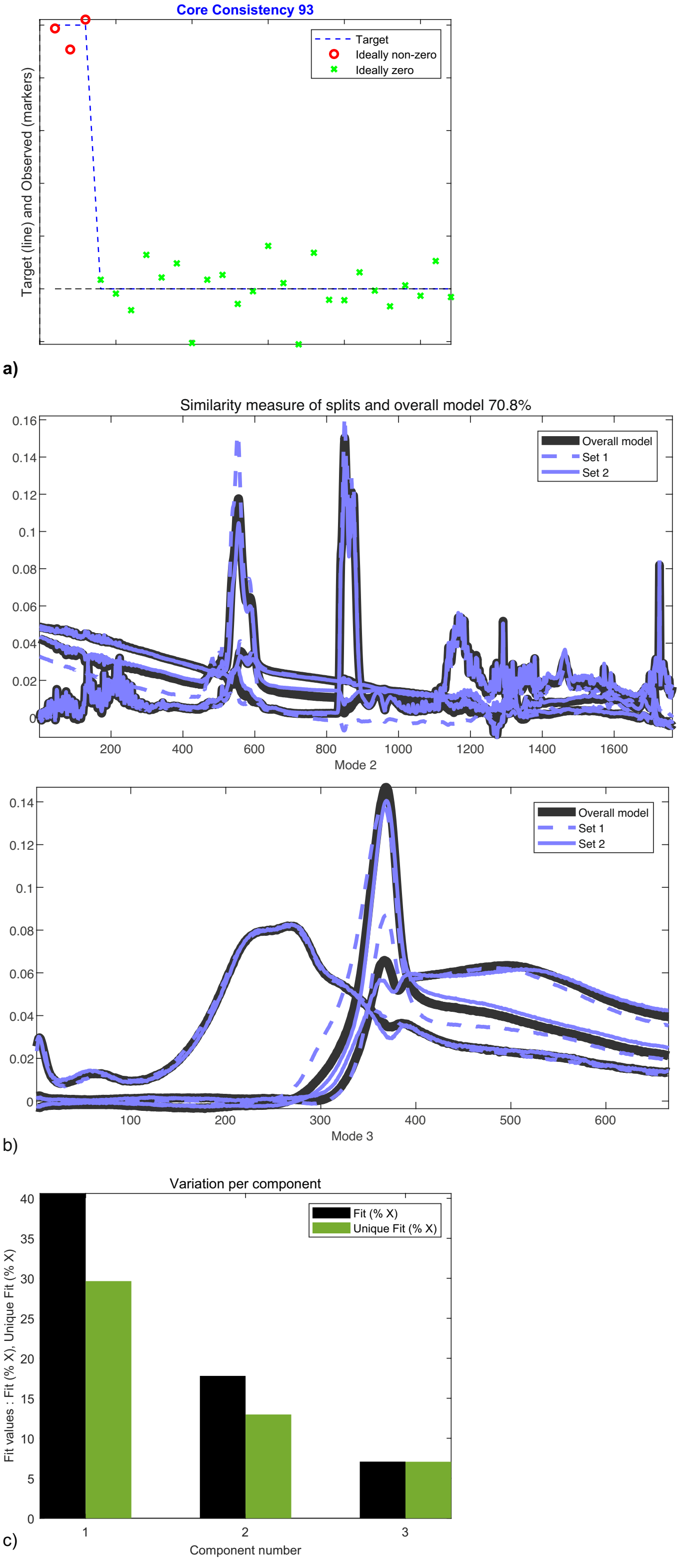
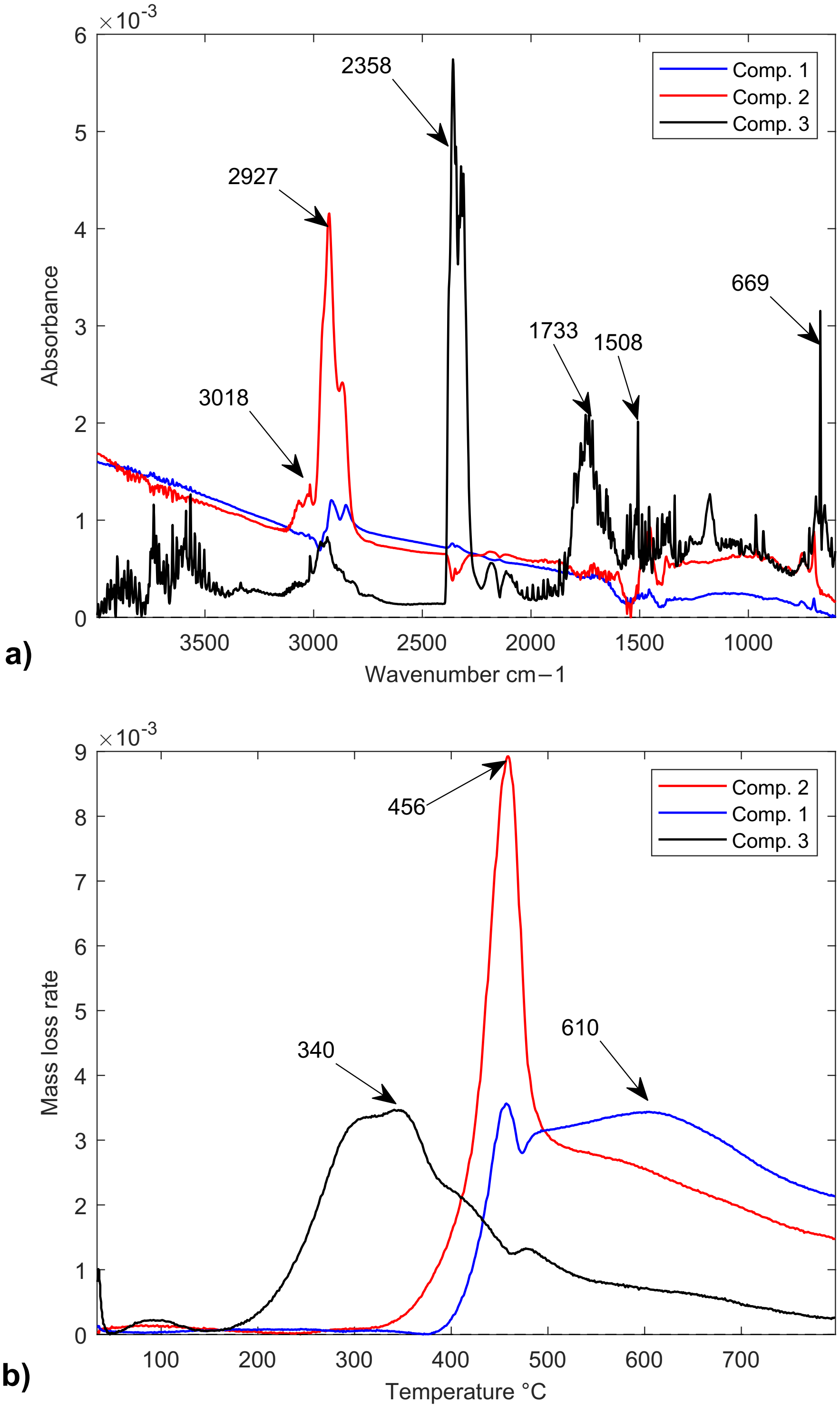


Fig. 3 Spectra for (**a**) FTIR and (**b**) pyrolysis temperature of the three components from the PARAFAC model. Component 1 (blue line) was identified as tire reinforcement microplastic (TRMP), component 2 (red line) was identified as rubber material (RM), and component 3 (black line) was identified as carbon dioxide and other substances. Peak numbers are typical identification markers



in Mengistu et al. (2019), indicating the deposition of TWP in the soil along the racetrack. Spectra of component 3 showed peaks mainly representing water and carbon dioxide. Additional signals, such as weak peaks at 3018, 2927, 2856 cm^{-1}, and a broad peak at 1733 cm^{-1} in the FTIR spectra, as well as peaks at ca. 340 and 456 °C in the mass loss profile, indicated the presence of degradation products from organic substances, likely plant materials, carbonyl-containing organic compounds, and bitumen (Kawamoto, 2017; Mohomed, 2016; Silverstein et al., 2015).

3.2 RM and TRMP Concentrations Along the Racetrack

RM and TRMP were detected at all locations (SF, LS, IC, and OC) and all distances from the edge of the racetrack (10, 110, and 270 cm). The normalized RM and TRMP concentrations (mg/g soil dw) are presented in Table 2.

RM concentrations in the soil size fraction 50–1000 µm (soil fraction analyzed in triplicates) showed statistically significant differences between the four locations ($F_{3,24} = 10.56$, $p < 0.001$), with RM concentrations significantly higher at SF, compared to the other locations (Tukey, $p < 0.05$). Considering that braking and acceleration are associated with high wear generation, this finding agrees with Pohrt (2019), who reported that high-speed, fast acceleration and retardation, and increased cornering speeds lead to increased tire wear. Mean concentrations in the soil size fraction 50–1000 µm showed statistically significant differences between the three distances from the edge of the racetrack ($F_{2,24} = 19.24$, $p < 0.001$), with higher RM concentrations 10 cm from the edge of the racetrack at locations SF and IC (Tukey, $p < 0.05$).

Only 36% of the samples in soil size fraction 50–1000 µm showed detectable TRMP. The results of correlation analysis showed a weak ($R^2 = 0.12$) linear relationship between RM and TRMP concentrations indicating variations in factors influencing the generation of these two types of microplastics. TRMP concentrations in the soil size fraction 50–1000 µm did not show any significant differences, neither between the four locations (SF, LS, IC, and OC) ($F_{3, 24} = 0.18$, $p = 0.91$) nor between distances from the edge of the racetrack ($F_{2,24} = 1.56$, $p = 0.23$).

Although the comparison cannot be evaluated statistically in the absence of replicates for the largest and lowest size fractions, it is interesting to notice that, close to the racetrack (0–20 cm), RM concentrations were the highest in the largest soil size fraction (1000–5000 µm), followed by the size fraction 50–1000 µm, and the lowest in the finest size fraction (25–50 µm), at all locations (Table 2 and Fig. 4a). Similarly, TRMP concentrations close to the racetrack were the highest in the largest size fraction, at

Table 2 Concentrations (mg/g) of rubber material (RM) and tire reinforcement microplastics (TRMP) in the three size fractions (25–50, 50–1000, and 1000–5000 µm). Concentrations in the size fraction 50–1000 µm are shown as mean ± one standard deviation. Locations: *SF*, start/finish; *LS*, long straight; *IC*, inward curve; *OC*, outward curve. Asterisks indicate significant differences between the three distances from the edge (A, B, C), for each given location

Distance from the edge of the racetrack (cm)	Soil size fraction (µm)	Microplastics (mg/g)							
		Rubber materials (RM)				Tire-reinforcing microplastics (TRMP)			
		Locations				Locations			
		SF	LS	IC	OC	SF	LS	IC	OC
A (0–20)	1000–5000	123.9	22.9	62.9	67.9	36.4	23.1	134.0	109.1
	50–1000	66.8* ± 25.5	5.9 ± 3.5	28.8* ± 6.7	8.9 ± 5.0	0.0 ± 0.0	10.6 ± 18.4	0.0 ± 0.0	2.0 ± 3.4
	25–50	11.6	1.1	2.4	0.0	0.0	24.9	0.0	0.0
B (100–120)	1000–5000	41.2	0.0	0.0	33.8	0.0	5.9	0.0	78.1
	50–1000	2.7 ± 1.5	2.3 ± 0.8	1.6 ± 3.4	19.7 ± 2.6	22.8 ± 18.8	1.8 ± 3.0	10.9 ± 9.6	6.8 ± 11.8
	25–50	0.0	3.3	4.1	1.2	13.6	0.0	0.0	0.0
C (260–280)	1000–5000	0.0	0.0	4.4	4.1	8.3	0.0	4.9	25.5
	50–1000	8.8 ± 3.8	2.3 ± 2.0	3.6 ± 2.6	25.8 ± 10.0	0.0 ± 0.0	0.2 ± 0.4	10.7 ± 14.4	8.8 ± 15.2
	25–50	0.8	0.8	9.6	0.0	20.2	0.0	0.0	0.0

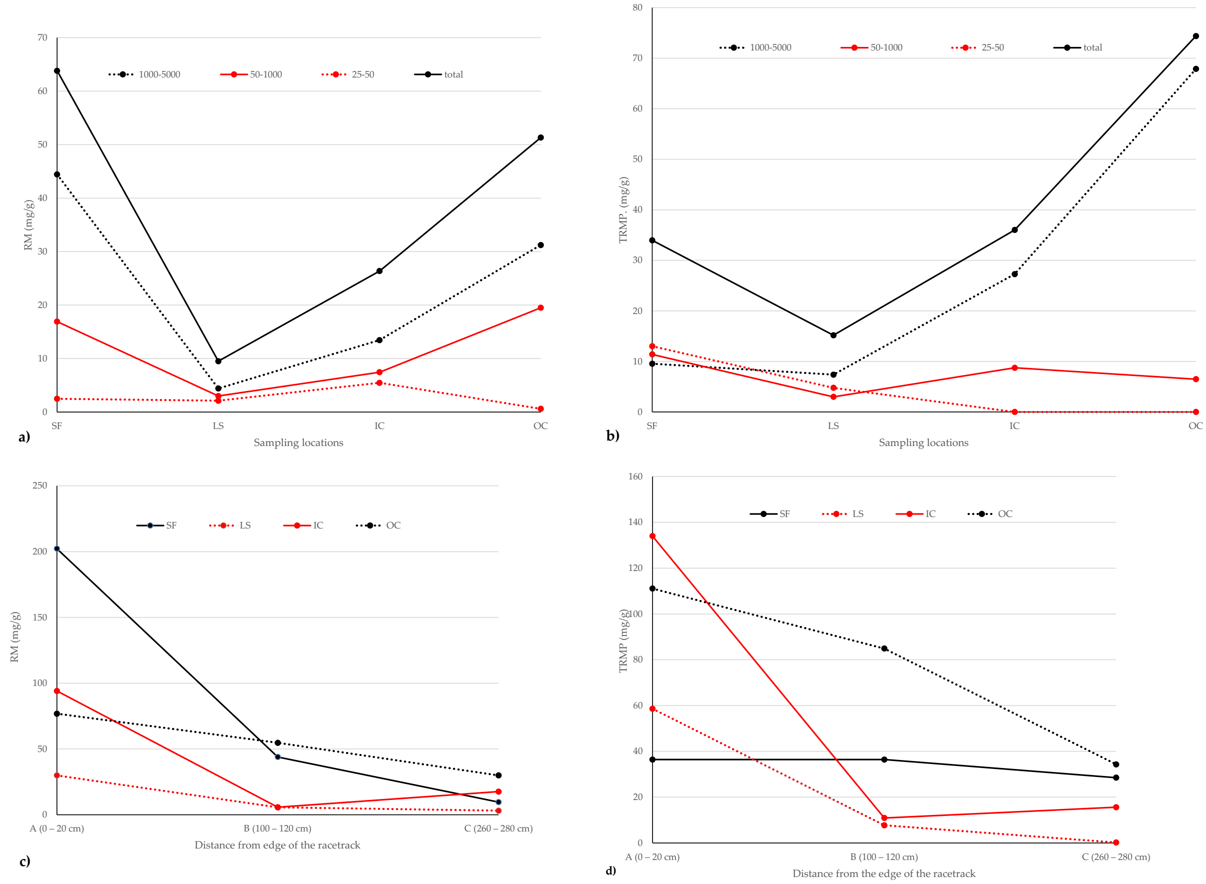


Fig. 4 Concentrations of microplastics in soil size fractions (25–50 μm, 50–1000 μm, and 1000–5000 μm) at different locations (start/finish, SF; long straight, SD; inward corner, IC; and outward corner, OC) along the Rudskogen racetrack. Distances from the edge of the racetrack: **A** (0–20 cm), **B** (100–120 cm), **C** (260–280 cm). Concentrations of rubber material (RM) in mg/g soil dry weight are shown in (a) and (c), while concentrations of tire reinforcement microplastics (TRMP) in mg/g soil dry weight are shown in (b) and (d)

locations SF, IC, and OC (Table 2). The higher concentrations of RM and TRMP in the size fraction of 1000–5000 μm suggest that coarser particles are generated from racetrack usage than from road traffic, where TWP have been reported to be in the range of 5–350 μm (Kreider et al., 2009). The generation of coarser TWP from racing seems in line with the nature of racing itself, compared to road driving, and the composition of race tires, and was qualitatively confirmed by visual observations of marbles (pieces of rubber of different sizes and shapes shredded from tires) in the grass along the racetrack, up to 9 cm long, and with scorched surfaces. Given the presence of these large tire fragments, the reported photo- and biodegradability of TWP in the environment (Baensch-Baltruschat et al., 2020), and the deposition of TWP over many years of racing, it is not here possible to determine the proportion of microplastics directly originating from racing from those produced by degradation and fragmentation of larger TWP. Further studies on the fate of TWP in soil along important TWP sources such as racetracks would bring valuable information.

RM concentrations, all size fractions considered, were 2.5–17 times higher at 20 cm from the edge of the racetrack than further away (Fig. 4c), suggesting that TWP mainly deposited within 20 cm from the edge of the track. The maximum RM concentration (202.4 mg/g) was observed at SF, followed by IC (94.2 mg/g) and lowest at LS (29.9 mg/g). The decreasing trend with distance from the edge of the track was notable even though the distance studied was only 2.8 m. These results agree with the findings by Cadle and Williams (1978), who reported an exponential decrease in TRWP concentrations with distance from the edge of the road. RM concentrations at SF and IC were higher than the highest RM concentrations reported in gully pot sediments by Mengistu et al. (2021). Similarly, a decreasing concentration trend with increased distance from the edge of the racetrack was observed for TRMP (Fig. 4d).

3.3 Environmental Impact

The results showed the presence of RM in soil at concentrations 29.9–202.4 mg/g soil dw (all size classes included) within 20 cm from the edge of the racetrack (Table 2). Since, according to Grigoratos and Martini (2014) and Wik and Dave (2009), RM make 40–60% of treads, this corresponds to TWP concentrations in soil in the range 50–500 mg/g soil dw. If exposed to flooding, the soil along the racetrack could thus pose an environmental risk, as stormwater is reported to transport TWP to receiving water bodies (Johannessen et al., 2021; Kole et al., 2017; Tian et al., 2021). Acute (Khan et al., 2019; Wik & Dave, 2005, 2006) and chronic (Khan et al., 2019; Villena et al., 2017) toxic effects of TRWP are widely reported with a growing evidence of negative impacts. Some recent studies (e.g., Tamis et al., 2021) have demonstrated the environmental risk posed by TWP and other associated chemical substances from stormwater runoff in Europe. In addition, by-products of tire manufacturing additives are reported to be acutely toxic to some species. For example, the mass mortality of coho salmon (*Oncorhynchus kisutch*) in the streams of the Pacific Northwest region of the USA was attributed to 6ppd–quinone (a transformation product of N-(1,3-dimethylbutyl)-N-phenyl-p-phenylenediamine (6PPD)) (Tian et al., 2021). However, the toxicity reported might be species-specific as a recent study found no acute toxicity of 6ppd-quinone on other organisms or even other salmon species tested (chum salmon, *Oncorhynchus keta*) (McIntyre et al., 2021). The high TWP concentrations in topsoil observed in the present study suggest significant annual TWP deposition. This may lead to high inflow of microplastics into rivers, as mass flux studies in watersheds showed that 50% of TRWP from roads reach freshwater systems if not treated (Unice et al., 2019). Since sweeping the racetrack after each race is the only treatment measure in the present case, it is possible that toxic effects could be observed in rivers receiving stormwater from the present study area, as sweeping is not considered effective in removing the finer microplastic particles (Janhäll et al., 2016). However, sweeping after the races may remove more TWP than reported in literature (Björklund et al., 2011; Janhäll et al., 2016) because of the high fraction of large-size microplastic particles observed in this study. Future studies on microplastics concentrations from racetrack dust before and after sweeping as well as concentrations along the route to rivers should be considered to better understand annual fluxes.

4 Conclusion

This study demonstrated the presence of microplastics (RM and TRMP) in the soil along a racetrack. Although the two different types of microplastics were found together in most samples, the correlation observed between RM and TRMP concentrations was weak, suggesting the effect of track alignment on the type of microplastics abraded. Distance from the edge of the racetrack affected the concentrations of RM and TRMP, as concentrations decreased with increased distance, when all size fractions were considered. Track locations also affected TWP deposition, with the highest RM concentrations observed in soil alongside the Start/Finish area. The findings of this study could be of interest to racetrack managers in terms of planning microplastic management. Even though additional studies are required to map environmental effects and policy measures, our initial results suggest that motorsport is of concern in terms of microplastics release to the environment.

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Data Availability The data analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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