Empa
Materials Science and Technology

Distribution of tire wear in the environment through atmospheric transport and deposition

Christoph Hueglin[a], Narain Ashta[a], Eric Ceglie[a], David Jaramillo-Vogel[b], Ralf Kaegi[c], Juanita Rausch[b], Ueli Schilt[a], Atiur Rahman[a]

[a] Empa, Lab. For Air Pollution / Environmental Technology
[b] Particle Vision AG
[c] Eawag, Department Process Engineering

Particle Vision

eawag aquatic research

Tire wear particles (TWP)

- Production: passenger car: ≈ 120 mg · km^{-1} [1]

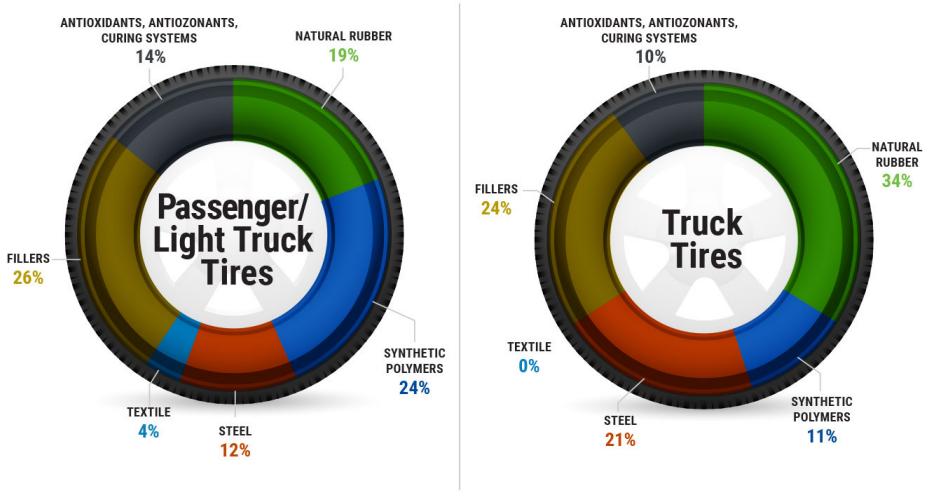
  thereof ≈ 1.1 mg · km^{-1} as PM10 [2]

  heavy duty vehicle: ≈ 38 - 61 mg · km^{-1} per wheel [3]

- In Switzerland: ≈ 13’500 tons/year [4]

[1] ADAC (2021), Tyre wear particles in the environment
[2] Saladin et al., Environ Sci. Technol. (2024)
[3] Polukarova et al., STOTEN (2024)
[4] Empa & wst21, Reifenabrieb als grösste Quelle von Mikroplastik – Massnahmen zur Verminderung (2023)

Tire wear



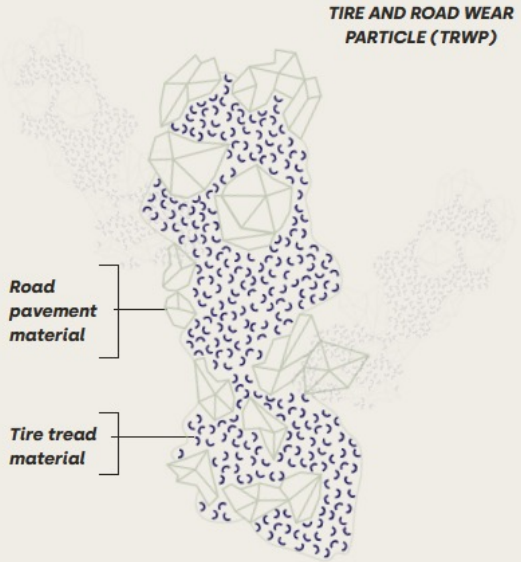
https://www.ustires.org/tires-101

- Tire wear consists of rubber (≈ 50 % by mass) and is one of the main forms of microplastics
- Tire wear contains a large number of potenitally toxic chemicals,

  e.g. the antioxidant N-(1,3-Dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD) and 6PPD quinone, which is toxic to fish [1]

[1] Tian et al., Science (2020)

Tire and Road Wear Particles (TRWP)



Elongated particles

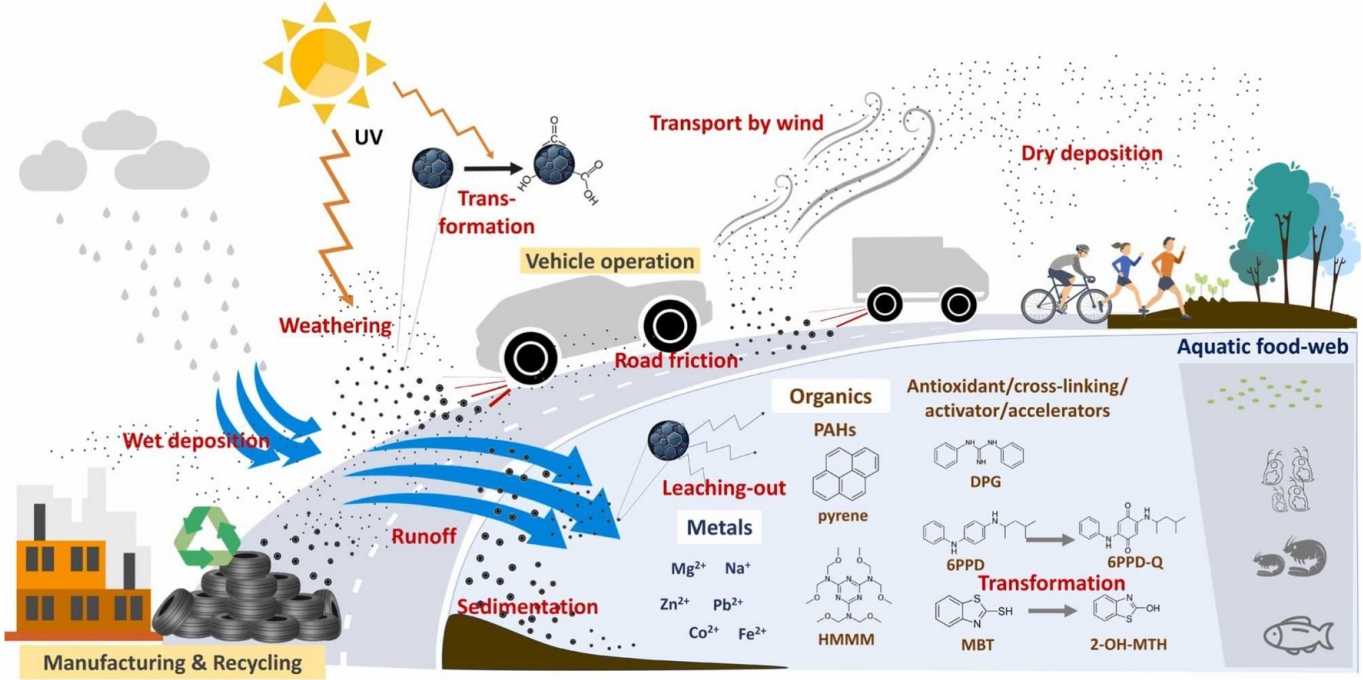
Approximately 100µm in length (around the thickness of a human hair)

A roughly 50:50 mix of tire tread & road pavement material

Denser than water (~1.8g/cm3)

https://tireparticles.info/

Tire wear in the environment



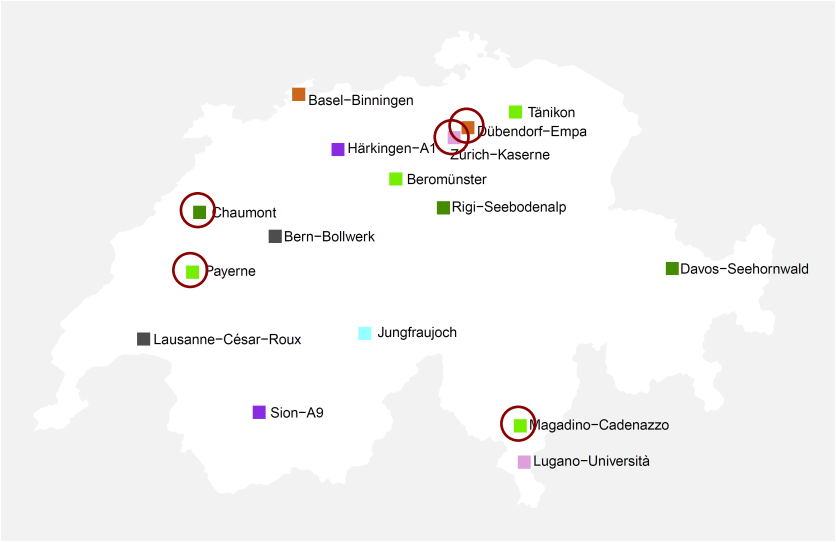
Yogandham et al., J. Hazardous Materials (2024)

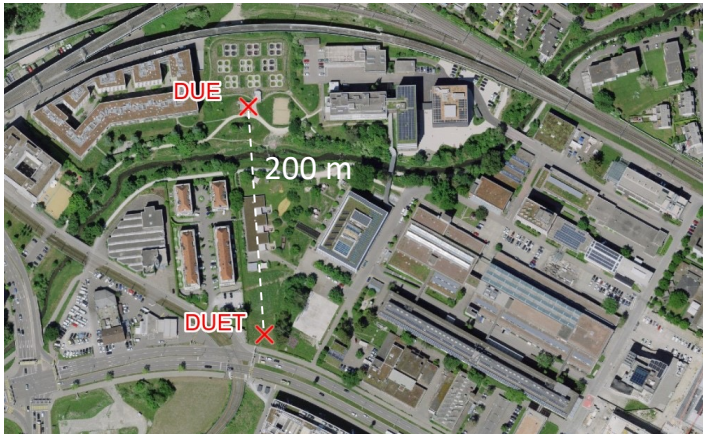
Research question

What is the role of the atmosphere in the transport and distribution of tire wear (and other types of microplastics) in the environment?

Disclaimer: No focus on air quality, we are interested in the mass flow of tire wear into the environment as a basis for risk assessment

One year measurement campaign



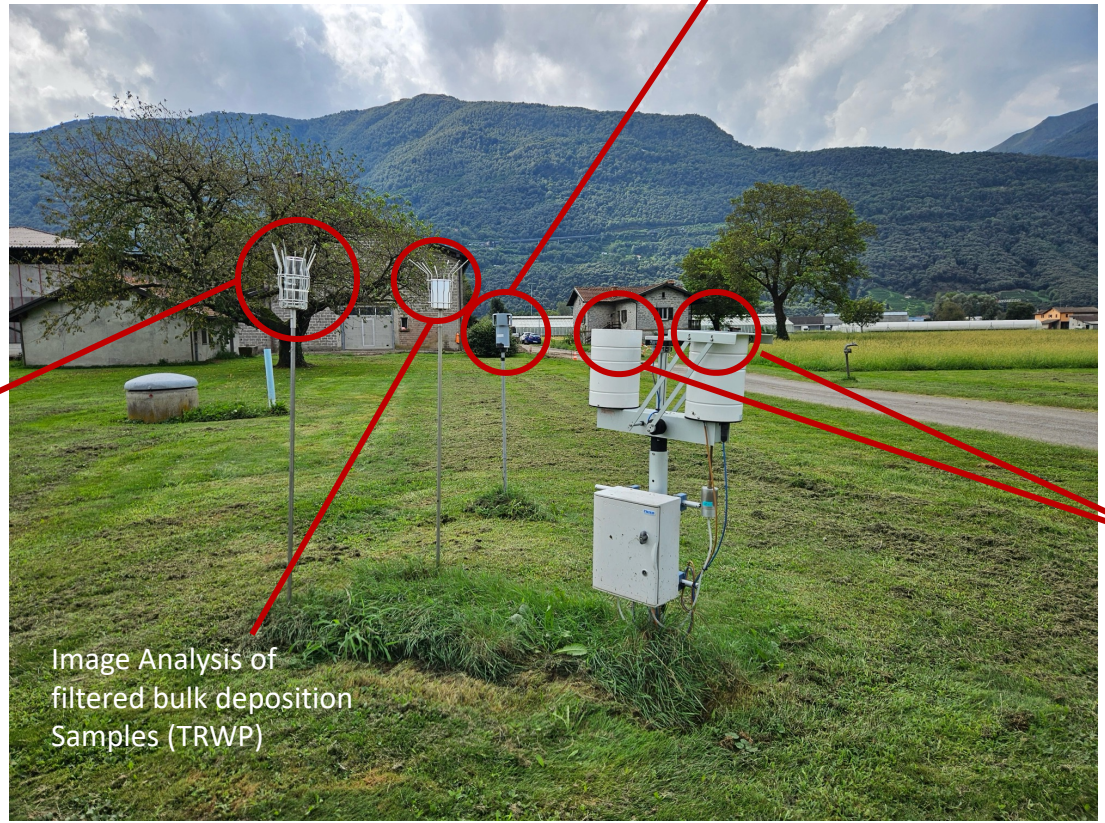


- Selected NABEL sites
- Urban, ZUE (Zürich-Kaserne)
- Suburban, DUE (Dübendorf-Empa)
- Rural, PAY & MAG (Payerne & Magadino-Cadenazzo)
- Remote, CHA (Chaumont)
- Traffic, DUET (Dübendorf-Überlandstrasse, 20’000 veh/day)

- Sampling frequency: every 4 weeks
- Sampling duration: 1 year (May 2024 – May 2025)

Sampling and analytics

Single Particle Analysis
(SEM/EDX, Particle Vision)
Dry deposition TRWP, 1-80µm,
Rausch et al., STOTEN 2022



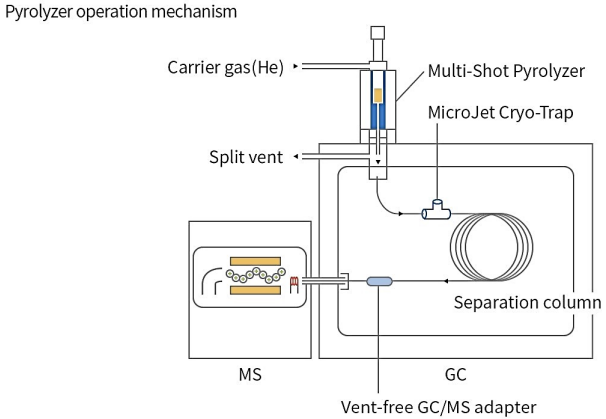
Analysis of rubber polymer fragments (Pyrolysis GC-MS).
Bulk deposition (TWP < 400µm)

Image Analysis of
filtered wet & dry
deposition (TRWP 15-200 µm).

Analysis of microplastics using
chemical imaging (FPA-µ-FTIR)

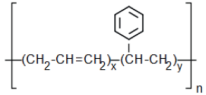
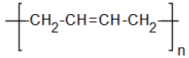
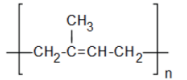
Magadino-Cadenazzo (MAG)

Analysis of tire wear particles using Pyrolysis GC-MS



- Thermal decomposition of rubber polymers at 670°C
- Gas chromatographic separation of decomposition products
- Quantification of pyrolysis fragments with MS

synthetic	SBR: styrene-butadiene rubber
synthetic	BR: butadiene rubber
natural	NR: natural rubber

Polymer Formula	Dimer
 SBR	VCH  vinylcyclohexene
 BR	VCH  vinylcyclohexene
 NR	limonene  dipentene

- ISO/TS 20593:2017 & ISO/TS 21396:2017
- Disadvantage: Assumption of known and constant SBR, BR and NR content in tires
- SBR, BR and NR content varies greatly between brands and models, which leads to large errors in the determination of tire wear (Rauert et al., EST 2023)

Collection of "reference" material

Collection of tire tread from used tires

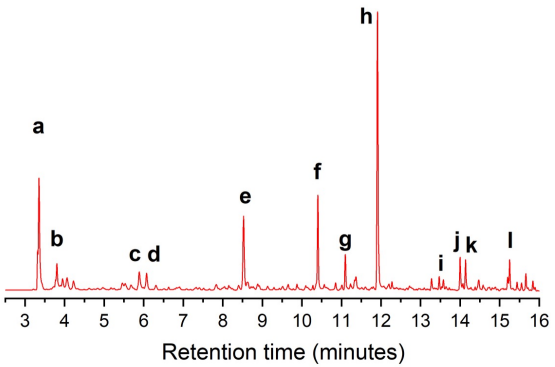
Cryo-milling

Milled tire wear particles (TWP)
(below 400 micron)

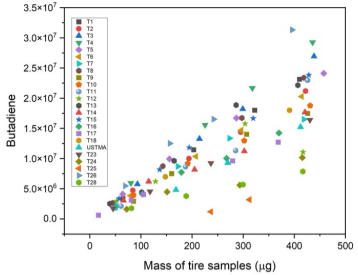
- Tire tread from 18 used passenger car tires and 5 used truck/bus tires collected
- In addition Cryo-milled Tire Tread (CMTT) as provided by the US Tire Manufacturers Association

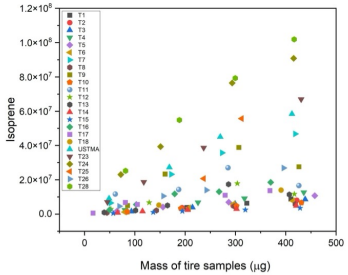
Analysis of tire wear particles using pyrolysis GC-MS

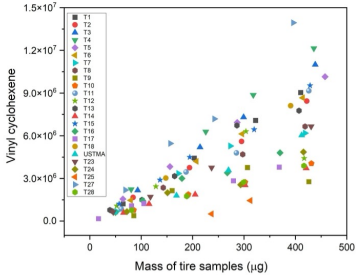
Typical pyrogram of a cryo-milled tire sample

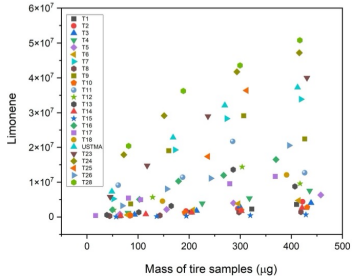


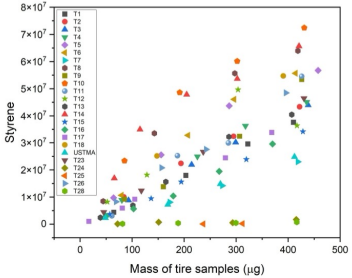
a. Butadiene
b. Pentadiene (Isoprene)
c. Cyclohexadiene/Hexatriene
d. Benzene
e. Toluene
f. 4-Vinylcyclohexene (VCH)
g. Ethyl benzene/Xylene
h. Styrene
i. Isolimonene
j. Aniline
k. a-Methylstyrene
l. Limonene (dipentene)

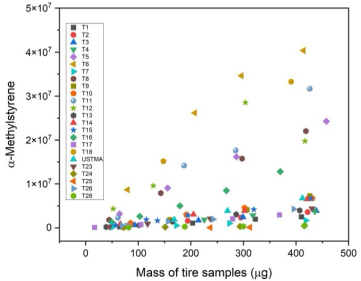


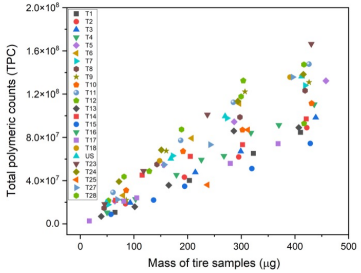




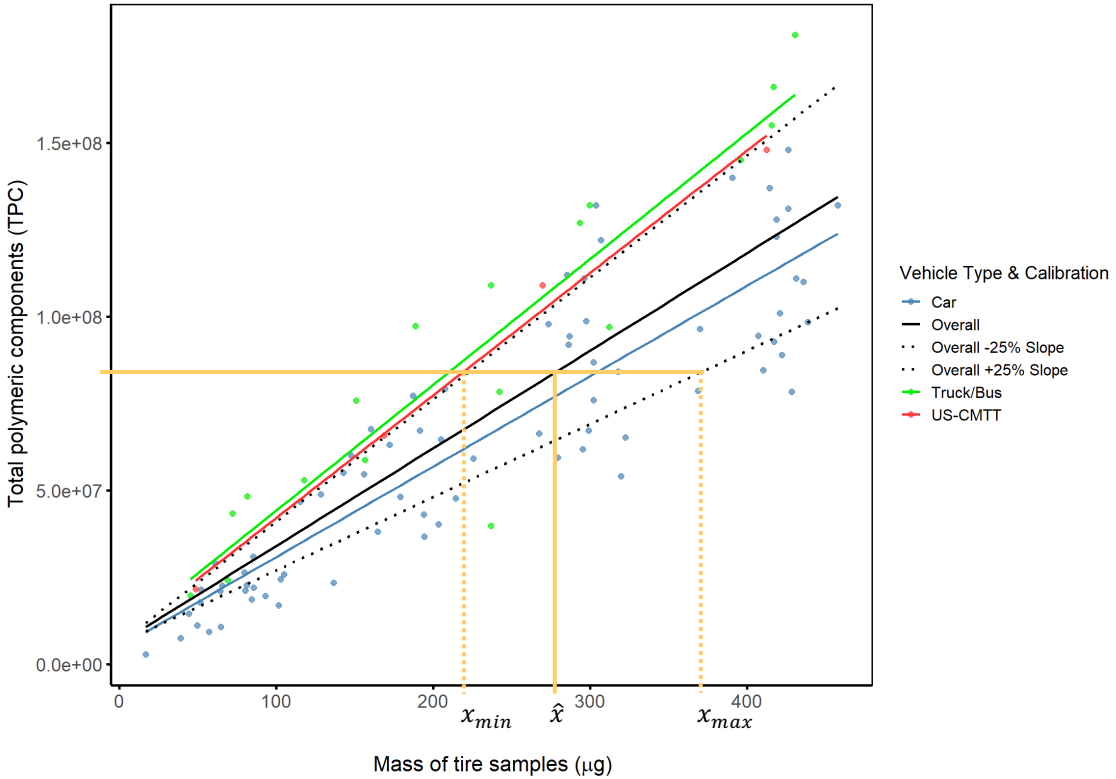




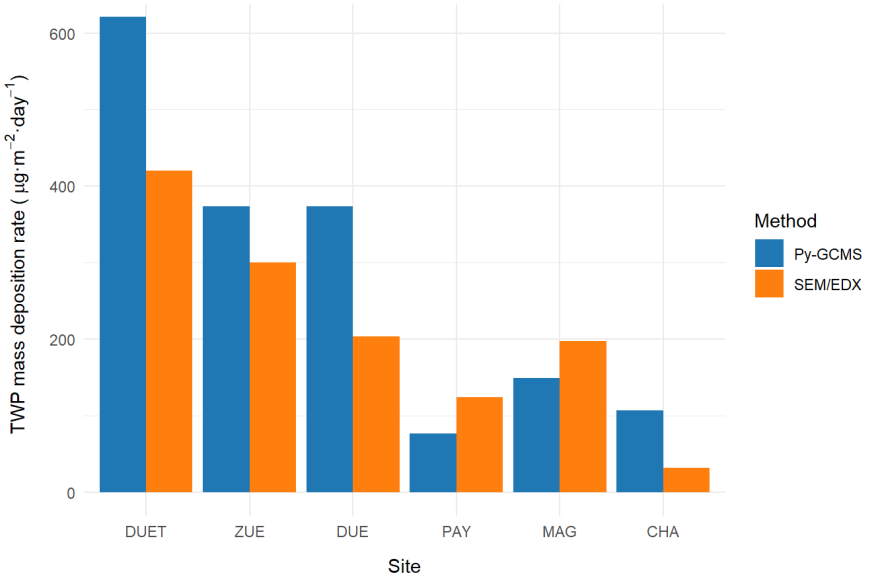




Pyrolysis GC-MS method calibration



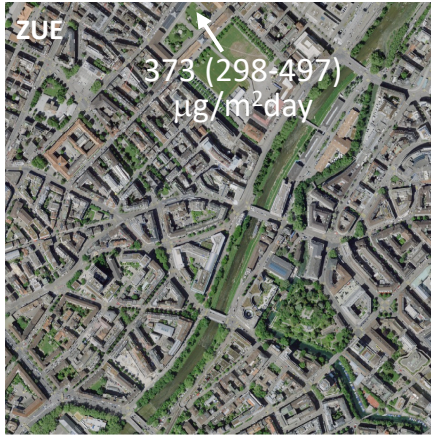
Mean calculated deposition rates (June – Oct. 2024)

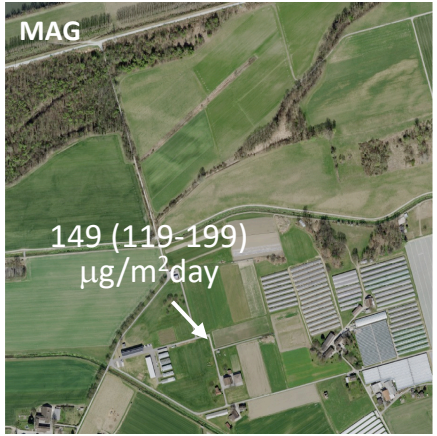


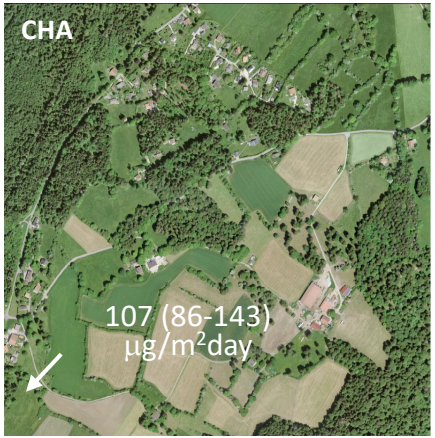
TWP deposition in µg/m² day

	Py-GCMS (total)	SEM/EDX (dry)	Image Analysis (YOLO) total	dry	wet
DUET	621 (497 - 828)	420			
ZUE	373 (298-497)	300	382	311	71
DUE	374 (299-499)	203	203	163	40
PAY	77 (62 - 103)	125	68	52	16
MAG	149 (119 - 199)	198	80	54	26
CHA	107 (86 - 143)	32	32	23	9

Mean atmospheric deposition of TWP (June-Oct 2024, Py-GCMS)







Luftaufnahmen: https://www.swisstopo.admin.ch/de/orthobilder-swissimage-10-cm

Estimation of total atmopheric TWP deposition across Switzerland

Total deposition as based on Py-GCMS and calculated from June-Oct 2024 samples

CH - Arealstatistik

https://www.bfs.admin.ch/bfs/de/home/statistiken/raum-umwelt/bodennutzung-bedeckung.html

Land use		**km^2**	**Representation**	**TWP (µg/m^{2}yr)**	**TWP (t/yr)**	**Range (t/yr)**
Settlement and road areas						
	Road areas	868	DUET	621	197	(157 – 246)
	Rest	2403	DUE, ZUE	373.5	328	(262 – 409)
Agricultural areas		14525	CHA, PAY, MAG	111	588	(471 – 736)
Wooded areas		13134	CHA, PAY, MAG	111	532	(426 - 665)
Unproductive areas		10361	CHA	107	405	(324 – 506)
Total		**41291**			**2050**	**(1640 – 2562)**

Work in progress

Summary

- A method for the quantification of TWP in atmospheric deposition samples based on Py-GCMS was developed
- Results are in good agreement with independent methods (SEM/EDX and image analysis)
- Mean bulk TWP deposition rate ≈ 100-600 µg/m^2 day (June-October 2024)
- For comparison: Mean total particle deposition rate = 52 mg/m^2 day (NABEL 2024)

  → Share of TWP in total particle deposition is ~ 0.2-1%

- Based on 5 months of data, **preliminary** estimation of annual atmospheric deposition of TWP in Switzerland is ≈2'000 tons/year (or ≈15% of annual production)

Thank you!

Acknowledgements:

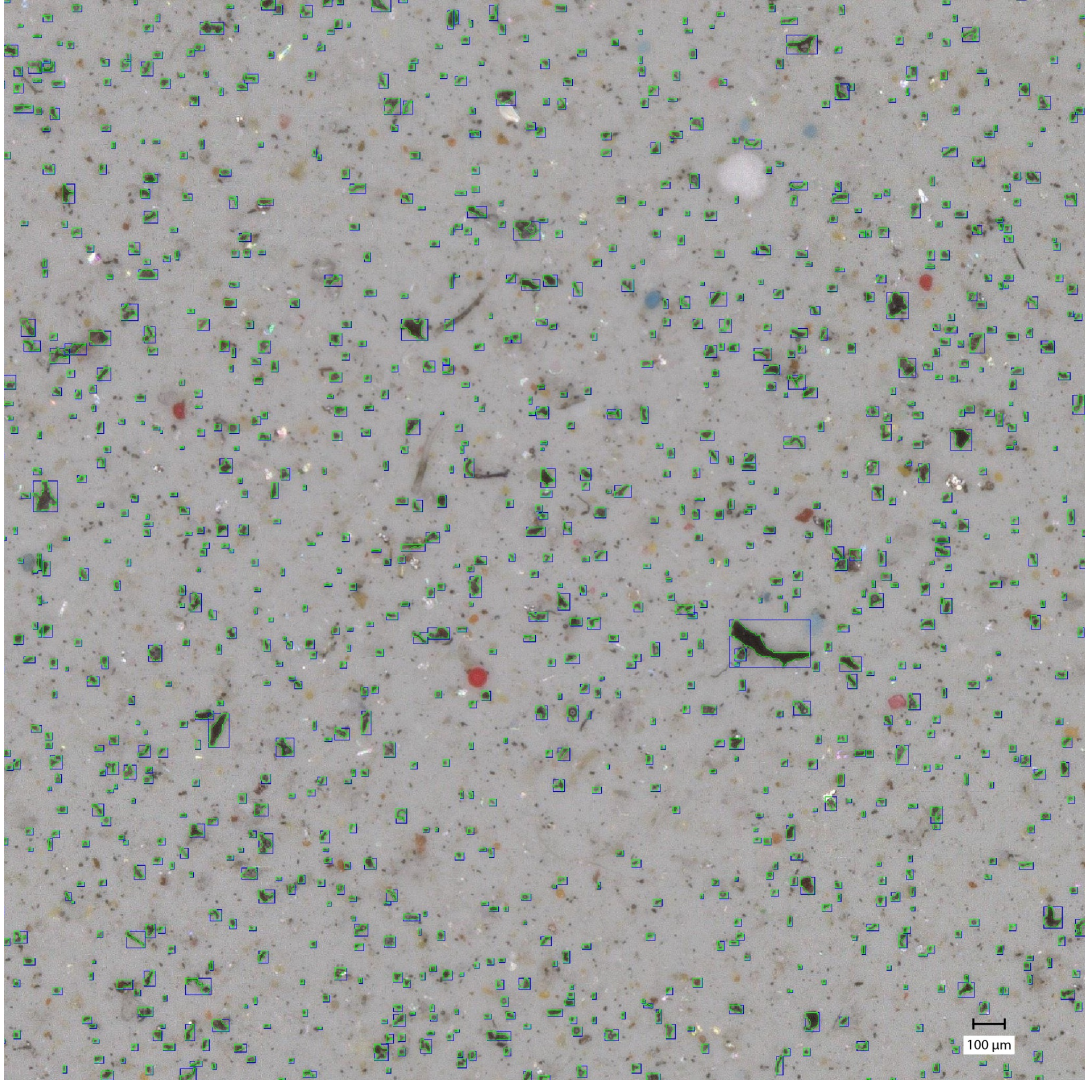
- NABEL-Team (BAFU/Empa)
- ASTRA (Projekt TRU_20_00E_01 ATMO)
- BAFU for funding MP project

Empa
Materials Science and Technology

Detection of suspect tire wear particles (TWP) in dry and wet deposition samples from partner project on microplastics

Two methods

- Image analysis using color threshold (HSV)
- Object detection in images (YOLO)



Duebendorf, Series 12 (August 2024),
dry deposition (detail of Anodisc filter)

Number and Mass size distributions of TWP (image analysis, wet deposition sample from Zurich)