

Review

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Review

Tire Wear Particles and Their Role in Microplastic Pollution

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Abstract

Every time we drive, tiny pieces of our car tires break off and spread into the environment. These small fragments, called tire wear particles, have become one of the biggest hidden sources of plastic pollution in the world. Together, they create about six million tonnes of microplastics every year—enough to fill dozens of large cargo ships. Most of these particles end up in soil, rivers, and oceans, while the smallest ones can float in the air and enter our lungs. Tire wear pollution is now growing even faster with the rise of electric vehicles, which are heavier and cause more tire friction. These particles contain toxic substances that can harm people, animals, and plants. Yet, there are still no clear laws to control them. Tackling tire wear pollution will be essential for cleaner air, safer water, and a healthier planet in the years ahead.

Keywords: tire wear particles; microplastics; tire-road wear particles; electric vehicles

Introduction

Tire wear particles (TWPs) are tiny bits that come off tires as vehicles move, and they've quietly become one of the biggest but least controlled sources of pollution today. Every year, they produce about 6 million tonnes of microplastics (MPs)—enough to fill 31 of the world's largest container ships (Giechaskiel et al. 2024; Kole et al. 2017). On average, each person is responsible for about 0.81 kilograms of these particles every year. But the amount varies: in the United States, people generate about 4.7 kilograms per year because of higher car use, while in India, it's only 0.23 kilograms per year due to fewer vehicles (Kole et al., 2017). These particles aren't just rubber—they're a mix of tire materials, road dust, brake residue, and other pollutants, forming what scientists call tire-road wear particles (TRWPs). They're released invisibly every time we drive, making them a hidden but major source of global MPs pollution.

Tire wear particles (TWPs) are created mainly in two ways when tires interact with the road: through mechanical abrasion and heat-driven chemical reactions. Under normal driving, the friction between the tire and the road scrapes off tiny bits of material, ranging from micron-sized dust to visible fragments. This effect becomes stronger when a car brakes, turns sharply, or accelerates quickly (Zhang et al. 2023). At the same time, the heat produced where the tire meets the road—sometimes reaching over 180°C—causes some of the tire's chemical ingredients, such as oils, plasticizers, and additives, to evaporate. These gases then cool and form ultrafine particles smaller than 100 nanometers (Zhang et al., 2023).

Interestingly, the shift toward electric vehicles (EVs) has made this issue more complicated. Because EVs are about 24% heavier than regular fuel-powered cars, the added weight increases friction, leading to around 20% more PM₁₀ (larger particles) and 30% more PM_{2.5} (finer particles) emissions (Timmers and Achten 2016). This creates a paradox—although EVs reduce exhaust pollution, they may unintentionally increase pollution from tire wear, highlighting the need to address TWPs as a growing environmental concern.

The estimated amount of tire particles released per kilometer of driving varies greatly—from 30 to 117 milligrams per kilometer for regular cars, and up to ten times higher for heavy trucks

(Giechaskiel et al., 2024). Even though tire wear particles (TWPs) are produced in massive amounts, they exist in a regulatory gray area. There are currently no global rules or limits specifically targeting TWP emissions (Giechaskiel et al., 2024). Their chemical makeup makes them even more concerning—they contain toxic metals like zinc (Zn), sulfur (S), and lead (Pb), as well as cancer-causing compounds such as polycyclic aromatic hydrocarbons (PAHs) and leachable additives like 6-PPD, which can harm both aquatic life and humans (Kreider et al., 2010; Giechaskiel et al., 2024). Since there are no standard ways to measure TWPs and data is often fragmented, these particles have become a “stealthy pollutant”—largely unnoticed but steadily building up in ecosystems around the world.

Measuring tire wear particles (TWPs) directly from vehicles on the road gives the most realistic picture of how much pollution they produce—but it’s also one of the hardest methods to get right. Scientists use portable sampling devices placed near a car’s wheels to collect particles while driving. This allows them to include real-world factors such as traffic, road texture, and weather (Giechaskiel et al., 2024). However, these samples often get mixed with road dust, brake particles, and other airborne matter, which makes it very difficult to separate TWPs from everything else (Pirjola et al., 2006). For instance, studies show that in urban areas, TWPs make up around 4–6% of all PM₁₀ particles in the air, but at roadside or kerbside locations, this can increase to about 10.5% because of their closeness to vehicles (Giechaskiel et al., 2024). To identify TWPs more accurately, researchers use chemical tracers—substances that tend to come from tires. Common examples are zinc (Zn) and benzothiazoles, but these aren’t perfect markers. Zinc can also come from brake pads or metal guardrails, and benzothiazoles are found in lubricants, so they don’t always confirm a tire source (Kreider et al., 2010). More advanced methods now use pyrolysis-GC/MS, a high-temperature analysis technique that detects unique chemical “fingerprints” from tire materials, such as vinyl cyclohexene for synthetic rubber and dipentene for natural rubber. These methods have achieved over 88% accuracy in matching known tire tread compositions (Unice et al., 2013). Yet, they still assume all tires are made the same way, even though the polymer content can vary from 40–60% between brands (Giechaskiel et al., 2024). Because of these challenges, on-road measurements often reflect average emissions across entire fleets, rather than showing differences caused by vehicle type, driving habits, or road conditions. This makes it harder to pinpoint exactly how and when tires release MPs pollution.

Estimates of tire wear pollution vary a lot from one study to another. For passenger cars, emissions are reported to be between 30 and 117 milligrams per kilometer, but scientists say these differences mostly come from inconsistent testing methods, not real changes in pollution levels (Giechaskiel et al., 2024). The numbers are even higher for heavy-duty vehicles (HDVs)—ranging from 107 to 1,500 milligrams per kilometer. Because trucks and buses travel longer distances and carry heavier loads, they can account for 50 to 80 percent of all tire wear emissions in some countries, such as India and South Korea (Kole et al., 2017).

Tire wear particles (TWPs) tend to settle mostly on land rather than in the air or water. Studies show that 50–70% of these particles end up in soils near roads, making them a major form of land-based pollution (Kole et al., 2017; Giechaskiel et al., 2024). This happens because the larger, heavier particles—those over 10 micrometers in size—quickly fall to the ground close to where they’re released. As a result, roadside soils can contain anywhere from 10 milligrams of tire material per gram of soil in rural areas to as much as 158 milligrams per gram in busy urban zones (Kole et al., 2017). Road design can make this problem worse. For instance, porous asphalt—which helps drain rainwater—can trap up to 95% of TWPs. However, when these surfaces are cleaned with high-pressure water, the trapped particles are often flushed into nearby ecosystems (Kole et al., 2017). Once tire particles settle into soil, they can change its natural properties. They reduce the soil’s ability to hold water, make it more water-repellent, and release harmful chemicals like zinc (Zn) and polycyclic aromatic hydrocarbons (PAHs). These substances can disrupt soil microbes and slow down plant growth (Tamis et al., 2021). Because tire materials are very resistant to breaking down, they can remain in soil for more than ten years, even after the original source of pollution is gone (Giechaskiel

et al., 2024). Over time, these soils act as a secondary pollution source—TWP can be blown back into the air or washed into rivers and streams during rainfall, spreading contamination across air, land, and water.

About 20–40% of tire wear particles (TWPs) eventually make their way into rivers, lakes, and oceans, mainly through road runoff and particles falling from the air (Kole et al., 2017; Giechaskiel et al., 2024). During rainstorms, runoff from roads can carry large amounts of tire debris, with concentrations reaching up to 50 milligrams per gram of runoff—sometimes as high as 150 mg/g (Kole et al., 2017). Urban drainage systems capture less than half of these particles, allowing the rest to flow directly into waterways (Giechaskiel et al., 2024; Bhowmik & Saha, 2025). Once in water, TWPs behave differently depending on their density. Lighter rubber fragments (1.2–1.8 g/cm³) stay suspended in the water, while heavier particles coated with minerals (over 2.0 g/cm³) sink to the bottom, accumulating in sediments (Zhang et al., 2023). Sediment studies show hotspots of TWP accumulation near river outlets, with concentrations as high as 730 mg per kilogram of wet sediment in European rivers (Giechaskiel et al., 2024). Globally, tire particles make up 5–10% of marine microplastics, and models suggest that 28–46% of all TWPs eventually reach the oceans through rivers or the atmosphere (Kole et al., 2017; Giechaskiel et al., 2024). This is especially concerning because TWPs can carry other pollutants, like heavy metals and pesticides, spreading toxins through the food chain and impacting aquatic life at multiple levels.

Airborne tire wear particles (TWPs) make up only 2–10% of all tire emissions, but they are the most mobile and the most relevant for human health (Kole et al., 2017; Giechaskiel et al., 2024). The smaller particles, called PM₁₀ (less than 10 micrometers), can stay in the air for days or even weeks and travel hundreds of kilometers on the wind. The tiniest particles, ultrafine particles (less than 100 nanometers), can reach deep into the lungs, making them particularly concerning (Zhang et al., 2023). In cities, TWPs make up about 3–7% of PM_{2.5}—fine particles that can enter the lungs—and at roadside locations, concentrations can be ten times higher than background levels because of nearby traffic (Giechaskiel et al., 2024; Huang et al. 2024). As they travel through the air, TWPs are chemically transformed: UV light changes their surface, making them more water-attracting, and they can mix with other pollutants like sulfates and nitrates, which affects how they move and settle (Zhang et al., 2023). Evidence of long-range transport is striking: TWPs have been found in Arctic snow and Alpine glaciers, showing that these particles can travel around the world (Kole et al., 2017).

Humans can be exposed to tire wear particles (TWPs) in three main ways: breathing them in, swallowing them, or through skin contact. Of these, inhalation is the most serious, because particles can reach deep into the lungs and deposit directly in the respiratory system (Giechaskiel et al., 2024; Huang et al. 2024; Saha and Saha, 2024). People who spend a lot of time near traffic—like commuters or roadside workers—are at the highest risk. Tiny particles carried on PM_{2.5} can deliver harmful chemicals, including carcinogens, as well as metals such as zinc and nickel, straight to the lungs' alveoli (Bhowmik et al. 2024; Giechaskiel et al., 2024; Saha and Saha, 2024).

Tire wear particles (TWPs) are no longer a minor environmental issue—they have become a major pollution challenge in today's era of increasing mobility. As vehicle exhaust emissions decrease, TWPs now make up the largest portion of traffic-related air particles, contributing 5–30% of PM₁₀ from road transport and 5–10% of microplastics in the world's oceans (Kole et al., 2017; Giechaskiel et al., 2024). Addressing tire wear pollution will require systemic policy changes. This could include linking TWP reduction goals to broader climate targets, like the EU Zero Pollution Action Plan, taxing tires that wear out quickly, and subsidizing environmentally friendly tire materials (Vedula, 2024). Without these measures, TWP emissions are expected to increase by 30% by 2030 as more vehicles hit the roads and electric vehicles become more common (Giechaskiel et al., 2024).

Conclusion

Tackling tire wear particles (TWPs) means tackling bigger environmental challenges: microplastic pollution, unequal exposure to air pollution, and the shift toward sustainable

transportation. Doing nothing, however, risks leaving future generations with a world where every journey pollutes, every breath contains tiny plastics, and every ecosystem shows the damage of our mobility choices. The science is clear, and the tools to act already exist—the only thing missing is collective will. As we face this crossroads in transportation, we have the chance to choose not just cleaner vehicles, but cleaner roads, cleaner air, and a healthier planet—a world where the tire tracks of progress leave no lasting mark.

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