WATER POLLUTION

Tyre wear particles and (water) pollution: A complex environmental issue

Against the background of the strong decline in rail transport and the simultaneous increase in light- and heavy-vehicle traffic on the South African road transport system, questions arise such as: What impact does tyre wear have on the environment? Do released tyre particles form part of microplastic pollution? Do tyre particles occur in water resources and soil samples? What health risks arise from this form of environmental pollution? Do climatic differences play a role in the intensity of tyre-wear pollution? What research methodologies are used to investigate the process, incidence and effects of tyre wear experimentally? How can the polluters responsible for this form of environmental pollution be held financially accountable? What role does the consumer, for example, driver's behaviour, play in the process? Handré Brand discusses some of these questions.



South African researchers Krüger, Snyman and Odendaal (2019) point out that a large proportion of anthropogenic metal emissions originates from vehicle traffic and enters all three environmental domains (air, water and soil), creating a pollution dilemma that is complex and problematic. In addition, chemicals such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals present in crumbed (recycled) rubber have been identified as harmful to human health and the environment by a South African group of chemists (Sibeko, Adeniji, Okoh and Hlangothi 2020).

Further, according to Kang et al. (2025), tyre wear particles represent a very large share of traffic-related microplastic emissions and may be a significant source of microplastics in aquatic systems. In Europe, approximately 1.3 million metric tonnes of particles are released annually, while more than 6 million metric tonnes are estimated to enter agricultural soils worldwide each year. Particles suspended in the air are inhaled and may be associated with physical health risks, such as respiratory and cardiovascular diseases.

Kundel et al. (2025) analysed soil samples collected along the Swiss road network. As expected, samples taken directly alongside road surfaces contained high concentrations of tyre wear particles, averaging approximately 111 000 particles per kilogram of dry soil, with up to 615 000 particles per kilogram measured at some locations. Concentrations declined significantly with increasing distance from the road surface. 10 metres from the road, concentrations were approximately ten times lower than at 1 metre. The particles were generally microscopic and elongated, with an average Feret diameter of approximately 63 micrometres (one thousandth of a millimetre).

Zhang et al. (2023) point out that, because of stricter exhaust-emission standards and the increasing use of electric vehicles, non-exhaust emissions (particularly tyre particles) are gradually beginning to exceed tailpipe emissions. Because electric vehicles are, in many cases, heavier than comparable internal-combustion vehicles, greater vehicle mass, together with factors such as torque and driving style, may contribute to increased tyre wear.

The authors also emphasise that, up to 2023, no standardised international regulatory framework existed to limit tyre-particle emissions, nor was there a universally applicable technology capable of eliminating tyre wear completely. This observation should, however, be viewed in context, because international and European regulatory initiatives concerning tyre wear are now being introduced. Regulation of TWP emissions remains at a developmental stage, with important gaps in testing, standardisation and coverage of different vehicle and tyre categories.

Measurement techniques and methods, for example, laboratory experiments versus real-road tests, are not uniform, which makes comparison of data between studies difficult. This highlights the need for standardised testing and measurement procedures in this important field of research (Zhang et al. 2023).

Tyre wear therefore appears to be an increasingly relevant global issue, but the question remains whether it receives sufficient attention in relation to the scale of the problem.

Direct costs

Because vehicle tyre wear, in addition to presenting a pollution dilemma, theoretically represents a direct cost factor, the principles of logistics management (Pienaar and Vogt 2025) are directly relevant. Logistics management may be defined as an aspect of supply-chain management concerned with planning, implementing and controlling the effective forward and reverse flow of goods between the point of origin and the consumer (Pienaar and Vogt 2025:29). A wide range of activities is associated with the flow of goods, including packaging, inventory management, customer service and the transport of goods.

In transport, tyre wear is a typical "running-cost item" (Pienaar 1985:100), because it is directly associated with vehicle movement. It can also be quantified objectively in physical units, for example, grams per kilometre. On an open tar road with relatively less traffic than in an urban environment, and taking factors such as driving style and tyre type into account, tyre wear increases as vehicle speed increases. Between 90 and 100 kilometres per hour, wear reaches a peak and then begins to decline after 100 kilometres per hour (Pienaar 1985:117).

Tread wear is caused in several ways (Pienaar 1986:205), including rolling-resistance friction, friction where the tyre meets the road surface, and the effects of braking forces when vehicle speed is reduced. Forces between the tyre and road surface arise from deformation and friction effects. These effects result directly from relative speed between the tyre structure and road surface, for example during braking or steering. Frictional forces and relative speed generate heat, causing temperature changes in both the tyre structure and tread (Schubert, Ketan, Schabauer, Lex and Hausberger 2026).

In a case study using a four-axle combination truck operated by Alpha Carriers as an illustration, total tyre-use cost in 2024 was given as 155 cents per kilometre for that vehicle (Pienaar and Vogt 2025).

Pollution resulting from tyre wear is regarded as an unpriced negative externality because particles released through tyre wear may cause substantial environmental and public-health damage, while the cost of damage is not included in the purchase price of tyres or in transport costs. Vehicle tyre wear therefore represents both a direct expenditure for companies in the form of tyre-use costs and an additional indirect, unpriced environmental cost.

Polluter pays principle

The polluter pays principle is the generally accepted practice according to which those who cause pollution should bear the costs of managing it (that is, prevention, control and rehabilitation) in order to prevent damage to human health or the environment (Ward and Hicks 2022). For example, a factory that produces a potentially toxic substance as a by-product of its operations is normally held responsible for the safe disposal of such by-products. The polluter pays principle forms part of a broader set of principles intended to promote sustainable development worldwide and is formally reflected in the 1992 Rio Declaration (Ward and Hicks 2022).

The National Environmental Management Act of 1998 (NEMA)

is South Africa's primary legislative framework for environmental management (Savannah Environmental 2026). It sets out fundamental principles for environmental management and establishes mandatory requirements for environmental impact assessments. NEMA applies across economic sectors and requires potential environmental consequences of listed or specified activities to be considered, investigated, assessed and reported to the competent authority in accordance with the Act and applicable regulations.

The extent to which NEMA and the polluter pays principle are applied consistently and successfully in practice and through South African case studies falls outside the scope of this article. Ridl and Couzens (2010:112) state in this regard: "It appears that we might be entering into a crucial phase in the development of South African environmental law – it is going to require extreme vigilance (even activism) from environmental lawyers if, out of the current maelstrom of case law, statute law, politics and policy, a proper balance amongst economic growth, social development and environmental protection is to emerge."

Tyre wear particles and soil quality

According to Kang et al. (2025), the structure and quality of agricultural soil decline significantly when tyre wear particles are present. Their global literature review reports reductions of up to 25% in soil porosity, 20–35% in the decomposition of organic material, and 40–60% in the presence of nitrogen-fixing bacteria in originally high-quality agricultural soils. Laboratory findings further indicate the presence of toxic substances and heavy metals such as zinc, copper and PAHs in soil samples. Risks include physical blockage of plant roots, zinc-induced oxidative stress, reduced photosynthesis and growth retardation. These processes also create risks of bioaccumulation in the food chain.

Kundel et al. (2025) similarly found that the carcinogenic substance benzo[a]pyrene, which also occurs in exhaust emissions, was present in Swiss soil samples, particularly those collected near highways. Sixty-three per cent of the samples



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analysed exceeded the Swiss soil threshold value for this substance. These chemical and tyre wear particles therefore appear to be two sides of the same pollution issue, without implying any causal relationship.

Bouredji, Lumière, Lakhmi, Muresan-Paslaru, Pourchez and Forest (2025) conclude that the toxicity of tyre wear particles in soil can be attributed to two main sources: the intrinsic toxic properties of tyre and road-surface particles, and exogenous contaminants that these particles accumulate from the local environment. It is therefore important to investigate the combined toxic effects of tyre wear particles and substances such as benzo[a]pyrene in soil samples.

Water systems: the central pollution pathway

Hapich, Van Emmerik, Waldschläger, Maurer, Yang and Gray (2026) investigated how tyre wear particles are transported during rainfall in urban areas. They used a rainfall-runoff simulator to determine the effects of factors such as surface roughness, rainfall intensity and terrain slope. Cryo-milled tyre-tread material supplied by the United States Tire Manufacturers Association was used in the experiment. The particles consisted of a composite mixture of tyre material from passenger cars (41%), light trucks (14%) and heavy-duty/commercial trucks (45%). These proportions were representative of tyre particles normally found in natural environments in the United States.

Low surface roughness, high rainfall intensity and low slopes resulted in the fastest particle wash-off, with rainfall intensity being the most important factor. Relatively large particles (>1 000 micrometres), once mobilised, moved faster than smaller particles (<125 micrometres). This contrasts with the movement patterns normally observed for mineral sediments. Flow depth was more important than flow velocity or shear stress. The particles were therefore transported more frequently as surface load than as bed load. This also differs fundamentally from sediment transport, possibly because of the hydrophobic properties of the particles and the possibility that air bubbles

adhere to them (Hapich et al. 2026).

The full implications of these findings remain an open question because existing urban stormwater systems are designed mainly to deal with sedimentation. The transport of tyre wear particles by water nevertheless differs fundamentally from sediment transport. Consequently, conventional preventative measures may not be sufficiently effective to intercept these particles before they reach natural watercourses.

The concentrations of vehicle tyre particles found in aquatic environments vary substantially according to the water source, sampling method and analytical method. Sun, Wang, Ouyang, Liu and Zhang (2025) report concentrations ranging from 0.03 to 179 milligrams per litre. The particles accumulate mainly in sediments because of their high particle density (Song, Lin, Oh, Grossart and Yang 2025), although water chemistry, turbulence, and particle shape and size also play a role.

The constituents of tyre particles can release toxic leachates, including heavy metals – especially zinc – and organic compounds such as 6-PPD. 6-PPD refers to chemical additives with useful industrial functions, such as protecting rubber against oxidative degradation, but they may pose unintended and serious risks to ecosystems when transformed into other chemical compounds and thereby enter aquatic environments. These releases can cause oxidative stress, DNA damage, altered immune responses and disturbed feeding behaviour in aquatic organisms. Effects vary according to species and exposure concentration (Song et al. 2025).

Taken together, the water-related evidence in the literature cited here points to an important pathway by which tyre wear particles can move from roads into stormwater, rivers and other aquatic environments. The problem is not limited to the physical presence of particles in water: the particles can also act as carriers or sources of chemical substances that are released into the aquatic environment.

Possible solutions

Kang et al. (2025) propose a three-level remediation approach: greater emphasis on source reduction by developing advanced technical tyre compositions designed to reduce wear substantially; environmental interception through effective bio-designed filtration systems and membranes; and chemical management of contaminants through the development of new bio-remediation techniques.

Kumar, Biswas, Mulla, Singh, Shukla, Ahanger, Shekhawat, Verma, Siddiqui and Seth (2024) focus on the management of micro- and nanoplastic pollution, which also includes vehicle tyre wear particles. For identification and monitoring, they recommend advanced analytical techniques such as spectroscopy, microscopy and spectrofluorometry.

No single, simple solution exists for pollution caused by vehicle tyre particles (Sivalingam, Gayathri, Boopathy, Choi and Sangeetha-Selvan 2026). In addition to Kang et al. (2025), this Indian and Korean research group proposes a multi-level approach: preventing pollution at the tyre itself as the primary source of the problem; early capture and removal of harmful chemicals before they reach water resources such as rivers and oceans; chemical degradation or neutralisation of pollutants; and ultimately the replacement or elimination of harmful chemicals, such as 6-PPD, associated with tyre wear.

Conclusion

This literature review emphasises that tyre wear should not be regarded merely as an unavoidable by-product of road transport, but as a significant and complex form of environmental pollution deserving increasing scientific attention.

Although effective road-transport systems are essential to any modern economy, the environmental costs associated with tyre wear can no longer be placed entirely outside the transport system. Tyre pollution is a systemic problem in which vehicle mass, tyre design, driving style, road surface, rainfall, stormwater management and regulation are closely interconnected. The central challenge for the future is therefore to develop reliable, standardised measurement methods; quantify the actual ecological and health risks; and allocate responsibility and costs among the relevant stakeholders in a fair and scientifically defensible manner.

Based on the literature considered, tyre wear is clearly an increasing environmental issue. Greater uncertainty remains about whether science, industry and policymakers are responding rapidly enough to the impacts and consequences of this difficult challenge. It also illustrates the principle that, when technical-industrial problems are solved innovatively, related problems of a different nature may often be created.

- This is a translated and edited version of the original LitNet article in Afrikaans, published on 29 September 2026.

Notes

The sources referred to in this article were used selectively, which may be regarded as a limitation. By-products of vehicle tyre wear also contribute to atmospheric pollution, and this factor, together with possible health implications, has received relatively little attention. The main purpose of the article is to raise awareness of the environmental implications of the release of tyre wear and tyre particles, rather than to constitute a comprehensive academic article or make a scientific contribution.

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For the purposes of this article, AI was used mainly for translation, basic linguistic editing and paraphrasing. Google Scholar and the Stellenbosch University Library databases were used to identify relevant publications for consideration and selection.