Modelling of the distribution and fate of tyre and road wear particles by the combination of a novel GIS and probabilistic model approach

Ilka Gehrke [1], Jan Blömer[1], Boris Dresen[1]

[1]Fraunhofer-Institute for Environmental, Safety and Energy Technology UMSICHT, Osterfelder Straße 3, 46047 Oberhausen, Deutschland
E-mail contact: ilka.gehrke@umsicht.fraunhofer.de

1. Introduction

Not only since the debates on plastic emissions and microplastics, tire abrasion has become an environmental topic that is increasingly coming into the focus of society and science. It is estimated that in the European Union 1,327,000 t/a tyre wear particles (TWP) and in Germany 133,000 t/a are released into the environment through road traffic [1,2].

Whereas several emission factors and predicting models for the fate of airborne TWP are published [3- 6], the fate of TWP via surface runoffs is hardly investigated. Unice et al. [7] investigated the fate of TWP in the Seine river estuary by the means of hydrological transport models. They forecast that approximately 2 % of the TWP released in the Seine river estuary reach the Mediterranean Sea. A recent Suisse study [8] states that in total 219±22 kt of rubber particles have accumulated in the environment since 1988 in Switzerland.

In contrast to these studies the describend research work focuses more on geographical data strongly connected to traffic data, land use and type of roads in order to create detailed TWP maps as basis for the subsequent calculation of the TWP fate.

2. Materials and methods

The authors developed and combined a probabilistic and GIS (Geo Information System) model in order to calculate the TWP distribution for the whole of Germany. Basing on this, the atmospheric transport of TWP will be modeled for Germany whereas due to the large complexity of the water and wastewater networks the propagation in water will be demonstrated only for two river basins: Wupper and Panke.

The GIS modelling was done by the use of ArcGIS (ESRI) and bases on the digital landscape model (DLM) of the Federal Office of Cartography and Geodesy supplemented by the road data set of OpenStreetMap. All geoprocessing steps were modeled by the means of scripts. The starting point for the GIS modelling is the determination of the average daily traffic volume (ADTV) on different road categories. Further relevant road properties, which affect the abrasion behavior, were estimated: brake zones at intersections, curve radius, slope inclination and the probability of wetness or dryness of the road.

As a basis for determining the traffic volumes, the geodata set of the state road construction companies was used. However, this road data set only contains traffic volumes for federal motorways and a small proportion of state and county roads. For this reasons, several additional sources related to traffic volumes such as public transport data was identified and added section by section to the basic DLM data set for each road.

3. Results and discussion

The tear and wear of tires depends strongly on the driving situation, i.e. the driving force. It is assumed that the TWP generation is approximately proportional to the square of the driving force whereby the radial force accounts to seven times more abrasion than the longitudinal force [9].

$$m_{TWP} = const.\,(F_l^2 + 7F_r^2)$$

The probabilistic model aims to estimate the average driving forces for each street segment, which is required for the implementation into the GIS model. The street related parameters like maximum allowed speed, curvature, slope, acceleration / braking are integrated in the model, while individual parameters of the car (air pressure, axis alignment) or driving style are not considered. Empirical models are implemented to describe the parameter relations.

Due to limited availability of traffic data only cars and trucks were categorized. As a result, each street segment can be assigned a *relative wear intensity*, which were adjusted by introducing a constant factor in order to match the already known total amount of TWP and, afterwards, submitted to the GIS system for the calculation of the local distribution of TWP particles.

The determination of the traffic strengths by existing data sets, supplementary sources and by the estimation in residential, commercial and mixed areas resulted in a cross-city traffic strength map (figure 1, left) representing the initial situation for the dispersion modelling (figure 1, right). As expected, the highest traffic volumes are recorded on the motorways accounting up to 85,000 vehicles per day which corresponds to maximum of 8 kg/m/a TWP. The subordinate road categories tend to be less important. The next step is to determine the emission quantities of tyre abrasion and the emission factors for each vehicle category, which together define the source strength of the emissions.

Due to the lack of a uniform database, the determination of traffic volumes in particular was associated with high processing and time expenditure. Also, the lack of spatial agreement of many geodata sets does not allow a fast and automated exchange of factual data between several data sets. Thus, a uniform geodata set should be considered in the future, which would unify all potential data sources on traffic volumes on all road categories in a single geodata set. This would significantly facilitate immission forecasts of tyre abrasion and road traffic emissions in general and help to derive more accurate forecasts of air pollution.

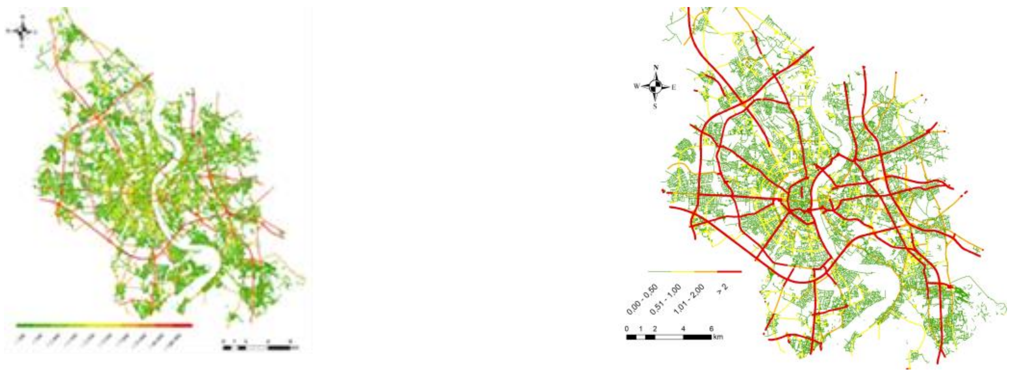

Figure 2: left: ADTV in Cologne [cars and trucks per street section and day], right: TWP in Cologne [g/m/a]

4. Conclusions

In the midterm view, these TWP dispersion models could be implemented in planning and decision tools allowing public authorities to identify hot spots and to take into consideration TWP while developing traffic plans. To evaluate the distribution model a comprehensive mapping should be carried out by the use of novel screening measuring methods such as SEM/EDX to analyze TWP in soil samples. Since the probabilistic model is based on several assumptions, finally a sensitivity analysis will be performed.

5. References

[1] Wagner S; Hüffer T; Klöckner P et al. 2018. Tire wear particles in the aquatic environment - A review on generation, analysis, occurrence, fate and effects. Water research 139:83–100

[2] Bertling J; Hamann L; Bertling R. 2018. Kunststoffe in der Umwelt. DOI: 10.24406/UMSICHT-N-497117.

[3] Padoan E, Ajmone-Marsan F, Querol X et al. (2018): An empirical model to predict road dust emissions based on pavement and traffic characteristics. In: Environmental pollut. (Barking, Essex 1987) 237, 713–72

[4] Non-Exhaust Emissions (2018): Elsevier.

[5] Broeke H, Hulskotte J, van der Gon HD (2008): Emission estimates for diffuse sources Emission estimates for diffuse sources. Netherlands Emission Inventory. Road traffic tyre wear

[6] Panko J, Kreider M, Unice K. (2018): Review of Tire Wear Emissions. In: Non-Exhaust Emissions: Elsevier, S. 147–160.

[7] Unice K, Weeber MB, Abramson MM (2019): Characterizing export of land-based microplastics to the estuary - Part I:Application of integrated geospatial microplastic transport models to assess tire and road wear particles in the Seine watershed. In: Science of the Total Environment 646, 1639–1649

[8] Sieber R, Kawecki D, Nowack B (2019): Dynamic probabilistic material flow analysis of rubber release from tires into the environment. In: Journal of Environmental Pollution (Pre-proof)

[9] Pohrt, R.: (2019)Tire Wear Particle Hot spots – Review of influencing Factors; Facta Universitatis Mechanical Eng. 17(1), 17-27

Acknowledgement - The authors thank the Federal Ministry of Traffic and Digital Infrastructure (BMVI) that funded the research work presented within the mFUND initiative (Project title: TyreWearMapping).