Modelling Of The Distribution Of Tyre Wear Particles in Germany

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Summary

Tire abrasion (Tire Wear Particles, TWP) has been identified as a major source of microplastic emissions. In order to understand the pathway of TWP in the environmental compartments the authors aimed to develop a model for the spatial distribution of TWP along the roads, which can be implemented in planning and decision tools allowing public authorities to identify hotspots. Thus, they combined a probabilistic and GIS (Geo Information System) model in order to calculate and map the TWP distribution for Germany. Basing on a specifically developed GIS data set for all federal states the distribution of the entire mass over all roads were modelled by the means of statistical data (traffic distribution, stress intensity, weather, etc.). Within the present paper the results are discussed as example of Berlin.

1 Introduction

1.1 Background

Forecasts expect up to 3.2 billion produced automotive tyres in 2022 corresponding to an increase of 4.9 % sales of tyres per year1. Not only since the debates on plastic emissions and microplastics, tyre 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, thereof 133,000 t/a in Germany and in the United States 1,120,000 t/a and of tyre wear particles (TWP) are released into the environment through road traffic [1]. TWP is classified as microplastics (primary microplastics) since it is man-made generated by car driving. In Germany it accounts to 57 % of the entire microplastics [2].

With respect to removal strategies for TWP the diffuse distribution of TWP is quite challenging and makes it necessary to adjust the overall traffic planning and to identify hotspots. This is because under an economic perspective, elaborate measures should be restricted to hotspots in order to safe costs while maximizing the benefit for the environment. However, it is unclear how exactly TWP spread and distribute where it accumulates and how it affects the environment so far.

Whereas within several studies emission factors and predicting models for the fate of airborne TWP are published, e.g. [3-5], the propagation of TWP via surface runoffs directly into water bodies or after passing waste water treatment plants is hardly investigated. Although it is expected that a high amount of TWP (around 66 % [2]) enter the environment via rainwater runoffs very poor reliable knowledge about the transport mechanisms exists. Measurements show that the total suspended solid concentration of highway runoffs is efficiently reduced by 85 % in sedimentation ponds [6, 7]. However, without knowing hotspots it is nearly impossible to develop appropriate management and technological strategies to remove or to avoid TWP.

Unice et al. [8] calculated the fate of TWP in the Seine watershed by the means of hydrological transport models. Their model estimates indicate that approximately 2 % of the TWP released in the Seine are exported to the estuary. However, due to a lack of basic and geographical data related to rainwater drainage systems, the geographical distribution of TWP is not shown. A recent Suisse study [9] states that in total 219±22 kt of rubber particles have accumulated in the environment since 1988 in Switzerland.

The research work presented focused more on geographical data and modeling strongly connected to traffic data, land use, type of roads, etc. in order to calculate the TWP distribution along roads.

1 https://www.freedoniagroup.com/industry-study/global-tires-3687.htm (as consulted online on 17 July 2020)

1.2 General information about tyre and road wear particles

Tyres are complex consumer goods, mainly consisting of synthetic and natural rubber, which have to fulfill high technical demands. Due to friction between tyres and roadway surfaces tyres underlie relatively high material losses during their service life in the form of particles in the range of micrometers to millimeters. These particles immediately form conglomerates with road wear particles (RWP) released from the pavement and road dusts transforming into tyre and road wear particles (TRWP). According to a study from Wagner [1], each TWP and RWP (road wear particle) comprise half of the TRWP mass resulting in a medium density of 1.8 g/cm. TRWP mainly consist of natural and synthetic rubber (20 to 30 %) and asphalt. Less than 10 % of TRWP account to suspended particulate matter smaller than 10 µm. According to [10], the TRWP agglomerate is shaped like an elongated "sausage" with an irregular structure of smaller and larger particles.

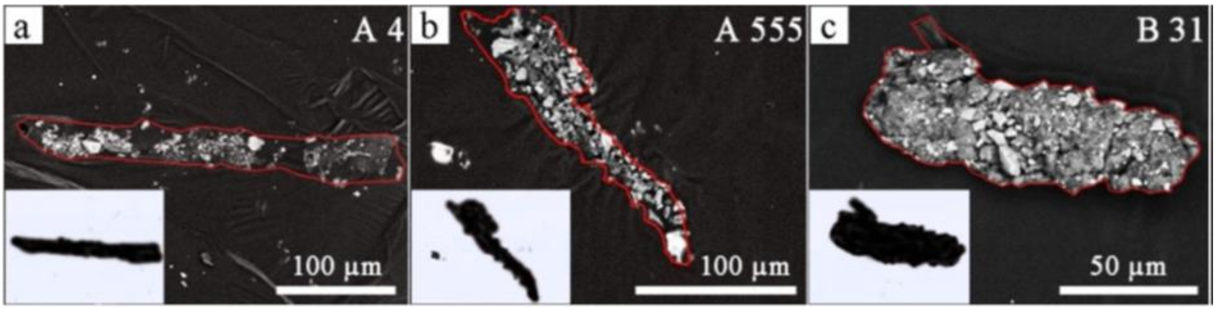


Fig. 1 Scanning Electron Microscopy pictures of typical super-coarse TRWP particles from motorways [10]

2 Materials and Methods

The authors developed a dispersion model of TWP for Germany by the combination of a probabilistic model with a GIS (Geo Information System) model.

The GIS modelling was done by the use of ArcGIS (ESRI) basing on the digital landscape model (DLM) which was provided by the German Federal Office of Cartography and Geodesy and was 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 was the determination of the average daily traffic volume (ADTV) on different road categories. As a basis for determining the traffic volumes, the geodata set of the state road construction companies was used, which contains traffic data from the last traffic census. The spatial correspondence with the basic DLM data set allowed to automatically transfer the factual data on the traffic volumes. However, this road data set only included traffic volumes for federal motorways and a small proportion of state and county roads. For this reason, it was necessary to find additional sources about the traffic volumes such as public transport data and to add them section by section to the basic DLM data set for each road.

TWP depends strongly on the driving situation, i.e. the driving force. It was assumed that the TWP generation was approximately proportional to the square of the driving force whereby the radial force accounted to seven times more abrasion than the longitudinal force [11].

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

The probabilistic model was realized as “plug-in” of the GIS. It aimed to calculate a relative wear intensity for each street segment depending on the estimated driving forces for cars and trucks, respectively. The forces depended inter alia on velocity, slope and curvature. 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. The results were combined with the information on the traffic intensity and the calculated TWP in each case were assigned to each street segment. A main issue was the compilation of the data sets, because the data were available in different formats and levels of detail due to the federal responsibilities.

3 Results and discussions

For each of the 16 federal states TWP dispersion models were created. As example, the model for the federal state of Berlin which is characterized as densely populated area with a high traffic volume will be presented in the following.

The determination of the traffic strengths by existing data sets, supplementary sources and the estimation for residential, commercial and mixed areas resulted in a cross-city traffic strength map (Fig. 2) representing the initial situation for the dispersion modelling. Fig. 2 shows a section of the center of Berlin with a maximum average daily traffic volume (ADTV) of 89,544 motor vehicles per day at the four-lane main road crossing the river Spree.

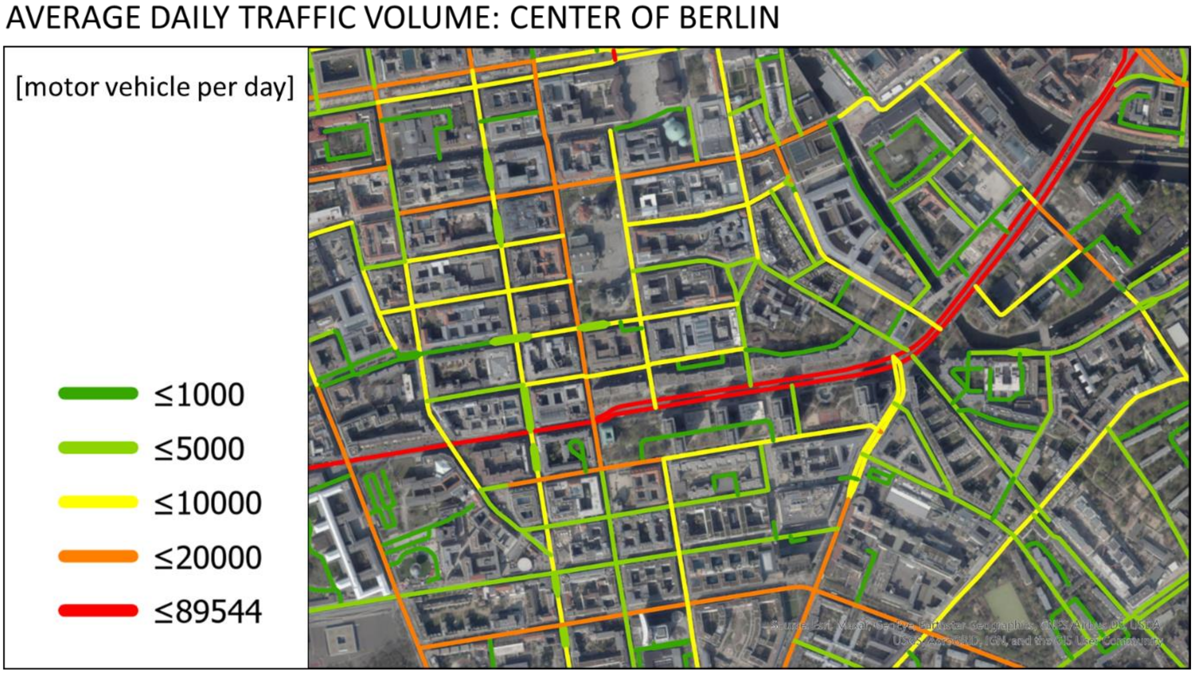


Fig. 2 Average daily traffic volume of the center of Berlin (due to technical reasons the picture is printed as black and white view reducing the informative value)

Within the next step, the probabilistic model calculated typical, probable, distance based tyre wear emissions for all road segments depending on statistical data such as daily traffic, stress intensity, weather, etc. The results were presented as relative wear intensities which were calibrated by a constant factor so that the model output a given average TWP emission per vehicle in Germany of 110 mg/km for cars and 900 mg/km for trucks (including light trucks), respectively. These values corresponded well to commonly reported results for the average TWP [12-15] and accounted to 117,953 to/a TWP for Germany. Taking into account that minor vehicle classes like motorbikes and busses were excluded in the dispersion model this result is in good accordance to Wagner [1] who calculated 133,000 to/a TWP for Germany.

Fig. 3 shows the distribution of the TWP per vehicle kilometer. The distributions were weighted by length of the street segment and the daily traffic amount. Most of the streets showed a very low emission intensity, while a very long tail with high emissions existed. The average emission intensity for cars in Berlin was much lower than for Germany (74 mg/km to 110 mg/km) whereas the emission intensity for trucks is higher (1284 mg/km to 900 mg/km). Similar deviations were observed for all German states. due to characteristic driving situations for each area. Further research steps will focus on the analyzing of the correlations in order to explain this effect.

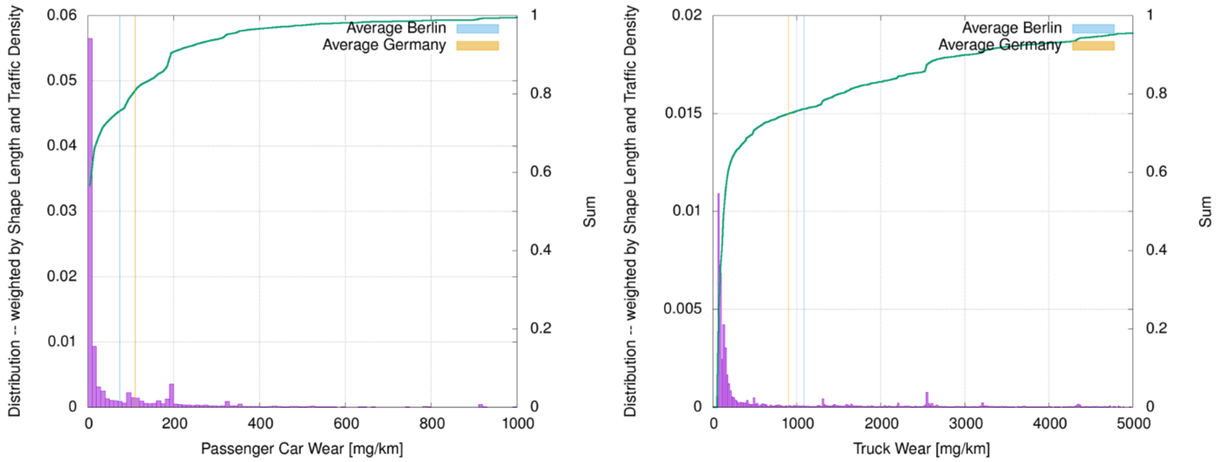
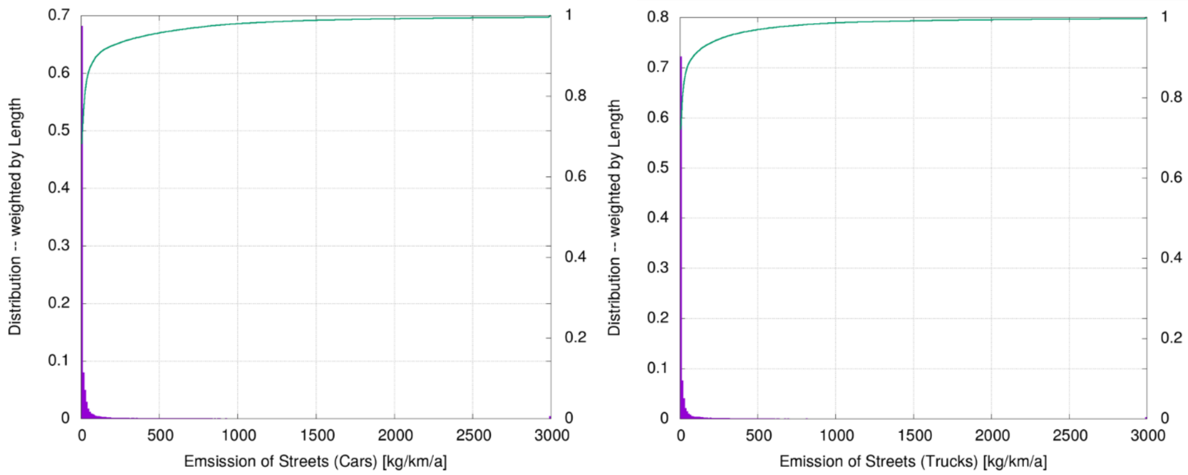


Fig. 3 Distribution of the TWP per vehicle kilometer. The distribution is weighted by shape length and traffic intensity

Fig. 4 shows the distribution of the TWP emission on the street for cars and trucks weighted by the length. For the identification of local hotspots the complete range of the calculated TWP emissions has to be accounted and the peak values have to be clearly marked in TWP maps, which are currently being developed (Fig. 4 above). In order to assess the regional situation of TWP emissions the detailed view (Fig. 4 below) is more appropriate since it shows the characteristic type of TWP distribution covering more than 90 % of the street emission.



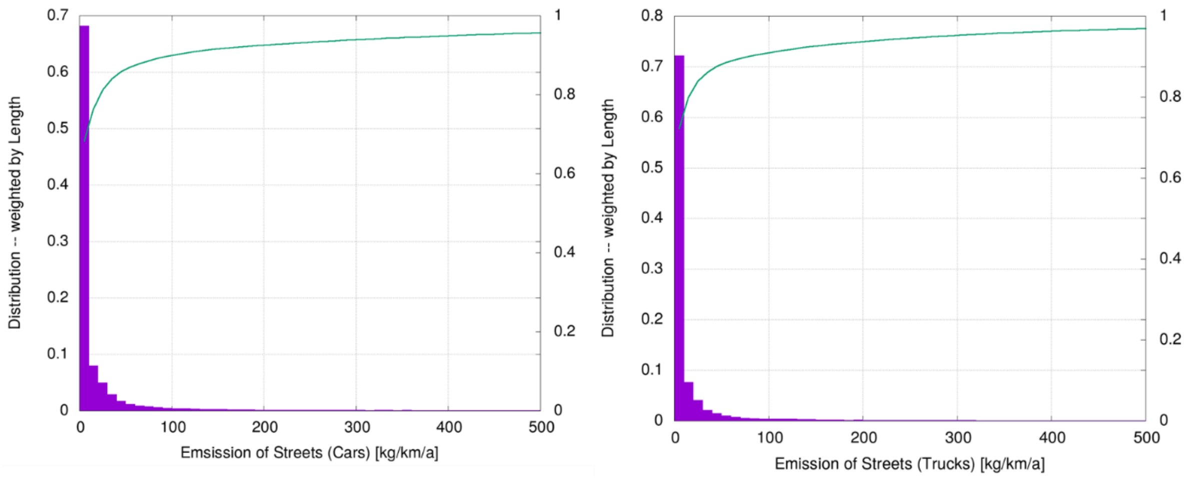


Fig. 4 Distribution of the street emissions. The distribution is weighted by length. (above: 0-3000 kg/km/a; below: 0-500 kg/km/a)

Adding up the emission of all road segments the whole amount of TWP for trucks and cars gave a total amount of 1,459 to/a TWP (Tab. 1) which corresponded to 1.24 % of Germany's TWP though the percentage of the area of Berlin is 0.25 %. This can be explained by the relative high vehicle mileage of Berlin which is even higher than in the federal state Saarland (car: 17,888,855 km/d, truck: 1,311,925) which is three times larger than Berlin.

Tab. 1 Vehicle mileage and TWP generation in Berlin for cars and trucks

Car mileage [km/d]	30,519,389
Car tyre wear in total [to/a]	826
Car tyre wear per car [mg/km]	74
Truck mileage [km/d]	1,596,479
Truck tyre wear in total [to/a]	633
Truck tyre wear per truck [mg/km]	1,086

4 Conclusions

Due to the lack of a uniform database, the determination of traffic volumes was associated with high processing and time expenditure. Furthermore, the absence of spatial agreement of many geodata sets did 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.

The probabilistic model was based on many assumptions. For example, the (micro-) texture of the road which is very important for the wear behavior was not included in the model due to limited availability of road conditions. Thus, a sensitivity analysis will be performed to investigate the influence of and sensitivity to these assumptions.

In order to evaluate the distribution model further research work has to focus on comprehensive mapping by the use of novel screening measuring methods such as SEM/EDX to analyze TWP in soil samples.

In the midterm view, these TWP dispersion models can be implemented in planning and decision tools allowing public authorities to identify hotspots and to adjust their traffic strategies. If the authors will proceed to develop dynamic dispersion models, even the impact of future traffic scenarios on the TWP propagation such as e-mobility could be predicted.

5 References

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