HEAVY METAL EMISSIONS FOR DANISH ROAD TRANSPORT

NERI Technical Report no. 780 2010

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
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Keywords: Heavy metals, road transport, fuel consumption, engine oil, tyre wear, brake wear, road abrasion

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Preface

This report presents new heavy metal emission factors for cars, vans, trucks, buses, mopeds and motorcycles for each of the emission sources fuel consumption, engine oil, tyre wear, brake wear and road abrasion. The emission components covered are Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), Selenium (Se) and Zinc (Zn), all of them relevant for emission reporting to the UNECE CLRTAP (United Nations Economic Commission for Europe Convention on Long Range Transboundary Pollutants) convention. The report also presents a new Danish inventory for the year 2007.

On behalf of the Ministry of the Environment and the Ministry of Climate and Energy, Denmark's National Environmental Research Institute, Aarhus University (NERI) is responsible for the calculation and reporting of the Danish national emission inventory to EU and the UNFCCC (United Nations Framework Convention on Climate Change) and UNECE CLRTAP (Convention on Long Range Transboundary Air Pollution) conventions. This documentation report for heavy metal emissions for road transport has been externally reviewed as a key part of the general national inventory QA/QC plan.

Summary

Introduction

This report presents new heavy metal emission factors for cars, vans, trucks, buses, mopeds and motorcycles, for each of the emission sources fuel consumption, engine oil, tyre wear, brake wear and road abrasion. The emission components covered are Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), Selenium (Se) and Zinc (Zn), all of them relevant for emission reporting to the UNECE CLRTAP (United Nations Economic Commission for Europe Convention on Long Range Transboundary Pollutants) convention. The report also presents a new Danish inventory for the year 2007.

Method

The heavy metal contents in fuel and engine oil used in the present study are based on measurement data from the European research organisation CONCAWE for fuel and information from key experts for engine oil. The fuel consumption pr km comes from the existing Danish emission inventory, and functions for engine oil consumption are established based on key expert information. The product of fuel/engine oil consumption pr km and the associated heavy metal content values make up the heavy metal emission factors. For each vehicle category total emissions are calculated as the product of emission factors and total mileage.

For tyre wear the present survey mainly uses information of wear rates pr vehicle type provided by the Danish Tyre Trade Environmental Foundation. This information has been combined with literature values for airborne fractions of worn particulate matter and heavy metal content in tyre material in order to estimate kilometre related emission factors for heavy metals. For each vehicle category total emissions are calculated as the product of emission factors and total mileage.

For brake wear and road abrasion pr vehicle type the kilometre based emission factors for airborne particulate matter come from the existing Danish non exhaust emission inventory. The product of these emission factors and literature values for heavy metal content in brake lining/road asphalt material make up the kilometre related emission factors for heavy metals. For each vehicle category total emissions are calculated as the product of emission factors and total mileage.

Results

For the list of heavy metal components, the following emissions in total TSP (in brackets) are calculated for the year 2007: As (8 kg), Cd (48 kg), Cr (197 kg), Cu (51 779 kg), Hg (28 kg), Ni (158 kg), Pb (6 989 kg), Se (33 kg) and Zn (28 556 kg).

The specific vehicle category activity/emission source category combinations and the related emission factors determine the total emissions for each vehicle type/emission source.

Table ES1 Total heavy metal emissions (kg) pr vehicle type for Denmark in 2007 calculated in the present study.

Vehicle	Cars	Vans	Trucks	Trucks	Trucks	Trucks
Emission component			Gasoline	3.5-7.5 t.	7.5-16 t.	16-32 t.
As	3.845	2.018	0.005	0.146	0.098	0.637
Cd	28.753	9.946	0.018	0.589	0.390	2.764
Cr	109.389	37.879	0.131	3.472	2.378	16.271
Cu	31 259.785	18 321.180	3.045	104.072	67.594	412.694
Hg	17.003	4.936	0.016	0.149	0.169	1.742
Ni	79.464	34.839	0.084	2.729	1.853	12.681
Pb	4 301.144	2 462.325	0.315	9.085	6.152	41.757
Se	14.755	7.929	0.014	0.469	0.369	2.937
Zn	14 347.945	6 807.679	8.479	350.512	273.864	2 224.187

Continued

Vehicle	Trucks	Urban buses	Coaches	Mopeds	Motorcycles	Total
Emission component	>32t.					
As	0.700	0.335	0.175	0.019	0.060	8.038
Cd	2.973	1.163	0.730	0.024	0.281	47.629
Cr	18.270	5.026	2.895	0.223	1.242	197.177
Cu	436.501	402.757	207.143	154.802	409.404	51 778.976
Hg	2.480	0.793	0.456	0.038	0.250	28.030
Ni	13.902	7.290	4.019	0.274	1.171	158.306
Pb	45.691	29.336	15.891	20.744	56.640	6 989.079
Se	3.500	1.352	0.739	0.098	0.408	32.570
Zn	2 632.965	1 021.562	582.966	57.048	248.947	28 556.153

Pr vehicle type cars are the most important source of emission for all heavy metal species, followed by vans, trucks, buses and 2-wheelers. However, the car emissions shares that range between 62 % (Pb) and 46 % (Se), are somewhat smaller than the share of total mileage. Trucks and buses use more fuel and engine oil pr kilometre driven, and have higher emission factors for brake, tyre and road wear, with Pb and Cu as an exception for brake wear.

Table ES2 Total heavy metal emissions (kg) pr source category for Denmark in 2007 calculated in the present study.

Emission component	Fuel	Engine oil	Tyre wear	Brake wear	Road abrasion	Total
As	0.8	-	0.8	6.5	-	8.0
Cd	0.5	39.4	2.5	5.2	0.1	47.6
Cr	31.6	65.0	3.4	74.5	22.7	197.2
Cu	21.7	106.5	14.8	51 624.6	11.4	51 779.0
Hg	28.0	-	-	-	0.1	28.0
Ni	4.5	39.4	24.2	72.1	18.2	158.3
Pb	3.3	173.5	76.3	6 682.2	53.8	6 989.1
Se	0.6	-	18.9	13.0	-	32.6
Zn	101.0	7 876.2	9 491.7	11 000.9	86.5	28 556.2

Almost all Hg emissions (100 % as a rounded share) come from **fuel usage**, and for Cr and As the emission shares are 16 and 9 %, respectively.

For fuel all other emission shares are insignificant (between 0 % and 3 %).

For **engine oil** the largest emission shares are noted for Cd (83 %) and engine oil also has substantial emission shares of Cr (33 %), Zn (28 %) and Ni (25 %).

For **tyre wear** the most important emissions are Se (58 %), Zn (33 %) and Ni (15 %).

Brake wear is the most important source of emissions for Cu (100 %), Pb (96 %), As (82 %), Ni (46 %), Zn (39 %) and Cr (37 %). For Se the brake wear emission share is 40 %.

For **road abrasion** the most important emission species are Cr (12 %) and Ni (11 %). The road abrasion emission shares of other emission components are between 0 % and 1 %.

Conclusion

Set in relation to a revised Danish emission budget, road transport (emission shares in brackets) is a key source for Cu (95 %), Zn (54 %) and Pb (53 %), and of some relevance for Cr (15 %). For the remaining emission components, road transport is only a small source of emission.

The road transport emissions of Cu and Pb almost solely originate from brake wear, also being the most dominating source for Cr. For Zn, brake and tyre wear are almost equally important sources. Consequently, brake wear, and secondly tyre wear, are the most relevant road transport sources to address, in order to reduce the Danish grand totals.

Important outcomes of the present project are the proposed heavy metal emission factors and calculated 2007 emission estimates pr fuel type and vehicle type, for each of the five emission sources; fuel and engine oil consumption, vehicle tyre and brake wear and road abrasion. The gathered information of heavy metal content pr unit of consumption/emission has been essential for the establishment of emission factors for each of the five sources of emissions.

For the exhaust based emissions related to fuel and engine oil consumption it is a big improvement to have two separate sets of emission factors based on new information of heavy metal content. Until now, bulk emission factors related to the total fuel consumption have been used. By treating the sources separately updates of emission factors and calculated totals become easier, if new emission knowledge become available.

As regards the wear related emissions, the wear rate and airborne fraction of the worn material, and the associated heavy metal content determine the resulting heavy metal emission factors. For tyre wear, the new factors for raw particulate emissions are regarded as being more precise than the ones used in the previous Danish non-exhaust emission inventory, since weight, wear percentage and tyre life times are provided by Danish experts in the tyre business.

The wear rates and airborne fractions of worn material for brakes, especially for heavy duty vehicles and for road abrasion in general, are regarded as uncertain. However, the outcome of the literature study did not bring any new information, which justifies any update of the particulate emission factors from the existing Danish inventory. These latter factors and the associated heavy metal content of worn material determine the heavy metal emission factors proposed in the present report.

Most importantly for the Cu and Pb metal content of brake material used by trucks and buses, there is a big difference between the figures used in the present study and averages based on other literature values. The metal content values used in this report for trucks and buses are very low, and rely on scarce data. The data differences point out the need for data updates, when new information become available.

By using the detailed emission factors and inventory calculation methods established in the present project, estimates of heavy metal emissions can be made for other years than 2007. The emission factors are independent from inventory year and the emissions for each source/fuel/-vehicle type combination are calculated as the product of the specific emission factor and the relevant inventory year specific activity data; fuel or engine oil consumption or total mileage.

Sammendrag

Indledning

Denne rapport opstiller nye tungmetalemissionsfaktorer for personbiler, varebiler, lastbiler, busser, knallerter og motorcykler indenfor emissionskilderne brændstofforbrug og motorolieforbrug, samt dæk-, bremse- og vejslid. Rapporten omfatter tungmetallerne Arsen (As), Cadmium (Cd), Krom (Cr), Kobber (Cu), Kviksølv (Hg), Nikkel (Ni), Bly (Pb), Selen (Se) og Zink (Zn), der alle rapporteres til UNECE CLRTAP (United Nations Economic Commission for Europe Convention on Long Range Transboundary Pollutants) konventionen. I rapporten beregnes også en ny dansk emissionsopgørelse for 2007.

Metode

Data for tungmetalindhold i brændstof og motorolie til brug for undersøgelsen bygger på målinger fra det europæiske forskningsinstitut CONCAWE for brændstof, og oplysninger fra brancheeksperter for motorolie. Brændstofforbruget pr. kørt km pr. køretøjstype kommer fra den eksisterende danske emissionsopgørelse, og funktioner for olieforbrug pr. kørt km er opstillet ud fra erfaringstal fra brancheeksperter. Produktet af brændstof-/olieforbrug pr. km og tungmetalindholdet bestemmer de kilometerbaserede tungmetalemissionsfaktorer for hver køretøjstype, og de totale tungmetalemissioner beregnes som produktet af tungmetalemissionsfaktorerne og det samlede trafikarbejde.

Data for dækslid pr. kørt km og køretøjstype stammer hovedsageligt fra Dækbranchens Miljøfond. Dækslidraterne og litteraturværdier for den luftemitterede del af dæksliddet bestemmer partikelemissionsfaktorerne. Produktet af disse faktorer og litteraturværdier for tungmetalindholdet i dæk bestemmer de kilometerbaserede tungmetalemissionsfaktorer. For hver køretøjstype beregnes de totale tungmetalemissioner som produktet af tungmetalemissionsfaktorerne og det samlede trafikarbejde.

For bremse- og vejslid bruges kilometerbaserede partikelemissionsfaktorer pr. køretøjstype fra den eksisterende danske non-exhaust emissionsopgørelse. Produktet af partikelemissionsfaktorer og litteraturværdier for tungmetalindholdet i bremse-/asfaltmateriale giver de endelige tungmetalemissionsfaktorer. For hver køretøjstype beregnes de totale tungmetalemissioner som produktet af tungmetalemissionsfaktorerne og det samlede trafikarbejde.

Resultater

For tungmetallerne er følgende TSP emissionstotaler beregnet i projektet for året 2007 (resultater i parentes): As (8 kg), Cd (48 kg), Cr (197 kg), Cu (51 779 kg), Hg (28 kg), Ni (158 kg), Pb (6 989 kg), Se (33 kg) and Zn (28 556 kg).

De enkelte køretøjstypers aktivitet indenfor hver enkelt emissionskilde og de sammenhørende emissionsfaktorer bestemmer totalemissionen for hver enkelt køretøjstype-/emissionskildekombination.

Tabel DS1 Samlede danske tungmetalemissioner (kg) pr. køretøjskategori i 2007.

Køretøj	Personbil	Varebil	Lastbil	Lastbil	Lastbil	Lastbil
Emission-skomponent			Benzin	3.5-7.5 t.	7.5-16 t.	16-32 t.
As	3,845	2,018	0,005	0,146	0,098	0,637
Cd	28,753	9,946	0,018	0,589	0,390	2,764
Cr	109,389	37,879	0,131	3,472	2,378	16,271
Cu	31 259,785	18 321,180	3,045	104,072	67,594	412,694
Hg	17,003	4,936	0,016	0,149	0,169	1,742
Ni	79,464	34,839	0,084	2,729	1,853	12,681
Pb	4 301,144	2 462,325	0,315	9,085	6,152	41,757
Se	14,755	7,929	0,014	0,469	0,369	2,937
Zn	14 347,945	6807,679	8,479	350,512	273,864	2 224,187

Fortsat

Køretøj	Lastbil	Bus Rute	Bus Turist	Knallert	MC	Total
Emissions-komponent	> 32 t.					
As	0,700	0,335	0,175	0,019	0,060	8,038
Cd	2,973	1,163	0,730	0,024	0,281	47,629
Cr	18,270	5,026	2,895	0,223	1,242	197,177
Cu	436,501	402,757	207,143	154,802	409,404	51 778,976
Hg	2,480	0,793	0,456	0,038	0,250	28,030
Ni	13,902	7,290	4,019	0,274	1,171	158,306
Pb	45,691	29,336	15,891	20,744	56,640	6 989,079
Se	3,500	1,352	0,739	0,098	0,408	32,570
Zn	2 632,965	1 021,562	582,966	57,048	248,947	28 556,153

Opdelt efter køretøjstype, er biler den største emissionskilde, efterfulgt af varebiler, lastbiler, busser og 2-hjulede køretøjer. Emissionsandelene for biler, der ligger mellem 62 % (Pb) og 46 % (Se), er noget mindre end bilernes andel af det samlede trafikarbejde. Lastbiler og busser bruger mere brændstof og motorolie pr. kørt km og har større emissionsfaktorer for dæk-, bremse- og vejslid, dog med undtagelse af Pb og Cu for bremseslid.

Tabel DS2 Samlede danske tungmetalemissioner (kg) pr. kildetype i 2007.

Emissions-komponent	Brændstof	Motorolie	Dækslid	Bremseslid	Vejslid	Total
As	0,8	-	0,8	6,5	-	8,0
Cd	0,5	39,4	2,5	5,2	0,1	47,6
Cr	31,6	65,0	3,4	74,5	22,7	197,2
Cu	21,7	106,5	14,8	51 624,6	11,4	51 779,0
Hg	28,0	-	-	-	0,1	28,0
Ni	4,5	39,4	24,2	72,1	18,2	158,3
Pb	3,3	173,5	76,3	6 682,2	53,8	6 989,1
Se	0,6	-	18,9	13,0	-	32,6
Zn	101,0	7 876,2	9491,7	11 000,9	86,5	28 556,2

Næsten al Hg-emission stammer fra forbruget af **brændstof**, og for Cr og As er denne kildes emissionsandele på hhv. 16 % og 9 %. Brændstofforbrugets emissionsandele for andre tungmetaller er meget små (mellem 0

% og 3 %). For **motorolie** beregnes de største emissionsandele for Cd (83 %). Forbruget af motorolie giver også betydelige emissioner af Cr (33 %), Zn (28 %) og Ni (25 %).

Bremseslid er den vigtigste emissionskilde for Cu (100 %), Pb (96 %), As (82 %), Ni (46 %), Zn (39 %) og Cr (37 %). For Se er bremsesliddets emissionsandel på 40 %. For **dækslid** beregnes de største emissionsandele for Se (58 %), Zn (33 %) og Ni (15 %). For **vejslid** beregnes de største emissionsandele for Cr (12 %) og Ni (11 %). Vejsliddets emissionsandel for andre tungmetaller er mellem 0 % og 1 %.

Konklusion

Set i forhold til en revideret dansk emissionstotal, er vejtrafik en vigtig kilde (emissionsandele i parentes) for Cu (95 %), Zn (54 %) og Pb (53 %), og til en vis grad for Cr (15 %). For de øvrige emissionskomponenter er vejtrafik kun en lille emissionskilde.

Vejtrafikkens Cu og Pb emission kommer næsten udelukkende fra bremseslid, der også er den vigtigste kilde for Cr. Bremse- og dækslid er næsten lige store kilder for Zn. Når dette tages i betragtning bliver bremseslid, og dernæst dækslid de mest relevante kilder at reducere indenfor vejtrafik, hvis de samlede danske emissioner skal nedbringes.

Det er en stor forbedring, at der nu er tilvejebragt tungmetalemissionsfaktorer og beregnet samlede 2007-emissionsestimater pr. brændstoftype og køretøjstype, for vejtransportens forbrug af brændstof og motorolie, samt køretøjernes dæk-, bremse- og vejslid. En vigtig forudsætning for de opstillede emissionsfaktorer har været projektets indsamlede viden om tungmetalindholdet pr. forbrugt/emitteret enhed for hver af de fem emissionskilder.

For de udstødningsbaserede emissioner knyttet til forbruget af brændstof og motorolie, er det en stor forbedring at emissionsfaktorerne nu er opstillet separat for disse to delkilder, og med opdaterede tungmetalindhold i hvert tilfælde, i stedet for som tidligere, hvor metoden blot knyttede sig til det samlede brændstofforbrug. På denne måde er det let at opdatere emissionsfaktorer og –beregninger, hvis ny viden bliver tilgængelig.

For de slidrelaterede emissioner er slidraten, den luftbårne del af det afslidte materiale samt tungmetalindholdet afgørende parametre for tungmetalemissionsfaktorerne. For dækslid vurderes de nye faktorer for rå partikelemissioner at være mere præcise end faktorerne for den eksisterende danske emissionsopgørelse, idet data for vægt, slidprocenter og levetider er oplyst af eksperter indenfor dækbranchen i Danmark.

For bremser anses slidraten og den luftbårne del af det afslidte materiale for at være usikre, specielt for tunge køretøjer og generelt for vejslid. Litteraturstudiet gav dog ikke ny viden som kunne retfærdiggøre en opdatering af partikelemissionsfaktorerne fra den eksisterende danske emissionsopgørelse, der sammen med det undersøgte tungmetalindhold danner grundlag for tungmetalemissionsfaktorerne i denne rapport.

Det skal fremhæves at der er stor forskel mellem denne rapports værdier for Cu og Pb metalindholdet i busser og lastbilers bremseslid, og et gennemsnit af bremsers metalindhold beregnet ud fra værdierne i den øvrige litteraur. Denne rapports værdier er meget lave, og bygger på få data. Dataforskellene peger på behovet for at opdatere disse data når ny information bliver tilgængelig.

Ud fra projektets detaljerede emissionsfaktorer og opstillede beregningsmetoder, kan tungmetalemissioner beregnes for andre år end 2007. De detaljerede emissionsfaktorer er uafhængige af opgørelsesåret, og kombineres med årlige aktivitetsdata for hhv. brændstofforbrug, motorolie og trafikarbejde i emissionsberegningen for hver enkelt emissionskilde/brændstoftype/køretøjstype kombination.

1 Introduction

The Danish National Environmental Research Institute prepares the Danish atmospheric emission inventories and reports the results on an annual basis to the UNFCCC (United Nations Framework Convention on Climate Change) and the UNECE LRTAP (United Nations Economic Commission for Europe Convention on Long Range Transboundary Pollutants) conventions. The latter convention prescribes emission estimates of the heavy metal species Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), Selenium (Se) and Zinc (Zn)to be submitted from the year 1990 onwards.

Concerning heavy metals in the previous Danish inventories, only broad estimates are made for road transport covering exhaust related emissions arising from fuel consumption and engine oil. The emission factors behind the estimates are bulk emission factors from the European EMEP/CORINAIR guidebook, related to the total fuel consumption. As explained in the EMEP/CORINAIR guidebook, these emission factors are considered as preliminary values only and no updates of the emission factors have been made during the time since their initial inclusion in the EMEP/CORINAIR guidebook many years ago.

The above facts explain the need for new heavy metal emission factors as basis input for the Danish emission inventory for road transport. During this exercise it is important to treat fuel consumption and engine oil as separate emission sources. Also, for each of the emission sources fuel consumption, engine oil, tyre wear, brake wear and road abrasion an emission factor split must be made between fuel types and vehicle categories in order to facilitate more detailed and accurate emission calculations subsequently.

This report presents new heavy metal emission factors for the road transport vehicle types cars, vans, trucks, buses and 2-wheelers, for each of the emission sources fuel consumption, engine oil, tyre wear, brake wear and road abrasion. The emission components covered are As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn - all of them relevant for emission reporting to the UNECE CLRTAP convention. The report also presents a new Danish inventory for the year 2007.

The Chapters 2, 3, 4 and 5 explain the sources behind the heavy metal emission factors proposed in this report, as well as new 2007 emission estimates related to exhaust (fuel consumption and engine oil usage), tyre wear, brake wear and road abrasion. Chapter 6 gives a summary view of the calculated emissions for 2007 and conclusions are given in Chapter 7.

2 Exhaust

During engine combustion, fuel is being burned together with small amounts of engine oil. Along with other emission components, metals are emitted to the ambient air if not deposited in the exhaust pipe or catalytic converter.

2.1 Metal content in fuels

For diesel and gasoline fuels the European CONCAWE research organisation recently made a comprehensive measurement campaign of the heavy metal content in gasoline and diesel available from gas filling stations (Denier van der Gon, 2009). In this experimental study, "Marketplace" petrol (70) and diesel (110) samples taken from the filling station pumps were collected in the nine EU countries Finland, Sweden, Poland, Germany, The Netherlands, United Kingdom, France, Italy and Spain. The fuel consumption in the covered countries represents over 80% of the diesel and petrol consumption in the EU-27. Samples are analyzed for metals that are of interest from an air quality perspective (Cd, Hg, Pb, As, Cr, Cu, Ni, Se, Zn) and from an Fuel Quality interest (Ag, Al, B, Ba, Ca, Fe, K, Mg, Mn, Mo, Na, Sn, Ti, V, Ce, Pt).

Table 1 Heavy metal content in gasoline and diesel fuels measured by CONCAWE.

	Diesel	Gasoline
Cadmium	< 0.05	0.2
Lead	0.5	1.6
Mercury	< 5.3	8.7
Arsenic	< 0.1	0.3
Copper	5.7	4.5
Chromium	8.5	6.3
Nickel	0.2	2.3
Selenium	< 0.1	0.2
Zinc	18	33

After review of the CONCAWE measurement data, the emission factors were adjusted and presented at the TFEIP (Task Force on Emission Inventories and Projection) meeting in Vienna In 2009 (Denier van der Gon & Kuenen, 2009).

These data are adopted for use for gasoline and diesel vehicle fuels in Denmark is presented Table 2. Liquefied petroleum gas (LPG) is to be considered free from metals and of less interest, since almost no cars run LPG in Denmark. The metal emissions are well below $PM_{2.5}$ in size (Wåhlin et al., 2006)[1].

[1] In general metals from combustion of fuel is perceived being much smaller than $PM_{2.5}$ size, below PM1 size.

Table 2 Metal content (µg pr kg fuel) in Danish road transport fuels.

Emission component		Diesel [µg pr kg]	Gasoline [µg pr kg]
Arsenic	As	0.1	0.3
Cadmium	Cd	0.05	0.2
Chromium	Cr	8.5	6.3
Copper	Cu	5.7	4.5
Mercury	Hg	5.3	8.7
Nickel	Ni	0.2	2.3
Lead	Pb	0.5	1.6
Selenium	Se	0.1	0.2
Zinc	Zn	18	33

A note must be made regarding lead, though. The lead content in gasoline has been examined by the Danish Environmental Protection Agency (DEPA), which finds a lead content of 40 ppb in the mid 1990's (DEPA, 1995). The use of lead as a gasoline fuel additive in Denmark has been gradually phased out from 1986 to 1994, and thus the weighted (leaded/unleaded gasoline) average content of lead has been reduced with almost 100 % in the same period.

A fuel content limit of 5 mg pr l (~ 6.7 ppm) for gasoline fuels is given in the EU directive 2003/17/EC, and the lead content in gasoline in Denmark is measured accordingly (Kubel, 2007). The measurement values are, however, not directly usable in the present study, since they are always below the detection limit of 2 mg pr l (~ 2.7 ppm). The latter limit is much higher than the 40 ppb figure stated by DEPA for the mid 1990's and the even lower 0.5 and 1.6 ppb figures measured by CONCAWE (Denier van der Gon & Kuenen, 2009) for diesel and gasoline in today's situation.

In spite of the significant difference between the CONCAWE and the DEPA lead contents (for gasoline), it has been decided to use the CONCAWE data for Denmark for 1994 onwards. The lead content of 40 ppb examined by DEPA is made in the mid 1990's when lead was removed from gasoline, and the high value from DEPA compared with the modern CONCAWE measurements may be due to traces of lead still present in the tanks at the filling station in Denmark by that time. Since no data is available it is however not possible to determine how rapidly this pollution of lead has decreased from the tanks.

In Figure 1, the lead content of gasoline used in the Danish inventory is shown from 1985 to 2007.

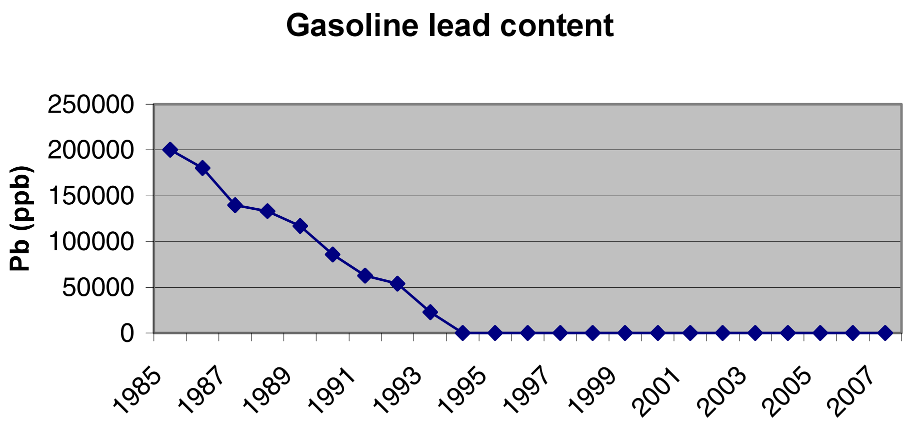

Figure 1 Lead content in ppb for gasoline in Denmark from 1985 to 2007.

2.2 Heavy metal emissions from fuel consumption

It is assumed that 100 % of the exhausted metals after fuel consumption become airborne. For lead, though, the airborne share is 75 % (EMEP/CORINAIR, 2007). It must be emphasized that some metal will deposit in the exhaust pipe system and the catalytic converter along with soot particles. However, the share of total exhaust particles is unknown and the technology of catalytic converters is not made to trap metal intentionally.

Particle filters, which is becoming more and more widespread for both diesel fuelled trucks and passenger cars, capture up to 95 % of all particles from passenger cars with the current technology and up to around 50 % for trucks (AECC, 2006). In two recent studies made by Vouitsis et al. (2007a, b), the emissions of trace metals from a EURO 4 diesel car are found to reduce by 76% and around 80 %, respectively over the diesel particulate filter.

However, due to the measurement data still being scarce in this case, no attempts are made to modify the Danish factors in the present study, in order to take into account the heavy metal emission reduction effect of particulate filters. Hence the use of the Danish factors give a worst case estimate of emissions from vehicles equipped with particulate filters.

From the fuel metal content figures in Table 2 and the fuel consumption for Danish vehicles in 2007 (see Table 3) taken from the Danish inventories, the heavy metal emissions from fuel consumption by Danish road transport in 2007 are calculated.

Table 3 Heavy metal emissions (kg) from fuel consumption in 2007.

	Road type	Unit	Cars Gasoline	Cars Diesel	Vans Gasoline	Vans Diesel	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coa-ches	Mopeds	Motor-cycles	Total
Fuel consumption	All	tonnes	1 618 669	544 820	77 964	801 211	1 812	27 776	31 679	327 375	466 510	149 216	85 700	4 322	28 658	4 165 710
	Urban	tonnes	710 055	225 688	37 733	338 509	736	8 545	11 311	75 285	107 669	84 309	33 072	3 501	12 930	1 649 343
	Rural	tonnes	632 776	219 855	31 352	348 360	721	12 234	13 344	138 785	203 856	55 475	37 251	821	10 845	1 705 676
	Highway	tonnes	275 837	99 277	8 879	114 342	354	6 996	7 024	113 305	154 985	9 432	15 377	-	4 882	810 692
As	All	kg	0.486	0.054	0.023	0.080	0.001	0.003	0.003	0.033	0.047	0.015	0.009	0.001	0.009	0.763
	Urban	kg	0.213	0.023	0.011	0.034	0.000	0.001	0.001	0.008	0.011	0.008	0.003	0.001	0.004	0.318
	Rural	kg	0.190	0.022	0.009	0.035	0.000	0.001	0.001	0.014	0.020	0.006	0.004	0.000	0.003	0.306
	Highway	kg	0.083	0.010	0.003	0.011	0.000	0.001	0.001	0.011	0.015	0.001	0.002	-	0.001	0.139
Cd	All	kg	0.324	0.027	0.016	0.040	0.000	0.001	0.002	0.016	0.023	0.007	0.004	0.001	0.006	0.468
	Urban	kg	0.142	0.011	0.008	0.017	0.000	0.000	0.001	0.004	0.005	0.004	0.002	0.001	0.003	0.197
	Rural	kg	0.127	0.011	0.006	0.017	0.000	0.001	0.001	0.007	0.010	0.003	0.002	0.000	0.002	0.187
	Highway	kg	0.055	0.005	0.002	0.006	0.000	0.000	0.000	0.006	0.008	0.000	0.001	-	0.001	0.084
Cr	All	kg	10.198	4.631	0.491	6.810	0.011	0.236	0.269	2.783	3.965	1.268	0.728	0.027	0.181	31.599
	Urban	kg	4.473	1.918	0.238	2.877	0.005	0.073	0.096	0.640	0.915	0.717	0.281	0.022	0.081	12.337
	Rural	kg	3.986	1.869	0.198	2.961	0.005	0.104	0.113	1.180	1.733	0.472	0.317	0.005	0.068	13.010
	Highway	kg	1.738	0.844	0.056	0.972	0.002	0.059	0.060	0.963	1.317	0.080	0.131	-	0.031	6.253
Cu	All	kg	7.284	3.105	0.351	4.567	0.008	0.158	0.181	1.866	2.659	0.851	0.488	0.019	0.129	21.667
	Urban	kg	3.195	1.286	0.170	1.929	0.003	0.049	0.064	0.429	0.614	0.481	0.189	0.016	0.058	8.483
	Rural	kg	2.847	1.253	0.141	1.986	0.003	0.070	0.076	0.791	1.162	0.316	0.212	0.004	0.049	8.911
	Highway	kg	1.241	0.566	0.040	0.652	0.002	0.040	0.040	0.646	0.883	0.054	0.088	-	0.022	4.273
Hg	All	kg	14.082	2.888	0.678	4.246	0.016	0.147	0.168	1.735	2.473	0.791	0.454	0.038	0.249	27.965
	Urban	kg	6.177	1.196	0.328	1.794	0.006	0.045	0.060	0.399	0.571	0.447	0.175	0.030	0.112	11.342
	Rural	kg	5.505	1.165	0.273	1.846	0.006	0.065	0.071	0.736	1.080	0.294	0.197	0.007	0.094	11.340
	Highway	kg	2.400	0.526	0.077	0.606	0.003	0.037	0.037	0.601	0.821	0.050	0.081	-	0.042	5.283
Ni	All	kg	3.723	0.109	0.179	0.160	0.004	0.006	0.006	0.065	0.093	0.030	0.017	0.010	0.066	4.469
	Urban	kg	1.633	0.045	0.087	0.068	0.002	0.002	0.002	0.015	0.022	0.017	0.007	0.008	0.030	1.936
	Rural	kg	1.455	0.044	0.072	0.070	0.002	0.002	0.003	0.028	0.041	0.011	0.007	0.002	0.025	1.762
	Highway	kg	0.634	0.020	0.020	0.023	0.001	0.001	0.001	0.023	0.031	0.002	0.003	-	0.011	0.771
Pb	All	kg	1.942	0.272	0.094	0.401	0.002	0.014	0.016	0.164	0.233	0.075	0.043	0.005	0.034	3.295
	Urban	kg	0.852	0.113	0.045	0.169	0.001	0.004	0.006	0.038	0.054	0.042	0.017	0.004	0.016	1.360
	Rural	kg	0.759	0.110	0.038	0.174	0.001	0.006	0.007	0.069	0.102	0.028	0.019	0.001	0.013	1.326
	Highway	kg	0.331	0.050	0.011	0.057	0.000	0.003	0.004	0.057	0.077	0.005	0.008	-	0.006	0.608
Se	All	kg	0.324	0.054	0.016	0.080	0.000	0.003	0.003	0.033	0.047	0.015	0.009	0.001	0.006	0.590

Continued																
	Urban	kg	0.142	0.023	0.008	0.034	0.000	0.001	0.001	0.008	0.011	0.008	0.003	0.001	0.003	0.241
	Rural	kg	0.127	0.022	0.006	0.035	0.000	0.001	0.001	0.014	0.020	0.006	0.004	0.000	0.002	0.238
	Highway	kg	0.055	0.010	0.002	0.011	0.000	0.001	0.001	0.011	0.015	0.001	0.002	-	0.001	0.110
Zn	All	kg	53.416	9.807	2.573	14.422	0.060	0.500	0.570	5.893	8.397	2.686	1.543	0.143	0.946	100.954
	Urban	kg	23.432	4.062	1.245	6.093	0.024	0.154	0.204	1.355	1.938	1.518	0.595	0.116	0.427	41.163
	Rural	kg	20.882	3.957	1.035	6.270	0.024	0.220	0.240	2.498	3.669	0.999	0.671	0.027	0.358	40.850
	Highway	kg	9.103	1.787	0.293	2.058	0.012	0.126	0.126	2.039	2.790	0.170	0.277	-	0.161	18.942

2.3 Engine oil and engine wear

In general, engine oil, in its virgin form, is free from copper, chromium, nickel and lead but contains zinc as an anti-wear additive compound. When in use the oil absorbs wear metal and compounds from the vehicle engine (Oil Analysers, 2006).

One distinguishes between mineral and synthetic motor oil. A mixture of both is very common. The possible *metal* content is not affected radically by the two different types (Castrol, 2006) as the main virtue about synthetic oil is a better viscosity index – being stable thickness whether cold or warm.

2.3.1 Metal content in pure engine oil

Engine oil is added viscosity index improvers, corrosion inhibitors as well as detergents and dispersants that keep the engine clean by reducing sludge build-up. Moreover, alkaline additives neutralise acidic oxides. Individual car owners may also add substances to the oil for additional protection or for driving in extreme situations, though this practice probably is not widespread in Denmark because of a relatively modern car fleet and non-extreme driving conditions.

The only relevant metal additive in our context is zinc, which is included in engine oil as an anti-wear additive. The zinc is present as dialkyl-dithio-phosphate (ZDDP) compound or associated compounds. Chemically the ZDDP reacts with the engine gear at spots with high pressure and temperature, caused by microscopic unevenness and following excessive friction. ZDDP reacts with the metal forming iron sulphates or iron phosphates smoothening out the surface. To avoid adverse effect of damaging catalytic converters the amount of zinc and other metals added to the engine oil are reduced as much as possible.

Copper is mentioned as a possible gasoline engine oil additive, see Table 4 (Blackstone Laboratories, 2006) and this is confirmed by Weckwerth (2001). This is probably not the case with modern engine oils since no analysis reviewed in this study (Neptune, 2006) and oil company laboratories information confirms this statement (Shell, 2006; Castrol, 2006). Here, the above mentioned averse side-effect of additive metals harming the catalytic converters may have been a reason for phasing out copper.

Most additives in engine oil are non-metallic compounds and hence not relevant for this part of the study. However, fulfilling the picture, other possible elements added virgin engine oil not to be reported to the UN-ECE, are: Molybdenum, Boron, Silicon, Sodium, Calcium, Magnesium, Phosphorus and Barium.

2.3.2 Metal content in used engine oil

Heavy metals engine wear particles accumulate in the first hand in the engine oil and afterwards they are led out by combustion of small amounts of the oil. When the engine is running a small amount of engine oil is being used to lubricate the engine pistons. A minimum oil film will be left and exposed for combustion in the combustion chamber.

For older engines, most of the engine oil goes into the combustion chamber through the leaks between the valve guide and shaft. These leaks gradually become bigger when the engine is getting more and more worn (pers. comm. Lars Vigild, Belladd, 2009).

Another part of the engine oil is led into the combustion chamber as oil vapour coming from the crankcase. The vaporised engine oil, though, is expected to have a smaller content of heavy metals than the liquid part of the engine oil (pers. comm. Lars Vigild, Belladd, 2009).

It is not regarded likely that any heavy metals are being permanently deposited by catalytic converters and filters, and hence the assumption in the present study is that 100 % of all engine oil being used by the engine is emitted into the air (pers. comm. Lars Vigild, Belladd, 2009).

Analyses of the engine oil are a common method of detecting problems with excessive engine wearing. The specific composition of wear metals relative to each others may indicate what is wrong and where. Table 4 lists possible elements occurring in oil and their sources. Metals relevant for reporting to the UNECE convention are highlighted.

Table 4 The most common sources of the elements in a gasoline or diesel engine oil.

Aluminium	Pistons, bearings, cases (heads and blocks)
Chromium	**Rings, a trace element in steel**
Iron	Cylinders, rotating shafts, the valve train, and any steel part sharing the oil
Copper	**Brass or bronze parts, copper bushings, bearings, oil coolers, also an additive in some gasoline engine oils**
Lead	**Bearings**
Tin	Bearings, bronze parts, piston coatings
Molybdenum	Anti-wear additive, coating on some new rings (washes off as break-in occurs)
Nickel	**Trace element in steel**
Manganese	Trace element, additive in gasoline
Silver	Trace element
Titanium	Trace element
Potassium	Antifreeze inhibitor, additive in some oil types
Boron	Detergent/dispersant additive, antifreeze inhibitors
Silicon	Airborne dirt, sealers, gaskets, antifreeze inhibitors
Sodium	Antifreeze inhibitors, additive in some gasoline engine oils
Calcium	Detergent/dispersant additive
Magnesium	Detergent/dispersant additive
Phosphorus	Anti-wear additive
Zinc	**Anti-wear additive**
Barium	Detergent/dispersant additive

Source: Blackstone laboratories (2006).

Zinc

Zinc is present in used engine oils mostly as the originally added anti wear additive and only to a minor degree caused by wearing processes in the engine (Fitch, 2004). The ppm content in engine oil listed in Table 6 is derived from two American samples on oil analysis (Neptune, 2006) giving 1113 ppm for virgin Amsoil and 921ppm for Mobile 1 Oil, averaging about 1000 ppm. Both oils are synthetic and not mineral oils. This figure is confirmed by Castrol (2006) that estimates about 1000-1050 ppm on average. Shell, 2006, says about 2000 ppm.

Copper

Copper particles from the engine are either present as metal wear or as chemical compound dispersed into the oil. Referring to Table 4 above, copper wear mainly originates from brass or bronze parts, copper bushings and from bearings. Several sources point at bearings as the main source for copper wear (FDM, 2006a; Shell, 2006; DTI, 2006). Especially the *crankshaft bearing* that prevents the crank to buckle is an important source (Castrol, 2006). Bearings are constructed from various types and layers of metals depending on their functionality. Three main types of upper layer are - in decreasing order of strength - copper-based, aluminium-based and tin or lead-based (white metal). The copper content in the former mentioned type is about 80 % and between 3 and 6 % for the latter, while only around 1 % is for the aluminium-based bearing.

Fitch (2004) suggests cooler cores as a copper leaching source for diesel cars. This is a chemical process in contrast to the physical wearing process. The process occurs especially in new engines below 1500 hours of service life. The engine oil anti-wear additive ZDDP, which beside zinc contains sulphur (along with phosphorous) - that reacts with the copper from the cooler tubes - results in copper sulphides forming on the tubes. This layer sloughs later off into the engine oil, which can reach a concentration at 300 ppm. Fitch (2004) refers to diesel vehicles but according to DTI (2006) the same process is possible for gasoline vehicles.

When analysing engine oil for chemical compounds, copper is one among other indicators for the malfunction of a car engine. As seen from Table 6 below, the laboratory Oil Analysers puts as a guideline an acceptable copper content in engine oil to 3-15 ppm for diesel engines, and 5-30 ppm for gasoline cars. Respectively, 50 and 100 is considered abnormal. Fitch (2004) states, in the same line, that 10-20 ppm is typical and not above 50 ppm. Finally, Shell (2006) considers ppm up to 80 as normal for gasoline vehicles, which is in the high end of the range.

Lead

Though lead levels are quite low in fuels, it may still occur in exhaust gas coming from the fuel and from worn metal alloys in the engine, e.g. the bearings as elaborated upon in the previous section on copper. Oil Analysers (2006) operates with a limit value at 15 ppm for diesel and 30 for gasoline engines while Shell (2006) consider up to 80 ppm as, still rather high.

Nickel

Nickel is present in fuel and as trace element in steel. It may also be included in virgin engine oil in very small amounts - about 1 ppm (mg pr litre) according to Castrol (2006). Oil Analysers (2006) operates with a limit value at 5 ppm for both gasoline and diesel engines while Shell (2006) states up to 15 ppm in general.

Chromium

Chromium is not an additive but it occurs in used oil from wearing of e.g. piston rings. Shell (2006) considers up to 15 ppm as normal while Oil Analysers (2006) sets a range at 1-8 ppm for diesel and 5-20 ppm for gasoline.

Cadmium

Cadmium is normally not tested for in relation to engine oil. However, supposed present in small amounts, stemming from engine alloys and as trace metal in fuels. Shell (2006) set a limit for normal occurrence to 0-10 ppm.

Mercury (Hg), Selenium (Se), Arsenic (As)

The three elements Hg, Se, and As are considered absent or neglectably low.

Taking into account the different sources considered in the present study, the basis information from Oil Analysers (2006) is regarded as the most comprehensive and consistent data for metal content in used engine oil. Guidelines value for normal, abnormal and excessive levels of metal in used engine oil from Oil Analysers (2006) are shown in the summary Table 5.

Table 5 Guideline values for normal, abnormal and excessive levels of metal in used engine oil.

	Diesel			Gasoline		
Emission component	Normal Ppm	Abnormal ppm	Excessive ppm	Normal ppm	Abnormal ppm	Excessive Ppm
Iron[a]	10-40	100	300	5-25	350	500
Chromium[a]	**1-8**	**12**	**15**	**5-20**	**25**	**40**
Lead[a]	**15**	**30**	**75**	**30**	**70**	**150**
Copper[a]	**3-15**	**50**	**150**	**5-30**	**100**	**300**
Tin[a]	15	20	30	20	30	40
Aluminum[a]	10	15	25	5-20	30	40
Nickel[a]	**5**	**10**	**15**	**5**	**10**	**15**
Silver[a]	3	10	30	3	10	30
Silicon[a]	15	25	30	20	30	40
Sodium[a]	25	100	150	20	100	150

[a] Oil Analysers (2006); [b] Castrol (2006) and Neptune (2006).

Table 6 shows the estimated content of the UNECE metals in the engine oil used in the present study with no distinction between the metal content of the virgin oil, additives or engine wear. For Cr, Cu, Ni and Pb the proposed metal contents are based on the Oil Analysers (2006) guideline for normal content of metals in engine oil in use[2]. The metals are considered within the $PM_{2.5}$ fraction, since exhaust particles in general are well below $PM_{2.5}$ (Khalek, 2006). An average value is calculated if the guideline value is within a range. The ppm value for Zn as a fuel additive is derived from Neptune (2006) verified by Castrol (2006) and other anonymous experts. For Cd, the ppm figure comes from Shell (2006).

[2] By choosing the normal levels, higher levels for break-in cars are assumed (new auto's first 10.000 km or so). Higher levels for older cars are balanced by lower levels for perfectly running newer cars. Also, the levels are assumed reflecting a balance between recently changed oil and old used.

Table 6 Metal content in used engine oil for gasoline and diesel engines.

Emission component		Gasoline engine [mg pr kg oil]	Diesel engines [mg pr kg oil]
Arsenic[a]	As	n.a.	n.a.
Cadmium[b]	Cd	5	5
Chromium[a]	Cr	4.5	12.5
Copper[a]	Cu	17.5	9
Mercury[a]	Hg	n.a.	n.a.
Nickel[a]	Ni	5	5
Lead[a]	Pb	15	30
Selenium[a]	Se	n.a.	n.a.
Zinc[c]	Zn	1 000	1 000

[a]Oil Analysers (2006); [b]Shell (2006; [c]Castrol (2006) and Neptune (2006).

2.3.3 Engine oil consumption

Passenger cars and vans

Engine oil is consumed during the usage mainly by combustion if no leakage. How much depends on the engine type, the engine age, the individual vehicle (engine) brand and model. 5-10 years ago a consumption of up to one litre pr thousand kilometres for passenger cars was stated acceptable by manufacturers. Nowadays, a guideline value says up to ½ litre pr thousand kilometres (FDM, 2006a; b). New cars, however, normally have much lesser consumption[3]. The consumption level targets normal combustion loss – leakage is not considered as normal. This guideline limit is in accordance with the vendors of Volkswagen and Audi in Denmark (SMC, 2006). However, it should be stressed that this value is the upper limit set by manufacturers. In practice values above 0.3 litre pr 1000 km may cause repairing under service guarantee conditions, e.g. by changing the engine pistons.

In practice, Castrol (2006), SMC (2006) and FDM (2006a) estimate the oil consumption to be one litre pr 10 000 km driven for new cars, irrespective of fuel type and production year. The same sources also state that the oil consumption is higher for older cars because of wearing or leakage and suggest around two times as much oil consumption for 20 year old vehicles. For diesel vans, Ford (2006) estimates also one litre pr 10 000 km for new vehicles. However, for the oil consumption during the break-in period, the first 10,000 km may be up to 0.4-0.5 litres pr 1000 km.

In the present study, an oil consumption of one litre pr 10,000 km for new cars and vans and around twice as much for 20 year old cars is used as a rule of thumb.

Trucks and buses

For heavy duty vehicles, Volvo Trucks Denmark (2006) gives as a rule of thumb about 2.5 litre oil consumed pr 10,000 km for new engines, and

[3] Also for vehicles that have a stable engine oil level throughout the entire time between periodical service check and engine oil shift, the engine oil is gradually being diluted; the oil absorbs impurities, condense water and fuel (FDM, 2006; Castrol, 2006). The oil consumption may be so small that adding oil before annual change is not necessary.

the double (5 litre pr 10,000 km) for 20 year old vehicles. It has not been possible to detail this figure further into total vehicle weight classes.

Motorcycles

As a rough estimate an average new motor cycle has an oil consumption of about 0.25 litres pr 10,000 km, and the double (0.5 litre pr 10,000 km) for 15-20 year old models, because of wearing (Aagesen Motorcykler, 2006). In the present survey, the oil consumption is set to 0.5 l pr 10000 km for vehicles more than 20 years old.

Mopeds

It is not possible at the moment to determine the oil consumption for mopeds in a way consistent with the data that underpins the calculations for the other vehicle types. This is due to the fact that for mopeds (2-stroke) the oil is mixed directly with the gasoline using an oil:fuel ratio of 1:28. This gives an oil use rate of around 700 km pr litre of oil, which is very high compared to the oil consumption for the other vehicle types (Yamaha Motors Scandinavia, 2006).

However, a large part of the oil is not in contact with the frictional parts of the engine and is combusted directly. No data exist and it is therefore decided not to give an estimate for mopeds in relation to the combination of oil consumption and engine wear.

The information from above lead to a simple model for oil consumption for passenger cars/vans, heavy duty vehicles and motor cycles as a function of vehicle age:

$$OC(X) = A \cdot X + B \text{, } 0<=X<=20 \quad (1)$$

Where OC=Oil Consumption (l/1000 km), X=Vehicle age, A=0.005/0.0125/0.0015 and B=0.1/0.25/0.025 for passenger cars/vans, heavy duty vehicles and motorcycles.

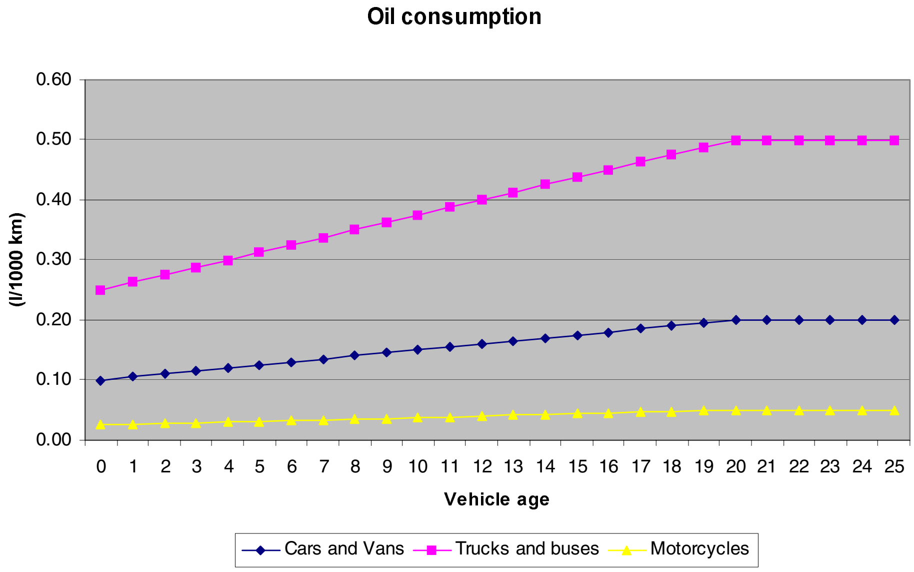

Figure 2 Oil consumption (l pr 1000 km) as a function of vehicle age.

2.4 Heavy metal emissions from engine oil

From the engine oil metal content figures in Table 6 and the estimated engine oil consumption for Danish vehicles in 2007 (see Table 7) taken from the Danish inventories (e.g. Nielsen et al., 2009) the heavy metal emissions from engine oil consumption by Danish road transportation vehicles in 2007 are calculated.

Table 7 Heavy metal emissions from engine oil in 2007.

Emission component	Road	Unit	Cars Gasoline	Cars Diesel	Vans Gasoline	Vans Diesel	Trucks Gasoline	Trucks 3.5-7.5t.	Trucks 7.5-16t.	Trucks 16-32t.	Trucks > 32t.	Urban buses	Coaches	Mopeds	MC	Total
EngOil	All	tonnes	3 539	1 328	108	1 412	3	104	67	467	492	193	124	-	39	7 876
	Urban	tonnes	1 239	465	38	494	1	33	21	89	94	98	40	-	18	2 630
	Rural	tonnes	1 628	611	54	706	1	49	32	210	222	79	58	-	15	3 665
	Highway	tonnes	672	252	16	212	1	22	14	168	177	15	26	-	5	1 582
As	All	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Urban	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Rural	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Highway	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	All	kg	17.697	6.640	0.540	7.059	0.015	0.518	0.336	2.333	2.462	0.965	0.622	-	0.194	39.381
	Urban	kg	6.194	2.324	0.189	2.470	0.005	0.166	0.107	0.443	0.468	0.492	0.199	-	0.091	13.149
	Rural	kg	8.141	3.055	0.270	3.529	0.007	0.243	0.158	1.050	1.108	0.396	0.292	-	0.076	18.324
	Highway	kg	3.362	1.262	0.081	1.059	0.003	0.109	0.070	0.840	0.886	0.077	0.131	-	0.027	7.908
Cr	All	kg	44.242	5.976	1.351	6.353	0.038	0.466	0.302	2.100	2.216	0.868	0.560	-	0.485	64.957
	Urban	kg	15.485	2.092	0.473	2.223	0.012	0.149	0.097	0.399	0.421	0.443	0.179	-	0.228	22.200
	Rural	kg	20.351	2.749	0.675	3.176	0.018	0.219	0.142	0.945	0.997	0.356	0.263	-	0.189	30.081
	Highway	kg	8.406	1.135	0.203	0.953	0.008	0.098	0.063	0.756	0.798	0.069	0.118	-	0.068	12.675
Cu	All	kg	31.854	23.241	0.973	24.705	0.027	1.812	1.175	8.167	8.618	3.377	2.176	-	0.349	106.474
	Urban	kg	11.149	8.134	0.340	8.647	0.009	0.580	0.376	1.552	1.637	1.722	0.696	-	0.164	35.007
	Rural	kg	14.653	10.691	0.486	12.352	0.013	0.852	0.552	3.675	3.878	1.385	1.023	-	0.136	49.696
	Highway	kg	6.052	4.416	0.146	3.706	0.006	0.381	0.247	2.940	3.103	0.270	0.457	-	0.049	21.771
Hg	All	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Urban	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Rural	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Highway	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	All	kg	17.697	6.640	0.540	7.059	0.015	0.518	0.336	2.333	2.462	0.965	0.622	-	0.194	39.381
	Urban	kg	6.194	2.324	0.189	2.470	0.005	0.166	0.107	0.443	0.468	0.492	0.199	-	0.091	13.149
	Rural	kg	8.141	3.055	0.270	3.529	0.007	0.243	0.158	1.050	1.108	0.396	0.292	-	0.076	18.324
	Highway	kg	3.362	1.262	0.081	1.059	0.003	0.109	0.070	0.840	0.886	0.077	0.131	-	0.027	7.908
Pb	All	kg	106.181	19.921	3.242	21.176	0.092	1.553	1.007	7.000	7.387	2.894	1.865	-	1.164	173.481
	Urban	kg	37.163	6.972	1.135	7.411	0.029	0.497	0.322	1.330	1.404	1.476	0.597	-	0.547	58.884
	Rural	kg	48.843	9.164	1.621	10.588	0.043	0.730	0.473	3.150	3.324	1.187	0.877	-	0.454	80.453
	Highway	kg	20.174	3.785	0.486	3.176	0.019	0.326	0.211	2.520	2.659	0.232	0.392	-	0.163	34.144
Se	All	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Urban	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued																
	Rural	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Highway	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	All	kg	3 539.375	1 328.066	108.057	1 411.711	3.052	103.543	67.123	466.669	492.466	192.962	124.344	-	38.786	7 876.154
	Urban	kg	1 238.781	464.823	37.820	494.099	0.977	33.134	21.479	88.667	93.569	98.411	39.790	-	18.229	2 629.779
	Rural	kg	1 628.113	610.910	54.029	705.856	1.434	48.665	31.548	210.001	221.610	79.114	58.442	-	15.126	3 664.848
	Highway	kg	672.481	252.332	16.209	211.757	0.641	21.744	14.096	168.001	177.288	15.437	26.112	-	5.430	1 581.528

2.5 Heavy metal emissions from fuel and engine oil

The total of all exhaust related heavy metal emissions is shown in Table 8 as the sum of heavy metal contributions from fuel (Table 3) and engine oil (Table 7).

Table 8 Heavy metal emissions from fuel and engine oil in 2007.

kg	Road type	Unit	Cars Gasoline	Cars Diesel	Vans Gasoline	Vans Diesel	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	Motorcycles	Total
As	All	kg	0.486	0.054	0.023	0.080	0.001	0.003	0.003	0.033	0.047	0.015	0.009	0.001	0.009	0.763
	Urban	kg	0.213	0.023	0.011	0.034	0.000	0.001	0.001	0.008	0.011	0.008	0.003	0.001	0.004	0.318
	Rural	kg	0.190	0.022	0.009	0.035	0.000	0.001	0.001	0.014	0.020	0.006	0.004	0.000	0.003	0.306
	Highway	kg	0.083	0.010	0.003	0.011	0.000	0.001	0.001	0.011	0.015	0.001	0.002	-	0.001	0.139
Cd	All	kg	18.021	6.668	0.556	7.099	0.016	0.519	0.337	2.350	2.486	0.972	0.626	0.001	0.200	39.849
	Urban	kg	6.336	2.335	0.197	2.487	0.005	0.166	0.108	0.447	0.473	0.496	0.201	0.001	0.094	13.346
	Rural	kg	8.267	3.066	0.276	3.547	0.007	0.244	0.158	1.057	1.118	0.398	0.294	0.000	0.078	18.511
	Highway	kg	3.418	1.267	0.083	1.065	0.003	0.109	0.071	0.846	0.894	0.078	0.131	-	0.028	7.992
Cr	All	kg	54.440	10.607	1.842	13.163	0.050	0.702	0.571	4.883	6.181	2.137	1.288	0.027	0.665	96.556
	Urban	kg	19.958	4.010	0.710	5.101	0.017	0.222	0.193	1.039	1.336	1.159	0.460	0.022	0.309	34.537
	Rural	kg	24.338	4.618	0.873	6.137	0.022	0.323	0.255	2.125	2.730	0.828	0.580	0.005	0.257	43.091
	Highway	kg	10.144	1.979	0.259	1.925	0.010	0.157	0.123	1.719	2.115	0.150	0.248	-	0.099	18.928
Cu	All	kg	39.138	26.347	1.323	29.272	0.036	1.970	1.355	10.033	11.277	4.227	2.665	0.019	0.478	128.141
	Urban	kg	14.344	9.421	0.510	10.576	0.012	0.629	0.440	1.981	2.251	2.203	0.885	0.016	0.222	43.490
	Rural	kg	17.501	11.944	0.627	14.338	0.016	0.921	0.628	4.466	5.040	1.701	1.235	0.004	0.185	58.606
	Highway	kg	7.294	4.982	0.186	4.357	0.007	0.420	0.287	3.586	3.986	0.324	0.545	-	0.071	26.044
Hg	All	kg	14.082	2.888	0.678	4.246	0.016	0.147	0.168	1.735	2.473	0.791	0.454	0.038	0.249	27.965
	Urban	kg	6.177	1.196	0.328	1.794	0.006	0.045	0.060	0.399	0.571	0.447	0.175	0.030	0.112	11.342
	Rural	kg	5.505	1.165	0.273	1.846	0.006	0.065	0.071	0.736	1.080	0.294	0.197	0.007	0.094	11.340
	Highway	kg	2.400	0.526	0.077	0.606	0.003	0.037	0.037	0.601	0.821	0.050	0.081	-	0.042	5.283
Ni	All	kg	21.420	6.749	0.720	7.219	0.019	0.523	0.342	2.399	2.556	0.995	0.639	0.010	0.260	43.850
	Urban	kg	7.827	2.369	0.276	2.538	0.007	0.167	0.110	0.458	0.489	0.509	0.206	0.008	0.121	15.085
	Rural	kg	9.596	3.099	0.342	3.599	0.009	0.246	0.160	1.078	1.149	0.407	0.300	0.002	0.101	20.086
	Highway	kg	3.997	1.282	0.101	1.082	0.004	0.110	0.072	0.863	0.917	0.079	0.134	-	0.038	8.679
Pb	All	kg	108.124	20.193	3.335	21.576	0.094	1.567	1.023	7.164	7.620	2.969	1.908	0.005	1.198	176.776
	Urban	kg	38.016	7.085	1.180	7.581	0.030	0.501	0.328	1.368	1.457	1.518	0.613	0.004	0.562	60.244
	Rural	kg	49.603	9.274	1.658	10.762	0.044	0.736	0.480	3.219	3.426	1.214	0.895	0.001	0.467	81.780
	Highway	kg	20.505	3.835	0.497	3.234	0.020	0.330	0.215	2.577	2.737	0.236	0.399	-	0.169	34.753
Se	All	kg	0.324	0.054	0.016	0.080	0.000	0.003	0.003	0.033	0.047	0.015	0.009	0.001	0.006	0.590
	Urban	kg	0.142	0.023	0.008	0.034	0.000	0.001	0.001	0.008	0.011	0.008	0.003	0.001	0.003	0.241
	Rural	kg	0.127	0.022	0.006	0.035	0.000	0.001	0.001	0.014	0.020	0.006	0.004	0.000	0.002	0.238
	Highway	kg	0.055	0.010	0.002	0.011	0.000	0.001	0.001	0.011	0.015	0.001	0.002	-	0.001	0.110
Zn	All	kg	3 592.791	1 337.872	110.630	1 426.133	3.111	104.043	67.693	472.562	500.864	195.648	125.887	0.143	39.731	7 977.108
	Urban	kg	1 262.213	468.885	39.065	500.192	1.001	33.288	21.683	90.022	95.507	99.928	40.385	0.116	18.656	2 670.941

Continued															
Rural	kg	1 648.994	614.868	55.063	712.126	1.458	48.885	31.788	212.499	225.279	80.113	59.112	0.027	15.484	3 705.698
Highway	kg	681.584	254.119	16.502	213.815	0.653	21.870	14.222	170.040	180.078	15.607	26.389	-	5.591	1 600.470

2.6 Comparing emission estimates from previous inventory and present study

The previous Danish emission inventory for road transport is calculated as the product of the fuel related HM emission factors from the COPERT IV model (EMEP/CORINAIR, 2007) and the total fuel consumption. The HM emission factors reflect the emissions coming from both fuel and engine wear/engine oil (Ntziachristos, 2005). No data is available for As, Hg and Pb in COPERT IV. In the case of Pb a national emission factor of 40 ppb is used for gasoline, whereas for diesel the lead content is zero, c.f. paragraph 3.1. Further, the assumption is that 75 % of the lead is emitted to the air.

The previous HM emission estimates are shown in Table 9, as well as the percentage difference between the previous estimates and the revised ones. In both cases the figures relate to fuel and engine oil consumption only.

Table 9 Previous Danish emission estimates and difference in percent between new and previous estimate in 2007.

Emission component	Mg pr kg	Previous estimate [kg]	New estimate [kg]	New vs. previous estimate [%]
As	-	-	1	
Cd	0.01	42	40	-4
Cr	0.05	208	97	-54
Cu	1.7	7 082	128	-98
Hg	-	0	28	-
Ni	0.07	292	44	-85
Pb	0.04	69	177	155
Se	0.01	42	1	-
Zn	1	4 166	7 977	91

For Cr, Ni and Cu the differences between the new and the previous emission total gradually increases, and for Cu the new emission estimate is only around 2 % of the previous figure. The new Zn and Pb emission totals are significantly higher than the previous ones, 91 % and 155 %, respectively. Zn is used as an engine oil additive and the difference in Pb emissions is due to engine wear (e.g. bearings).

3 Tyre wear

As mentioned in the previous section on brakes, especially zinc is expected to emit from tyre wearing. This mostly happens during high friction, that is braking and acceleration. Furthermore, the wear is dependent on the characteristics of tyres, vehicles, road surface and also dependent on vehicle operation mode (Urban, rural or highway driving) and driving style (hard or soft accelerations and decelerations).

Table 10 lists the typical content of tyres according to Gustafsson (2001) citing from Ahlbom and Duus (1994) and Baekken (1993).

Table 10 Tyre components.

Component	All tyre, weight %	Tread weight %	Component	All tyre, weight %	Tread weight %
Rubber polymers	40-60	50	Accelerators	0.5	0.5
Reinforcing fillers	22-35	25	Antioxidants	1-2	1
Softening fillers	15-20	20	Hardener	0-3	-
Activators (ZnO)	1.5-5	1.5	Stabilisators	< 1	-
Softener (stearic acid)	0.7	0.7	Other additives	< 1	-
Vulcanisers (S)	1-2	1	Steel constructions	10	-

3.1 Metal contents in tyre material

Quoting Johansson and Burman (2006) tyres normally contains 2 % Zn. The European EMEP/CORINAIR guidebook (EMEP/CORINAIR, 2007) quotes Smolders and Degryse (2002) for the Zn content in tyres, present as zinc oxide acting as vulcanising agent, as a significant additive in concentrations between 1.2 % for car tyres and 2.1 % for truck tyres.

Also, the tyres may contain Cu, Ni, Co, Pb, Cr (Lindgren, 1996; Luhana et al., 2004) which is emitted by wearing. Studs made of steel, which are common in the Swedish climate (Snow, ice), and absent in Denmark, also contain some metals, like wolfram and others like aluminium alloys (Lindgren, 1996).

Luhana et al. (2004) quotes various studies on tyre rubber content, listed in Table 11. As seen, the range is quite wide for several elements. A mean value has been calculated from the interval figures. The same method is used by the EMEP/CORINAIR Emission Inventory Guidebook (2007) based on the same sources[4].

Luhana et al. (2004) also analyse three tyre samples. The authors, however, have low confidence in the result since the figures varies too much to other studies, e.g. Legret and Pagotto (1999). The results from Luhana et al. (2004) are nevertheless presented in Table 11 below, where the rounded figures are read from a graph representation of the results. The

[4] In addition EMEP/CORINAIR (2003) also includes an analysis of one single tyre, which was disregarded by Luhana et al. (2004).

results for Zinc is quite in line with the values given by Fauser (1999), see beneath. Only for copper the result is not within the literature range.

Table 11 Metal speciation of tyre rubber, from literature survey and analysis made by Luhana et al. (2004) and Fauser (1999).

	Luhana et al. (2004)	Luhana et al. (2004)	Luhana et al. (2004)	Fauser (1999)
Emission component	Literature Mg pr kg	Mean Mg pr kg	Analysis Mg pr kg	Analysis Mg pr kg
As	0.8	0.8		
Cd	0.28-4.96	2.6	1	
Cr	0.4-6.73	3.6	2	
Cu	1.8-29.3	15.6	43	
Hg	n.e.	n.e.	n.e.	n.e.
Ni	0.9-50	25.5	4	
Pb	1-160	80.5	20	
Se	20	20.0		
Zn	8 378-13 494	10 936.0	10 000	8 029 (car)/ 14 587 (HDV)
Fe	2.12-533	267.6		
Al	81-420	250.5		

Luhana et al. (2004) points out that a reason for the diverging values, besides different chemical compositions, also may be the chemical detecting method, sometimes not able to detect all amounts of a metal. Moreover one has to bear in mind that the values doing the range reflects analysis of tyres from various countries (climates) and decades.

From Fauser (1999) is deducted a zinc emission factor of 8 029 ppm of tyre tread, based on four passenger car tyre powder analyses. This is seemingly a thorough method of analysis detecting all zinc, no matter the size. In addition, Fauser (1999) analysed rubber powder from a truck, which showed notably higher content of zinc (14587 ppm) compared to passenger car tyres.

Table 12 shows the metal contents for tyre material to be used in the present study. The metal speciation is adopted from Luhana et al. (2004), apart from zinc, where the values from Fauser (1999) for passenger car tyres are used for cars, vans and 2-wheelers, and HDV values are used for trucks and buses.

Table 12 Metal content in tyre metal (mg pr kg) used in the present study.

Emission component	Metal content mg pr kg
As	0.8
Cd	2.6
Cr	3.6
Cu	15.6
Ni	25.5
Pb	80.5
Se	20.0
Zn	8 029 (car)/ 14 587 (HDV)
Fe	267.6
Al	250.5

3.2 Tyre wear rates from the literature

Gustafsson (2001) quotes Rogge et al. (1993) and Lindström and Rossipal (1987) for tyre wear emission factors. They are listed in Table 13 along with emission factors from CEPMEIP (Visschedijk et al., 2004), Luhana et al. (2004) and EMEP/CORINAIR (2007).

Table 13 Tyre wear rates from the literature.

Sources	A	B	C	C	D	E	F/G/H/I	J	J
	Mg pr vkm	Mg pr vkm	Mg pr vkm	Mg pr vkm	Mg pr vkm	Mg pr vkm	Mg pr vkm	Mg pr vkm	Mg pr vkm
Category	Total wear	Total wear	Total wear	PM_{10}	Total wear	Total wear	PM_{10}	TSP	PM_{10}
Cars	24-360	90	69	3.45	100	57/85	(F) 5.0/ (G) 6.1	10.7	6,4
Buses		1 000							
Vans			90	4.5			(H)13	16.8	10,1
Trucks			371.3	18.56			(I) 200	45	27,0
MC			34.5	1.72				4.7	2,8

A. Rogge et al. (1993).

B. Lindström and Rossipal (1987).

C. CEPMEIP: PM_{10} = 5 % of total wear.

D. Luhana et al. (2004) (based on English tyre sale statistics).

E. Luhana et al. (2004) Actual test: 57 mg pr vkm for highway driving and 85 mg pr vkm for mixed driving.

F. USEPA, 1995 (quoted by Luhana et al., 2004).

G. Rauterberg-Wulff (1999), (quoted by Luhana et al., 2004).

H. EMPA, 2000.

I. Lükewille et al. 2001.

J. EMEP/CORINAIR (2007): PM_{10} = 60 % of TSP.

The figures in column D on total wear from Luhana et al. (2004) are based on the UK sale of tyres in 1999, assuming 10-20 % wear before scrapping, which equals 1-1,5 kg out of 8 kg for an new average passenger car tyre, and moreover, assuming 50-60 000 km lifetime for a tyre. A tyre wear percentage of 10-20 % is also assumed in the Norwegian Emission Inventory (NEI, 2005).

Luhana et al. (2004) measured the weight loss of four front-wheel driven vehicles during 11 000 to 40 000 kilometres driving, and found an average loss at 57 mg pr vkm when mostly motorway driving. Mixed driving including rural and suburban driving gave values of about 85 mg pr vkm. However, the test is based on only four vehicles and the results are not consistent, that is, the wearing differs unexplainably.

There is great uncertainty about the PM_{10} fraction of total tyre wear and of TSP. Luhana et al. (2004) quotes Rauterberg-Wulff (1999) and Lükewille et al. (2001) for PM_{10} emission factors as seen in Table 13. EMEP/CORINAIR (2007) estimates the PM_{10}/TSP ratio to be 0.6 and operates with values for PM_{10} for passenger cars, MCs and vans similar to the other sources. However, the values are a literature study compromise rather than based on actual measurements.

3.3 New Danish tyre wear rates

In the present study, the Danish tyre wear rates are estimated based on data for tyre life time, average no. of tyres pr vehicle, tyre weights and wear percent, as shown in Table 14. For private cars, vans, trucks and buses the data are provided by the Danish Tyre Trade Environmental Foundation (2007), and for 2-wheelers the data are obtained from Bridgestone (2007).

Table 14 Danish tyre wear rates based on average tyre life time and wear.

Eq. parameter	Name	Unit	Cars	Vans	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Ur. buses	Coaches	Mopeds	Motor-cycles
A	Life time	km	45 000	45 000	60 000	80 000	120 000	200 000	80 000	120 000	5 000	8 000
B	No. of tyres		4	4	6	6	10	14	6	8	2	2
C	Weight pr tyre	kg	8.6	13.6	20	40	50	60	60	60	2.5	5
D	Wear-%		17	17	17	17	17	17	17	17	17	17
(BxCxD)/A	Wear rate	Mg pr vkm	130	206	340	510	708	714	765	680	170	213

It is essential for 2-wheelers to have a good road hold and therefore the rubber material is very soft for these vehicle types (Bridgestone, 2007). This also means that the tyre lifetimes are much shorter for 2-wheelers compared to the remaining vehicle categories. The largest trucks have long tyre lifetimes due to their distinct transportation pattern, which are mostly long distance transports characterised by constant driving and only few accelerations and decelerations.

Alternative tyre wear estimates can also be made based on total mileage in 2007 and the tyre sales statistics (including also tyres mounted on new sold vehicles) from the Danish Tyre Trade Environmental Foundation (2006), see Table 15. An extra 2 % is added to statistical sales for private cars to account for the import of tyres.

Table 15 Danish tyre wear rates based on tyre sales statistics.

Eq. parameter	Name	Unit	Cars	Vans	HDV	2-wheelers
A	Total mileage	Km	3.87E+10	8.16E+09	2.9E+09	1.1E+09
B	Total weight of tyres	Tonnes	28 431	5 669	15 332,3	403
C	Wear-%		17	17	17	17
	Wear factor	Mg pr vkm	125	118	887	60

The results of the tyre lifetime and sales based methods are in fine accordance for passenger cars, but differs more for the remaining vehicle types. For 2-wheelers though, the sales data are generally regarded as uncertain and for vans an unknown part of the tyres used are registered as car tyres. In terms of trucks, the calculated wear rate based on statistical tyre sales becomes too high in all cases, since a lot of driving by Danish trucks is being made abroad. Although Danish truck drivers also buy new tyres when being abroad, this is to some extent outbalanced by the number of tyres mounted on Norwegian trucks in Denmark due to tyre price differences.

Conclusively, the tyre wear rates based on tyre sale statistics in Table 15 are regarded as more uncertain than those derived from tyre lifetime/wear percent estimates.

The latter wear rates cover the mix of all driving modes in the Danish traffic. However, it is desirable to differentiate these average wear rates in order to account for the different driving characteristics in urban, rural and highway driving.

A relation between average trip speed and relative changes in tyre wear rates is established in EMEP/CORINAIR (2007) based on experimental data. The relation is shown in Figure 3 and is used in the following to split the average tyre wear rates into rates for urban, rural and highway driving.

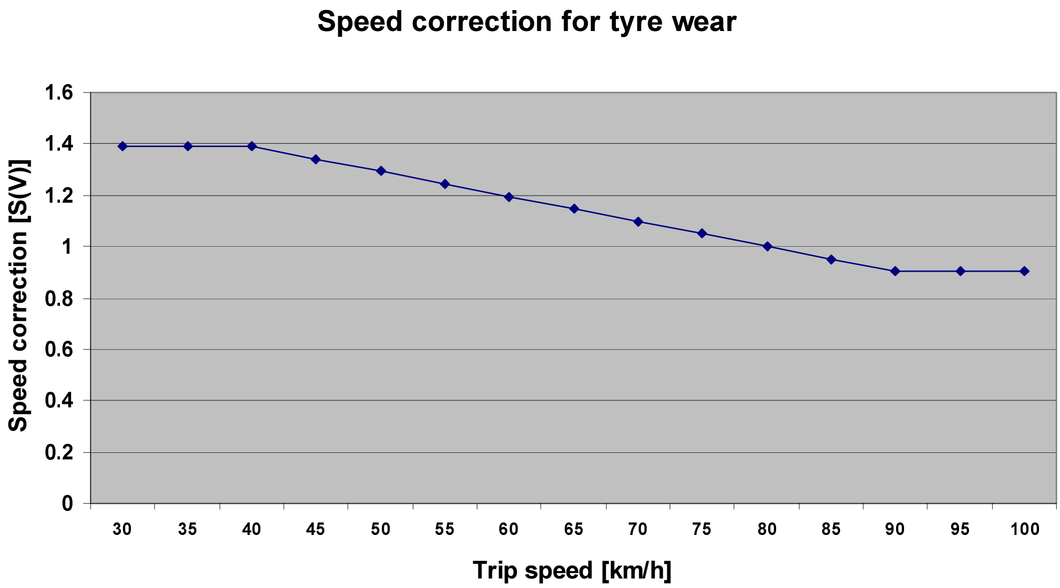

Figure 3 Relative trip speed correction for tyre wear.

The approach is to calculate an intermediate tyre wear rate, e_X, which go into the calculation formula (4) for the total Danish tyre wear. In the equation, the e_X factor is corrected for trip speed in order to obtain the tyre wear factors for urban, rural and highway driving:

$$e_T \cdot M_T = e_X \cdot S(V)_U \cdot M_U + e_X \cdot S(V)_R \cdot M_R + e_X \cdot S(V)_H \cdot M_H \Leftrightarrow$$

$$e_X = \frac{e_T \cdot M_T}{\sum_{k=U,R,H} S(V)_k \cdot M_k} \tag{4}$$

Where e_T = average Danish wear rate (Table 14), M_T = Total Danish mileage, e_X = intermediate wear rate, S(V) = trip speed correction factor, $M_{U,R,H}$ = total Danish urban, rural and highway mileage, k = road type (urban/rural/highway).

For urban driving, the wear rate becomes:

$$e_U = e_X \cdot S(V)_U = \frac{e_T \cdot M_T}{\sum_{k=U,R,H} S(V)_k \cdot M_k} \cdot S(V)_U \quad (5)$$

The wear rates for rural and highway driving are calculated in a similar way.

Table 16 shows the general parameters used in the expressions 4 and 5 and the calculated wear rates for urban, rural and highway driving.

Table 16 Calculation parameters and resulting tyre wear rates for urban, rural and highway driving.

Road	Mileage	Unit	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Ur. buses	Coaches	Mopeds	MC
All	Total mileage (MT)	km	3.90E+10	1.27E+10	1.02E+07	3.46E+08	2.25E+08	1.56E+09	1.65E+09	5.93E+08	3.82E+08	2.38E+08	9.17E+08
	Wear rate (eT)	Mg pr vkm	130	206	340	340	510	708	850	765	680	170	213
	Intermediate wear rate (eX)	Mg pr vkm	112	170	279	279	419	609	731	577	559	122	176
Urban	Trip speed	Km pr h	40	40	35	35	35	35	35	30	35	30	40
	Speed correction S(V)U		1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39
	Total urban mileage (MU)	Km	1.36E+10	4.45E+09	3.27E+06	1.11E+08	7.18E+07	2.97E+08	3.13E+08	3.02E+08	1.22E+08	1.93E+08	4.31E+08
	Wear rate, urban (eU)	Mg pr vkm	155	236	388	388	583	847	1016	801	777	170	245
Rural	Trip speed	Km pr h	70	65	60	60	60	60	60	50	60	30	70
	Speed correction S(V)R		1.10	1.15	1.20	1.20	1.20	1.20	1.20	1.29	1.20	1.39	1.10
	Total rural mileage (MR)	Km	1.79E+10	6.35E+09	4.80E+06	1.63E+08	1.06E+08	7.02E+08	7.41E+08	2.43E+08	1.80E+08	4.53E+07	3.58E+08
	Wear rate, rural (eR)	Mg pr vkm	123	195	334	334	501	729	874	745	668	170	193
Highway	Trip speed	Km pr h	100	80	80	80	80	80	80	70	80		100
	Speed correction S(V)U		0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.10	1.00		0.90
	Total highway mileage (MH)	Km	7.41E+09	1.91E+09	2.14E+06	7.27E+07	4.71E+07	5.62E+08	5.93E+08	4.74E+07	8.03E+07		1.28E+08
	Wear rate, highway (eH)	Mg pr vkm	101	170	280	280	419	610	732	633	559		159

Compared to the tyre wear rates from Table 13 the new Danish wear rate for passenger cars is 30 %, 44 % and 88 % above the factors from Luhana et al. (2004; sales based), Lindström and Rossipal (1987) and CEPMEIP (2006), respectively, and around 50 and 75 % above the factors from Luhana et al. (2004; experimental), for mixed (average urban and rural) and highway driving, respectively. Here differences in tyre material, road surface, traffic situation, and driving style may influence the result.

3.4 Airborne particulate fractions of Danish tyre wear

As mentioned previously there is a great uncertainty about the PM_{10} fraction of total wear and this uncertainty also exists as regards the remaining tyre particle size fractions. Luhana et al. (2004) summarise from literature studies that the PM_{10} share of total tyre wear lies between 1 % and 15 %.

In the present study it is assumed that 5 % of total wear is within the airborne PM_{10} fraction. The same PM_{10} fraction of total wear is chosen by CEPMEIP. The PM_{10} mass fraction of TSP, and the $PM_{2.5}$, PM_1 and $PM_{0.1}$ mass fractions of TSP are taken from EMEP/CORINAIR (2007).

Table 17 Mass fractions of TSP for tyre wear (from EMEP/CORINAIR, 2007).

Particle size class	Mass fraction of TSP
TSP	1.000
PM_{10}	0.600
$PM_{2.5}$	0.420
PM_1	0.060
$PM_{0.1}$	0.048

The mass fractions of TSP are given in Table 17, and the tyre wear particulate emission factors are given in Table 18.

Table 18 Airborne particulate fractions of Danish tyre wear (mg pr km) for different particle size classes.

Road type	Particle size class	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Ur. buses	Coaches	Mopeds	MC
All	TSP	10.83	17.13	28.33	28.33	42.50	59.03	70.83	63.75	56.67	14.17	17.71
Urban	TSP	12.94	19.68	32.36	32.36	48.55	70.59	84.70	66.78	64.73	14.17	20.38
Rural	TSP	10.22	16.23	27.84	27.84	41.76	60.71	72.86	62.12	55.67	14.17	16.10
Highway	TSP	8.40	14.16	23.30	23.30	34.95	50.82	60.99	52.76	46.60	-	13.22
All	PM_{10}	6.50	10.28	17.00	17.00	25.50	35.42	42.50	38.25	34.00	8.50	10.63
Urban	PM_{10}	7.77	11.81	19.42	19.42	29.13	42.35	50.82	40.07	38.84	8.50	12.23
Rural	PM_{10}	6.13	9.74	16.70	16.70	25.05	36.43	43.71	37.27	33.40	8.50	9.66
Highway	PM_{10}	5.04	8.50	13.98	13.98	20.97	30.49	36.59	31.66	27.96	-	7.93
All	$PM_{2.5}$	4.55	7.19	11.90	11.90	17.85	24.79	29.75	26.78	23.80	5.95	7.44
Urban	$PM_{2.5}$	5.44	8.26	13.59	13.59	20.39	29.65	35.57	28.05	27.19	5.95	8.56
Rural	$PM_{2.5}$	4.29	6.82	11.69	11.69	17.54	25.50	30.60	26.09	23.38	5.95	6.76
Highway	$PM_{2.5}$	3.53	5.95	9.79	9.79	14.68	21.34	25.61	22.16	19.57	-	5.55
All	PM_1	0.65	1.03	1.70	1.70	2.55	3.54	4.25	3.83	3.40	0.85	1.06
Urban	PM_1	0.78	1.18	1.94	1.94	2.91	4.24	5.08	4.01	3.88	0.85	1.22
Rural	PM_1	0.61	0.97	1.67	1.67	2.51	3.64	4.37	3.73	3.34	0.85	0.97
Highway	PM_1	0.50	0.85	1.40	1.40	2.10	3.05	3.66	3.17	2.80	-	0.79
All	$PM_{0.1}$	0.52	0.82	1.36	1.36	2.04	2.83	3.40	3.06	2.72	0.68	0.85
Urban	$PM_{0.1}$	0.62	0.94	1.55	1.55	2.33	3.39	4.07	3.21	3.11	0.68	0.98
Rural	$PM_{0.1}$	0.49	0.78	1.34	1.34	2.00	2.91	3.50	2.98	2.67	0.68	0.77
Highway	$PM_{0.1}$	0.40	0.68	1.12	1.12	1.68	2.44	2.93	2.53	2.24	-	0.63

3.5 Heavy metal emission factors for Danish tyre wear

The heavy metal emission factors for tyre wear are calculated as the product of the metal contents in tyres (Table 12) and the tyre wear particulate emission factors shown in Table 18. The heavy metal emission factors are shown pr vehicle category and road type in Table 19 for total TSP. Annex 1 list the heavy metal emission factors for other size fractions as well.

Table 19 Heavy metal emission factors (µg pr km) for tyre wear pr vehicle category and road type (total TSP).

Emission component	Road type	Particle size class	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	Motor cycles
As	All	TSP	0.0087	0.0137	0.0227	0.0227	0.0340	0.0472	0.0567	0.0510	0.0453	0.0113	0.0142
As	Urban	TSP	0.010	0.016	0.026	0.026	0.039	0.056	0.068	0.053	0.052	0.011	0.016
As	Rural	TSP	0.008	0.013	0.022	0.022	0.033	0.049	0.058	0.050	0.045	0.011	0.013
As	Highway	TSP	0.007	0.011	0.019	0.019	0.028	0.041	0.049	0.042	0.037	-	0.011
Cd	All	TSP	0.028	0.045	0.074	0.074	0.111	0.153	0.184	0.166	0.147	0.037	0.046
Cd	Urban	TSP	0.034	0.051	0.084	0.084	0.126	0.184	0.220	0.174	0.168	0.037	0.053
Cd	Rural	TSP	0.027	0.042	0.072	0.072	0.109	0.158	0.189	0.162	0.145	0.037	0.042
Cd	Highway	TSP	0.022	0.037	0.061	0.061	0.091	0.132	0.159	0.137	0.121	-	0.034
Cr	All	TSP	0.039	0.062	0.102	0.102	0.153	0.213	0.255	0.230	0.204	0.051	0.064
Cr	Urban	TSP	0.047	0.071	0.117	0.117	0.175	0.254	0.305	0.240	0.233	0.051	0.073
Cr	Rural	TSP	0.037	0.058	0.100	0.100	0.150	0.219	0.262	0.224	0.200	0.051	0.058
Cr	Highway	TSP	0.030	0.051	0.084	0.084	0.126	0.183	0.220	0.190	0.168	-	0.048
Cu	All	TSP	0.169	0.267	0.442	0.442	0.663	0.921	1.105	0.995	0.884	0.221	0.276
Cu	Urban	TSP	0.202	0.307	0.505	0.505	0.757	1.101	1.321	1.042	1.010	0.221	0.318
Cu	Rural	TSP	0.160	0.253	0.434	0.434	0.651	0.947	1.137	0.969	0.869	0.221	0.251
Cu	Highway	TSP	0.131	0.221	0.364	0.364	0.545	0.793	0.951	0.823	0.727	-	0.206
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	0.276	0.437	0.723	0.723	1.084	1.505	1.806	1.626	1.445	0.361	0.452
Ni	Urban	TSP	0.330	0.502	0.825	0.825	1.238	1.800	2.160	1.703	1.651	0.361	0.520
Ni	Rural	TSP	0.261	0.414	0.710	0.710	1.065	1.548	1.858	1.584	1.420	0.361	0.410
Ni	Highway	TSP	0.214	0.361	0.594	0.594	0.891	1.296	1.555	1.345	1.188	-	0.337
Pb	All	TSP	0.872	1.379	2.281	2.281	3.421	4.752	5.702	5.132	4.562	1.140	1.426
Pb	Urban	TSP	1.042	1.584	2.605	2.605	3.908	5.682	6.819	5.376	5.211	1.140	1.641
Pb	Rural	TSP	0.823	1.307	2.241	2.241	3.361	4.887	5.865	5.001	4.482	1.140	1.296

Continued													
Pb	Highway	TSP	0.676	1.140	1.876	1.876	2.814	4.091	4.909	4.247	3.752	-	1.064
Se	All	TSP	0.217	0.343	0.567	0.567	0.850	1.181	1.417	1.275	1.133	0.283	0.354
Se	Urban	TSP	0.259	0.394	0.647	0.647	0.971	1.412	1.694	1.336	1.295	0.283	0.408
Se	Rural	TSP	0.204	0.325	0.557	0.557	0.835	1.214	1.457	1.242	1.113	0.283	0.322
Se	Highway	TSP	0.168	0.283	0.466	0.466	0.699	1.016	1.220	1.055	0.932	-	0.264
Zn	All	TSP	86.951	137.504	227.488	413.298	619.948	861.038	1 033.246	929.921	826.597	113.744	142.180
Zn	Urban	TSP	103.935	157.977	259.848	472.089	708.133	1 029.624	1 235.549	974.153	944.177	113.744	163.640
Zn	Rural	TSP	82.093	130.311	223.506	406.064	609.096	885.625	1 062.750	906.173	812.128	113.744	129.250
Zn	Highway	TSP	67.426	113.711	187.090	339.904	509.856	741.329	889.595	769.651	679.808	-	106.159

3.6 Heavy metal emissions from tyre wear

The heavy metal emissions for tyre wear are calculated as the product of the total mileage pr vehicle category (Table 16) and the heavy metal emission factors for tyre wear shown in Table 19. The heavy metal emissions are shown pr vehicle category and road type in Table 20 for total TSP. Annex 1 list the heavy metal emissions for other size fractions as well.

Table 20 Heavy metal emissions (kg) for tyre wear pr vehicle category and road type (total TSP).

Emission component	Road type	Particle size class	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	MC	Total
As	All	TSP	0.338	0.174	0.000	0.008	0.008	0.074	0.093	0.030	0.017	0.003	0.013	0.758
As	Urban	TSP	0.141	0.070	0.000	0.003	0.003	0.017	0.021	0.016	0.006	0.002	0.007	0.287
As	Rural	TSP	0.147	0.082	0.000	0.004	0.004	0.034	0.043	0.012	0.008	0.001	0.005	0.339
As	Highway	TSP	0.050	0.022	0.000	0.001	0.001	0.023	0.029	0.002	0.003	-	0.001	0.132
Cd	All	TSP	1.097	0.566	0.001	0.026	0.025	0.240	0.303	0.098	0.056	0.009	0.042	2.463
Cd	Urban	TSP	0.459	0.228	0.000	0.009	0.009	0.054	0.069	0.053	0.021	0.007	0.023	0.932
Cd	Rural	TSP	0.477	0.268	0.000	0.012	0.011	0.111	0.140	0.039	0.026	0.002	0.015	1.102
Cd	Highway	TSP	0.162	0.070	0.000	0.004	0.004	0.074	0.094	0.007	0.010	-	0.004	0.430
Cr	All	TSP	1.520	0.783	0.001	0.035	0.034	0.332	0.420	0.136	0.078	0.012	0.058	3.410
Cr	Urban	TSP	0.636	0.315	0.000	0.013	0.013	0.075	0.095	0.073	0.028	0.010	0.032	1.290
Cr	Rural	TSP	0.660	0.371	0.000	0.016	0.016	0.154	0.194	0.054	0.036	0.002	0.021	1.525
Cr	Highway	TSP	0.224	0.097	0.000	0.006	0.006	0.103	0.130	0.009	0.013	-	0.006	0.595
Cu	All	TSP	6.585	3.395	0.005	0.153	0.149	1.437	1.820	0.590	0.338	0.053	0.253	14.777
Cu	Urban	TSP	2.755	1.365	0.002	0.056	0.054	0.327	0.414	0.315	0.123	0.043	0.137	5.590
Cu	Rural	TSP	2.860	1.609	0.002	0.071	0.069	0.665	0.842	0.236	0.156	0.010	0.090	6.609
Cu	Highway	TSP	0.970	0.421	0.001	0.026	0.026	0.445	0.564	0.039	0.058	0.000	0.026	2.578
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	10.763	5.550	0.007	0.250	0.243	2.349	2.975	0.964	0.552	0.086	0.414	24.155
Ni	Urban	TSP	4.503	2.232	0.003	0.091	0.089	0.534	0.676	0.515	0.202	0.070	0.224	9.138
Ni	Rural	TSP	4.674	2.630	0.003	0.116	0.112	1.087	1.377	0.385	0.255	0.016	0.147	10.803
Ni	Highway	TSP	1.586	0.688	0.001	0.043	0.042	0.728	0.922	0.064	0.095	-	0.043	4.214
Pb	All	TSP	33.978	17.519	0.023	0.790	0.768	7.417	9.392	3.044	1.743	0.272	1.307	76.254
Pb	Urban	TSP	14.215	7.045	0.009	0.289	0.281	1.685	2.134	1.626	0.637	0.220	0.707	28.848
Pb	Rural	TSP	14.757	8.301	0.011	0.365	0.355	3.433	4.347	1.216	0.805	0.052	0.463	34.104
Pb	Highway	TSP	5.006	2.173	0.004	0.136	0.133	2.299	2.911	0.202	0.301	-	0.137	13.302
Se	All	TSP	8.442	4.353	0.006	0.196	0.191	1.843	2.333	0.756	0.433	0.068	0.325	18.945
Se	Urban	TSP	3.532	1.750	0.002	0.072	0.070	0.419	0.530	0.404	0.158	0.055	0.176	7.167
Se	Rural	TSP	3.666	2.062	0.003	0.091	0.088	0.853	1.080	0.302	0.200	0.013	0.115	8.473
Se	Highway	TSP	1.244	0.540	0.001	0.034	0.033	0.571	0.723	0.050	0.075	-	0.034	3.305
Zn	All	TSP	3 388.959	1 747.364	2.322	143.131	139.180	1 343.947	1 701.887	551.519	315.909	27.106	130.382	9 491.706
Zn	Urban	TSP	1 417.825	702.636	0.849	52.317	50.873	305.346	386.670	294.654	115.471	21.956	70.528	3 419.125

Continued														
Zn	Rural	TSP	1 471.818	827.977	1.072	66.094	64.270	622.045	787.717	220.348	145.878	5.150	46.225	4 258.595
Zn	Highway	TSP	499.316	216.751	0.401	24.720	24.037	416.556	527.499	36.517	54.560	-	13.629	1 813.986

3.7 Comparing tyre wear factors from EMEP/CORINAIR and present study

In the following Table 21 the previous Danish PM_{10} tyre wear factors based on EMEP/CORINAIR (2007) data are listed together with the ratios between the new TSP emission factors (Table 22) and EMEP/CORINAIR (2007). The comparative ratios will be the same for other particulate size ratios, since the new set of emission factors use the mass fractions of total TSP as given in EMEP/CORINAIR (2007).

Table 21 Comparison of tyre wear emission factors (airborne TSP) from EMEP/CORINAIR (2007) and present study.

Study	Unit	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Ur. buses	Coaches	Mopeds	MC
EMEP/CORINAIR	Mg pr vkm	12.45	20.45	27.34	27.34	27.34	52.24	78.36	29.82	28.83	6.39	5.56
New factors: EMEP/CORINAIR	%	87	84	104	104	155	113	90	214	197	222	319

For passenger cars, vans and trucks between 3.5-7.5 t. and > 16 t. there is a reasonably good accordance between the previous (EMEP/CORINAIR based) and the new Danish emission factors. For the medium-sized heavy duty vehicles and 2-wheelers, the new factors are considerably higher than the EMEP/CORINAIR based ones.

In general the new emission factors are regarded as more accurate than the previous ones, since the underlying wear rate parameters are provided by Danish experts in the tyre business. The EMEP/CORINAIR (2007) factors for heavy duty vehicles are produced by scaling the passenger car emission factors in a simple calculation expression using number of axles and load factor as input parameters. For 2-wheelers, the low EMEP/CORINAIR (2007) emission factors show that no consideration is taken to the high tyre wear caused by the soft rubber material for these vehicle categories.

4 Brake wear

Brakes are an important source for Cu, Pb, Cd, Cr, Ni och Zn (Westerlund, 2001) and also Sb and Ba (Folkeson, 2005). When braking, the friction between metal parts results in wear emissions.

Previously, the brake system consisted of disc brakes in the front and either disc brakes or drum brakes in the rear of the vehicle. Today more on-road vehicle are equipped with disc brakes both front and rear (FDM, 2006c). About 25 % of the passenger cars (especially the cheaper ones) still have drum bakes at the rear.

The disc brake consists of a disc or rotor and two brake pads squeezing against the disc from each side, when braking. The drum brake system consists of a cylinder – or drum – where from the inside *brake shoes* squeezes, when braking. The friction surface (linings) of the pads or shoes is heated by brake friction, which causes wearing.

The disc rotor in the disc brake and the drum in the drum brake are made of cast iron (Ofria, 2006). Brake linings were earlier made of asbestos as prime component. However, these have been phased out due to health legislations. According to Westerlund (2001) brake linings "consists of compounds where fibres from steel, glass and plastic serves as reinforcements in the material. Casts of iron chip can also occur. In addition, some substances have a heat conducting effect. Copper, brass and zinc are also used to conduct heat".

4.1 Metal contents in brake linings

Brake wear material depends on the manufacturer, the vehicle type and the desired properties of the brake pads (e.g. EMEP/CORINAIR (2007)). The latter source refers to Legret and Pagotto (1999) and Hildemann et al. (1991) who have shown a Fe contribution up to 46 %, Cu content of up to 14 %, organic material in the order of 13 % and then several other metals including Pb (~4 %), Zn (~2 %), Ca, Ba. The proposed metal content values from EMEP/CORINAIR (2007) shows extremely high variances, e.g. the copper content ranges from 370-142000 ppm. This may reflect ongoing developments finding the optimal brakes composition, after the forced phasing out asbestos.

Westerlund (2001) made a thorough analysis of the metal content in Swedish brake linings for passenger cars, heavy duty trucks and buses.

For passenger cars, brake lining measurements (front and rear linings) have been made for 24 new cars (0-4 years of age) and five old cars (>4 years of age). Making a fine representation of the Swedish car fleet, the selected cars had a relatively high share of the national brands, Volvo and Saab, but also included other typical cars on the European (and Danish) roads. For heavy duty trucks and buses, in both cases brake linings from one Volvo and one Scania vehicle model were analysed.

The results presented by Westerlund (2001) are regarded as the most accurate data available for metal speciation of brake lining material. Hence, metal content figures for Zn, Cu, Pb, Cd, Cr and Ni are taken from this latter source whereas metal content data for As and Se is taken from EMEP/CORINAIR (2007) due to lack of data from Westerlund (2001).

For passenger cars, only data for new vehicles are selected from Westerlund (2001). In the latter study new cars have first registration years of 1994+, and as years pass these cars make up the vast majority of vehicles in today's car traffic. Also, the Westerlund (2001) study has examined the specific Swedish vehicle composition, which may deviate to some extent from the Danish one. The data for new passenger cars are used for vans also due to lack of data.

For Cu and Pb two important studies have been made recently which deserve further attention and some conclusive remarks.

In a study made by Denier van der Gon et al. (2007) assessments were made of the Cu content of brake pads and linings, based on the studies Westerlund (2001), Luhana et al. (2004), Brake Pad Partnership (2006), Sanders et al. (2003), van Hyfte (2005) and recalculations from Garg et al. (2000). A low and high estimate of 5 % and 10 % for Cu was proposed by Denier van der Gon et al. (2007). In relation to Pb, Denier van der Gon and Appelman (2009) found 0.5 % Pb content for brakes, based on the findings from Westerlund (2001), Luhana et al. (2004), Sanders et al. (2003) and EMEP/CORINAIR, 2007).

The present study's Cu content for cars are similar to the upper case values from Denier van der Gon (2007). For trucks and buses, however, the present study's Cu content values of 0.8 % and 1.4 %, respectively, are remarkably lower than the Cu content values proposed by Denier van der Gon et al. (2007). It must be noted that in general the factors from Westerlund (2001) for trucks and buses, which are adopted in the present study, are in each case based on an average of two vehicles only.

For cars there is a large difference between the Pb contents from the present study and Denier van der Gon and Appelman (2009), and the discrepancies become even larger for buses and trucks. For cars the present study's Pb content is almost a factor 2.8 higher and a factor of 12.5 and 6.8 smaller for trucks and buses, respectively, compared to the values from Denier van der Gon and Appelman (2009).

For trucks and buses in particular, the Cu and Pb content values used in the present study may be subject to updates, if newer information become available for these specific vehicle types.

Table 22 Metal speciation of brake linings used in the present study.

Emission component	Cars and vans	Trucks	Buses
As[b]	10	10	10
Cd[a]	9.8	3.1	3.0
Cr[a]	105	164	64
Cu[a]	105 070	7 538	13 694
Ni[a]	105	114	159
Pb[a]	13 854	407	731
Se[b]	20	20	20
Zn[a]	20 164	7 514	9 336

[a] Westerlund (2001)

[b] EMEP/CORINAIR (2007)

4.2 Airborne TSP from Danish brake wear

The TSP particulate emission factors from the airborne part of Danish brake wear comes from the current Danish inventory, based on EMEP/CORINAIR (2007) data and method.

The experimentally derived speed correction for brake wear from EMEP/CORINAIR (2007), shown in Figure 4, and the equations 4 and 5 are used to split the average brake wear rates into rates for urban, rural and highway driving (see Table 23).

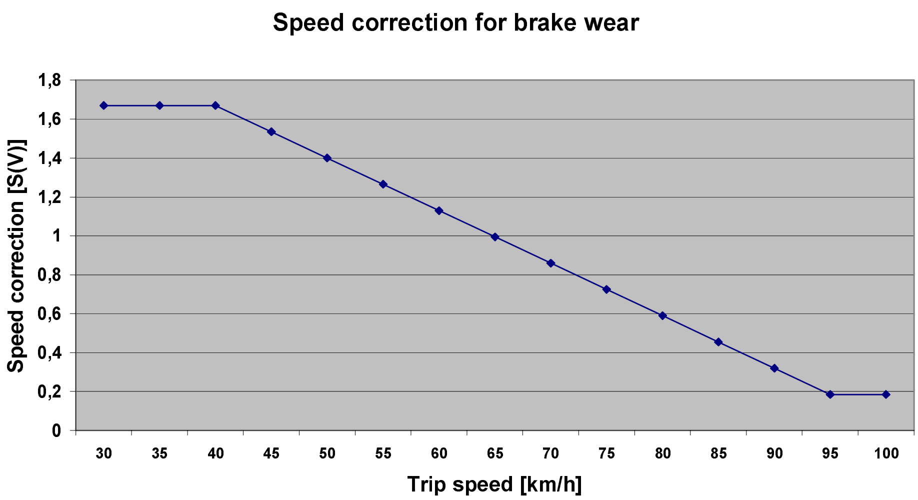

Figure 4 Relative trip speed correction for brake wear from EMEP/CORINAIR (2007).

Table 23 Calculation parameters and resulting brake wear TSP emission factors for urban, rural and highway driving.

Road	Mileage	Unit	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	Motor cycles
	Total mileage (MT)	km	3.90E+10	1.27E+10	1.02E+07	3.46E+08	2.25E+08	1.56E+09	1.65E+09	5.93E+08	3.82E+08	2.38E+08	9.17E+08
	TSP	Mg pr vkm	7.5	11.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	3.7	3.7
Urban	Trip speed	Km pr h	40	40	35	35	35	35	35	30	35	30	40
	Speed correction S(V)U		1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67
	Total urban mileage (MU)	km	1.36E+10	4.45E+09	3.27E+06	1.11E+08	7.18E+07	2.97E+08	3.13E+08	3.02E+08	1.22E+08	1.93E+08	4.31E+08
	TSP	Mg pr vkm	12.5	19.5	54.7	54.7	54.7	54.7	54.7	54.7	54.7	6.2	6.2
Rural	Trip speed	Km pr h	70	65	60	60	60	60	60	50	60	30	70
	Speed correction S(V)R		0.86	1.00	1.13	1.13	1.13	1.13	1.13	1.40	1.13	1.67	0.86
	Total rural mileage (MR)	km	1.79E+10	6.35E+09	4.80E+06	1.63E+08	1.06E+08	7.02E+08	7.41E+08	2.43E+08	1.80E+08	4.53E+07	3.58E+08
	TSP	Mg pr vkm	6.5	11.6	37.0	37.0	37.0	37.0	37.0	45.8	37.0	6.2	3.2
Highway	Trip speed	Km pr h	100	80	80	80	80	80	80	70	80		100
	Speed correction S(V)U		0.19	0.59	0.59	0.59	0.59	0.59	0.59	0.86	0.59		0.19
	Total highway mileage (MH)	km	7.41E+09	1.91E+09	2.14E+06	7.27E+07	4.71E+07	5.62E+08	5.93E+08	4.74E+07	8.03E+07	0.00E+00	1.28E+08
	TSP	Mg pr vkm	1.4	6.9	19.3	19.3	19.3	19.3	19.3	28.2	19.3		0.7

4.3 Airborne particulate fractions of Danish brake wear

The PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$ mass fractions of TSP shown in Table 24 are taken from EMEP/CORINAIR (2007).

Table 24 Mass fractions of TSP for tyre wear (from EMEP/CORINAIR, 2007).

Particle size class	Mass fraction of TSP
TSP	1.00
PM_{10}	0.98
$PM_{2.5}$	0.39
PM_1	0.10
$PM_{0.1}$	0.08

The mass fractions of TSP are given in Table 24 and the brake wear particulate emission factors for TSP in Table 23 are used to calculate the brake wear particulate emission factors for other size classes and road types as well.

Table 25 Airborne particulate fractions of Danish brake wear (mg pr km) for different road types and particle size classes.

Road type	Fraction	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	MC
All	TSP	7.61	13.69	38.95	38.95	38.95	34.00	34.00	48.94	38.95	6.18	4.24
Urban	TSP	12.53	19.54	54.69	54.69	54.69	54.69	54.69	54.69	54.69	6.18	6.18
Rural	TSP	6.45	11.64	37.00	37.00	37.00	37.00	37.00	45.85	37.00	6.18	3.18
Highway	TSP	1.39	6.90	19.32	19.32	19.32	19.32	19.32	28.16	19.32	-	0.68
All	PM_{10}	7.46	13.42	38.17	38.17	38.17	33.32	33.32	47.96	38.17	6.06	4.16
Urban	PM_{10}	12.27	19.15	53.59	53.59	53.59	53.59	53.59	53.59	53.59	6.06	6.06
Rural	PM_{10}	6.32	11.41	36.26	36.26	36.26	36.26	36.26	44.93	36.26	6.06	3.12
Highway	PM_{10}	1.36	6.76	18.93	18.93	18.93	18.93	18.93	27.60	18.93	-	0.67
All	$PM_{2.5}$	2.97	5.34	15.19	15.19	15.19	13.26	13.26	19.09	15.19	2.41	1.65
Urban	$PM_{2.5}$	4.88	7.62	21.33	21.33	21.33	21.33	21.33	21.33	21.33	2.41	2.41
Rural	$PM_{2.5}$	2.52	4.54	14.43	14.43	14.43	14.43	14.43	17.88	14.43	2.41	1.24
Highway	$PM_{2.5}$	0.54	2.69	7.54	7.54	7.54	7.54	7.54	10.98	7.54	-	0.27
All	PM_1	0.76	1.37	3.90	3.90	3.90	3.40	3.40	4.89	3.90	0.62	0.42
Urban	PM_1	1.25	1.95	5.47	5.47	5.47	5.47	5.47	5.47	5.47	0.62	0.62
Rural	PM_1	0.65	1.16	3.70	3.70	3.70	3.70	3.70	4.58	3.70	0.62	0.32
Highway	PM_1	0.14	0.69	1.93	1.93	1.93	1.93	1.93	2.82	1.93	-	0.07
All	$PM_{0.1}$	0.61	1.10	3.12	3.12	3.12	2.72	2.72	3.92	3.12	0.49	0.34
Urban	$PM_{0.1}$	1.00	1.56	4.38	4.38	4.38	4.38	4.38	4.38	4.38	0.49	0.49
Rural	$PM_{0.1}$	0.52	0.93	2.96	2.96	2.96	2.96	2.96	3.67	2.96	0.49	0.25
Highway	$PM_{0.1}$	0.11	0.55	1.55	1.55	1.55	1.55	1.55	2.25	1.55	-	0.05

4.4 Heavy metal emission factors for Danish brake wear

The heavy metal emission factors for brake wear is calculated as the product of the metal contents in brake linings (Table 22) and the brake wear particulate emission factors shown in Table 25. The heavy metal emission factors are shown pr vehicle category and road type in Table 26 for total TSP. Annex 1 list the heavy metal emission factors for the other PM size fractions as well.

Table 26 Heavy metal emission factors for brake wear (µg pr km) pr vehicle category and road type (total TSP).

Emission component	Road type		Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	Motorcycles
As	All	TSP	0.076	0.137	0.390	0.390	0.390	0.340	0.340	0.489	0.390	0.062	0.042
As	Urban	TSP	0.125	0.195	0.547	0.547	0.547	0.547	0.547	0.547	0.547	0.062	0.062
As	Rural	TSP	0.065	0.116	0.370	0.370	0.370	0.370	0.370	0.458	0.370	0.062	0.032
As	Highway	TSP	0.014	0.069	0.193	0.193	0.193	0.193	0.193	0.282	0.193	-	0.007
Cd	All	TSP	0.075	0.134	0.120	0.120	0.120	0.104	0.104	0.148	0.118	0.061	0.042
Cd	Urban	TSP	0.123	0.192	0.168	0.168	0.168	0.168	0.168	0.165	0.165	0.061	0.061
Cd	Rural	TSP	0.063	0.114	0.114	0.114	0.114	0.114	0.114	0.138	0.112	0.061	0.031
Cd	Highway	TSP	0.014	0.068	0.059	0.059	0.059	0.059	0.059	0.085	0.058	-	0.007
Cr	All	TSP	0.801	1.441	6.388	6.388	6.388	5.576	5.576	3.133	2.494	0.650	0.446
Cr	Urban	TSP	1.318	2.056	8.969	8.969	8.969	8.969	8.969	3.501	3.501	0.650	0.650
Cr	Rural	TSP	0.679	1.225	6.069	6.069	6.069	6.069	6.069	2.935	2.369	0.650	0.335
Cr	Highway	TSP	0.146	0.726	3.169	3.169	3.169	3.169	3.169	1.803	1.237	-	0.072
Cu	All	TSP	800.039	1 438.911	293.623	293.623	293.623	256.297	256.297	670.210	533.387	649.224	445.593
Cu	Urban	TSP	1 315.995	2 052.953	412.267	412.267	412.267	412.267	412.267	748.913	748.913	649.224	649.224
Cu	Rural	TSP	677.698	1 223.167	278.959	278.959	278.959	278.959	278.959	627.831	506.750	649.224	334.331
Cu	Highway	TSP	145.784	725.295	145.651	145.651	145.651	145.651	145.651	385.668	264.586	-	71.920
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	0.802	1.442	4.440	4.440	4.440	3.876	3.876	7.782	6.193	0.651	0.447
Ni	Urban	TSP	1.319	2.057	6.234	6.234	6.234	6.234	6.234	8.695	8.695	0.651	0.651
Ni	Rural	TSP	0.679	1.226	4.219	4.219	4.219	4.219	4.219	7.290	5.884	0.651	0.335
Ni	Highway	TSP	0.146	0.727	2.203	2.203	2.203	2.203	2.203	4.478	3.072	-	0.072
Pb	All	TSP	105.486	189.722	15.853	15.853	15.853	13.837	13.837	35.752	28.453	85.601	58.752
Pb	Urban	TSP	173.515	270.684	22.258	22.258	22.258	22.258	22.258	39.950	39.950	85.601	85.601
Pb	Rural	TSP	89.355	161.276	15.061	15.061	15.061	15.061	15.061	33.491	27.032	85.601	44.082
Pb	Highway	TSP	19.222	95.631	7.864	7.864	7.864	7.864	7.864	20.573	14.114	-	9.483
Se	All	TSP	0.152	0.274	0.779	0.779	0.779	0.680	0.680	0.979	0.779	0.124	0.085
Se	Urban	TSP	0.251	0.391	1.094	1.094	1.094	1.094	1.094	1.094	1.094	0.124	0.124
Se	Rural	TSP	0.129	0.233	0.740	0.740	0.740	0.740	0.740	0.917	0.740	0.124	0.064
Se	Highway	TSP	0.028	0.138	0.386	0.386	0.386	0.386	0.386	0.563	0.386	-	0.014
Zn	All	TSP	153.536	276.143	292.651	292.651	292.651	255.448	255.448	456.916	363.637	124.593	85.514
Zn	Urban	TSP	252.554	393.984	410.902	410.902	410.902	410.902	410.902	510.572	510.572	124.593	124.593

Continued													
Zn	Rural	TSP	130.058	234.739	278.036	278.036	278.036	278.036	278.036	428.025	345.477	124.593	64.162
Zn	Highway	TSP	27.978	139.192	145.169	145.169	145.169	145.169	145.169	262.929	180.382	-	13.802

4.5 Heavy metal emissions for Danish brake wear

The heavy metal emissions for brake wear are calculated as the product of the total mileage pr vehicle category (Table 16) and the heavy metal emission factors for brake wear shown in Table 26. The heavy metal emissions are shown pr vehicle category and road type in Table 27 for total TSP. Annex 1 list the heavy metal emissions for other size fractions as well.

Table 27 Heavy metal emissions (kg) for brake wear pr vehicle category and road type (total TSP).

Emission component	Road type		Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Ur. buses	Coaches	Mopeds	Motorcycles	Total
As	All	TSP	2.968	1.740	0.004	0.135	0.087	0.531	0.560	0.290	0.149	0.015	0.039	6.518
As	Urban	TSP	1.709	0.869	0.002	0.061	0.039	0.162	0.171	0.165	0.067	0.012	0.027	3.283
As	Rural	TSP	1.156	0.740	0.002	0.060	0.039	0.260	0.274	0.111	0.066	0.003	0.011	2.723
As	Highway	TSP	0.103	0.132	0.000	0.014	0.009	0.109	0.115	0.013	0.016	-	0.001	0.511
Cd	All	TSP	2.911	1.707	0.001	0.041	0.027	0.163	0.172	0.088	0.045	0.014	0.038	5.208
Cd	Urban	TSP	1.676	0.853	0.001	0.019	0.012	0.050	0.053	0.050	0.020	0.012	0.026	2.770
Cd	Rural	TSP	1.134	0.726	0.001	0.019	0.012	0.080	0.084	0.034	0.020	0.003	0.011	2.123
Cd	Highway	TSP	0.101	0.129	0.000	0.004	0.003	0.033	0.035	0.004	0.005	-	0.001	0.315
Cr	All	TSP	31.221	18.308	0.065	2.212	1.434	8.703	9.184	1.858	0.953	0.155	0.409	74.502
Cr	Urban	TSP	17.974	9.142	0.029	0.994	0.644	2.660	2.807	1.059	0.428	0.125	0.280	36.144
Cr	Rural	TSP	12.165	7.781	0.029	0.988	0.640	4.263	4.498	0.714	0.426	0.029	0.120	31.653
Cr	Highway	TSP	1.081	1.384	0.007	0.230	0.149	1.780	1.879	0.086	0.099	-	0.009	6.705
Cu	All	TSP	31 181.875	18 285.286	2.997	101.686	65.919	400.039	422.153	397.489	203.850	154.715	408.617	51 624.627
Cu	Urban	TSP	17 952.038	9 130.927	1.347	45.688	29.618	122.262	129.021	226.525	91.590	125.319	279.815	28 134.148
Cu	Rural	TSP	12 150.258	7 771.832	1.338	45.405	29.435	195.935	206.766	152.666	91.025	29.396	119.569	20 793.626
Cu	Highway	TSP	1 079.579	1 382.527	0.312	10.593	6.867	81.842	86.366	18.299	21.235	0.000	9.233	2 696.853
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	31.250	18.325	0.045	1.538	0.997	6.050	6.384	4.615	2.367	0.155	0.410	72.136
Ni	Urban	TSP	17.991	9.151	0.020	0.691	0.448	1.849	1.951	2.630	1.063	0.126	0.280	36.201

Continued													
Ni	Rural	TSP	12.177	7.789	0.020	0.687	0.445	2.963	3.127	1.773	1.057	0.029	0.120	30.186
Ni	Highway	TSP	1.082	1.386	0.005	0.160	0.104	1.238	1.306	0.212	0.247	-	0.009	5.748
Pb	All	TSP	4 111.356	2 410.930	0.162	5.490	3.559	21.598	22.792	21.204	10.874	20.399	53.877	6 682.240
Pb	Urban	TSP	2 366.991	1 203.920	0.073	2.467	1.599	6.601	6.966	12.084	4.886	16.523	36.894	3 659.003
Pb	Rural	TSP	1 602.022	1 024.722	0.072	2.451	1.589	10.579	11.163	8.144	4.856	3.876	15.765	2 685.239
Pb	Highway	TSP	142.343	182.287	0.017	0.572	0.371	4.419	4.663	0.976	1.133	-	1.217	337.998
Se	All	TSP	5.935	3.481	0.008	0.270	0.175	1.061	1.120	0.581	0.298	0.029	0.078	13.036
Se	Urban	TSP	3.417	1.738	0.004	0.121	0.079	0.324	0.342	0.331	0.134	0.024	0.053	6.567
Se	Rural	TSP	2.313	1.479	0.004	0.120	0.078	0.520	0.549	0.223	0.133	0.006	0.023	5.447
Se	Highway	TSP	0.205	0.263	0.001	0.028	0.018	0.217	0.229	0.027	0.031	-	0.002	1.022
Zn	All	TSP	5 984.147	3 509.149	2.987	101.349	65.701	398.715	420.756	270.989	138.975	29.692	78.418	11 000.878
Zn	Urban	TSP	3 445.195	1 752.326	1.342	45.536	29.520	121.857	128.594	154.434	62.442	24.050	53.700	5 818.995
Zn	Rural	TSP	2 331.769	1 491.501	1.334	45.255	29.337	195.287	206.082	104.080	62.056	5.641	22.947	4 495.289
Zn	Highway	TSP	207.183	265.322	0.311	10.558	6.844	81.571	86.080	12.475	14.477	-	1.772	686.594

4.6 Assessment of wear rates for brakes

It has been outside the present project to carry out experimental studies. However, in order to get an overall feeling for the level of brake wear rates for vehicles in the Danish traffic, a rough examination of wear rates were carried out for passenger cars and heavy duty vehicles. Brake linings were examined for passenger cars, trucks and buses, and brake discs were examined for trucks and buses only.

4.6.1 Brake linings

Table 28 lists the data for the duration and wear of brakes estimated by the Federation of Danish Motorists (FDM, 2006c). FDM (2006c) expects that brakes are worn 70 % in front and 35 % in rear within an average mileage of 55 000 km.

Measurements of front brake pads for Peugeot 307 and Fiat Uno gave weights of 379g and 259g, respectively[5]. After consulting FDM (2006a) it is perceived that the brake pads for Peugeot, a very common sold car in Denmark, is a reasonable representation of the average of the Danish passenger car fleet, while the Fiat brake pads is in the lower end representing smaller cars.

The rear brake is estimated having half the weight and dimension of the front pads. The brake lining is glued to a holder that for the measured pads does about ¼ out of the total thickness. Assuming the same mass density for the holder and the lining, the weight of the brake lining for a Peugeot pad is ¾ of 380g, or 285 g, and so the half, 143 g for the rear pad lining.

Table 28 Brake lining wear rates for passenger cars estimated from rough experimental data.

Front	A	Life time	km	55000
		No. of axles		1
		No. of brakes		2
	B	No. of pads		4
	C	Weight/pad	kg	0.285
		Total pad weight		1.14
	D	Wear-%		70
	(BxCxD)/A	Wear factor	Mg pr vkm	15
Back	A	Life time	Km	55000
		No. of axles		1
		No. of brakes		2
	B	No. of pads		4
	C	Weight/pad	Kg	0.143
		Total pad weight		0.572
	D	Wear-%		35
	(BxCxD)/A	Wear factor	Mg pr vkm	4
		Wear factor, total	Mg pr vkm	18

[5] Measured at T Hansen (Peugeot), Copenhagen S. and Svend Engstrøm (Fiat), Copenhagen N.

The resulting wear rate of 18 mg pr vkm for passenger cars from Table 28 is very similar to the values proposed by Legret and Pagotto (1999), Westerlund (2001) and Garg et al. (2000), see Table 30. The proposed wear rate is assumed to be the same for cars equipped with rear drum brakes.

The EMEP/CORINAIR (2007) methodology is not fully transparent in the documentation of the selected TSP emission factors and in the brake wear rates, which is the underlying basis. However, using the assumption from Westerlund and Johansson (2002) and Garg et al. (2000) which estimates airborne TSP suspended into the air to be 35 % of total metal wear from brakes, a wear rate of 22 mg pr vkm is estimated (Table 30). This figure is reasonably in line with the rough estimate from Table 28, and the published data by Legret and Pagotto (1999), Westerlund (2001) and Garg et al (2000).

From Skifter Lastbil, a large Danish company dealing with repair, conversion, service and sales of new and used Volvo trucks, brake wear data for trucks have been provided (Boisen, 2007). Brake wear data for buses and coaches have been provided by Volvo Truck Denmark (Koch, 2007).

Table 29 Brake lining wear rates for heavy duty vehicles estimated in the present study.

	Eq. parameter	Parameter	Unit	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Buses	Coaches
Front	A	Life time/pad	Km	350 000	350 000	450 000	450 000	70 000	350 000
		No. of axles		1	1	1	1	1	1
		No. of brakes		2	2	2	2	2	2
	B	No. of pads		4	4	4	4	4	4
	C	Area/pad	cm2	160	160	192	192	170	170
	D	Wear	Cm	1.7	1.7	1.7	1.7	1.6	1.6
	E	Density/pad	G pr cm3	3.00	3.00	3.00	3.00	3.00	3.00
	(BxCxDxE)/A	Wear factor	Mg pr vkm	9	9	9	9	47	9
Back	A	Life time/pad	Km	350 000	350 000	450 000	450 000	70 000	350 000
		No. of axles		1	1	1.5	3	1	2
		No. of brakes		2	2	3	6	2	4
	B	No. of pads		4	4	6	12	4	8
	C	Area/pad	Kg	160	160	192	192	170	170
	D	Wear	Cm	1.7	1.7	1.7	1.7	1.6	1.6
	E	Density/pad	G pr cm3	3.00	3.00	3.00	3.00	3.00	3.00
	(BxCxDxE)/A	Wear factor	Mg pr vkm	9	9	13	26	47	19
		Wear factor, total	Mg pr vkm	19	19	22	35	93	28

The derived wear factors for heavy duty trucks from Table 29 are considerably lower than the factors suggested by Westerlund (2001) and Legret and Pagotto (Table 30), and those EMEP/CORINAIR based factors that can be derived from the current Danish inventory. It is not possible to explain why these considerable differences exist. In the case of urban buses there is a rather fine harmony between the Danish data based on experience from daily operation and the factor proposed by Westerlund (2001) and EMEP/CORINAIR (2007).

The average wear rates for heavy duty trucks obtained from Danish sources are surprisingly different from the scarce data available from the literature, and these data differences point out the need for further surveys, in order to improve the knowledge in relation to wear rates for brakes.

An additional contribution from wear of brake disc and drums (see following paragraph) cannot explain the differences between the Danish data and the literature values from Westerlund (2001) and Legret and Pagotto (1999), since the latter sources do not include brake disc and drums in their reported figures.

Table 30 Brake lining wear rates from various sources.

Vehicle type	Luhana et al. (2004) Total wear Mg pr v-km	Legret and Pagotto (1999) Total wear Mg pr v-km	Garg et al. (2000) Total wear Mg pr v-km	Westerlund (2001) Total wear Mg pr v-km	EMEP/CORINAIR (Danish inventory) Total wear Mg pr v-km
Passenger cars	8.8	20	11-17 (small-large)	17	22
LDVs		29	29		39
HDVs		47		84*	99
Busses				110	129

*4-wheel brake HDV>10 tonnes.

4.6.2 Brake disc and drums

Brake disc and drums do not seem included in various studies on brake wear, probably because they were worn less in earlier days, because of softer pads. The main material of discs is cast iron, that is, iron and a few percent of carbon. Other metals are often included giving various qualities of the cast iron, e.g. cadmium and nickel can be included along with molybdenum in Pearlitic iron[6] (Key-to-steel, 2006).

The wear rate of the brake drum is estimated as being the same as for the brake disc. The disc and drum wear is not highly relevant for the present study focusing on metal emissions reported to the UNECE convention, since most material is iron and carbon. Although chromium and nickel may be present in some amounts, it has not been possible to get precise information on the metal speciation.

For brake linings, Boisen (2007) and Koch (2007) has provided wear data for brake discs mounted on Volvo heavy duty trucks and buses, respectively.

[6] Pearlitic iron may contain 0,5-2 % nickel, chromium up to 0,8 % and molybdenum up to 0,6, according to Key-to-steel (2006).

Table 31 Brake disc/drum wear rates for heavy duty vehicles estimated in the present study.

	Parameter	Unit	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Buses	Coaches
Front	Life time/disc	Km	1 000,000	1 000,000	1 000,000	1 000,000	300,000	1 000,000
	No. of axles		1	1	1	1	1	1
	No. of brakes		2	2	2	2	2	2
	No. of discs		2	2	2	2	2	2
	Wear track inner radius	Cm	11.5	11.5	13.0	13.0	13.0	13.0
	Wear track outer radius	Cm	19.0	19.0	21.5	21.5	21.5	21.5
	Wear track, width	Cm	7.5	7.5	8.5	8.5	8.5	8.5
	Wear track, depth	Cm	0.25	0.25	0.25	0.25	0.25	0.25
	Wear track/disc		2	2	2	2	2	2
	Density, iron	G pr cm3	7.9	7.9	7.9	7.9	7.9	7.9
	Wear mass/disc	G	2 837	2 837	3 637	3 637	3 637	3 637
	Wear mass, total	G	5 674	5 674	7 274	7 274	7 274	7 274
	Wear rate	Mg pr vkm	5.7	5.7	7.3	7.3	24.2	7.3
Back	Life time/disc	Km	1 000,000	1 000,000	1 000,000	1 000,000	300,000	1 000,000
	No. of axles		1	1	1.5	3	1	2
	No. of brakes		2	2	3	6	2	4
	No. of discs		2	2	3	6	2	4
	Wear track inner radius	Cm	11.5	11.5	13.0	13.0	13.0	13.0
	Wear track outer radius	Cm	19.0	19.0	21.5	21.5	21.5	21.5
	Wear track, width	Cm	7.5	7.5	8.5	8.5	8.5	8.5
	Wear track, depth	Cm	0.25	0.25	0.25	0.25	0.25	0.25
	Wear track/disc		2	2	2	2	2	2
	Density, iron	G pr cm3	7.9	7.9	7.9	7.9	7.9	7.9
	Wear mass/disc	G	2 837	2 837	3 637	3 637	3 637	3 637
	Wear mass, total	G	5 674	5 674	10 912	21 823	7 274	14 549
	Wear rate	Mg pr vkm	5.7	5.7	10.9	21.8	24.2	14.5
	Wear rate, total	Mg pr vkm	11	11	18	29	48	22

Using the assumption that 35 % of total wear is being emitted as airborne TSP it is concluded that, in general, the combined wear factors for brake pads and disc/drums for heavy duty vehicles are closer to the wear factors from EMEP/CORINAIR (2007), than the wear factors derived for brake pads alone. For urban buses, though, the latter factors are almost similar to the EMEP/CORINAIR based ones.

5 Road abrasion

The major component in asphalt is quartz SiO_2 stemming from sand and stone fillers. Other major components are Al, Fe, Ca, K, Mn, Mg och Ti, while trace elements are Ba, Sr, Zr, Zn, V, Pb and Cr. Bitumen, a viscous oil product consisting of asphaltenes and oils, present in 4-8 % w/w, is used as a binding and strengthen agent. (Lindgren, 1996).

Bitumen is part of raw oil, in various percentages, depending on origin. South American (Venezuelan) oil may content 60-75 % bitumen, oil from the Middle East 25-30 % and oil from the North Sea only 1 %, reflecting the algae types in past time turned into oil. The usual 16 PAHs, including the six Borneff components, reported to various international authorities are not present in significant amounts (Danish Road Directorate, 2006).

Road abrasion is influenced by various factors: vehicle speed, climate, moistness of the road and type of asphalt and share of heavy duty vehicles and of tyre studs (Johansson and Burman, 2006). Studs, which is a major source of road abrasion is, however, not used in Denmark.

5.1 Metal contents in asphalt material

Different heavy metal species are present in both bitumen and mineral filler materials. Gustafsson (2001) finds that road dust from Swedish roads reflects the asphalt composition of 95 % minerals and 5 % bitumen. Also Danish asphalt assumed containing 5 % w.t. bitumen on average (Danish Road Directorate, 2006).

Table 32 shows metal content in bitumen from Gustafsson (2001), referring data from Lindgren (1996), Bækken (1993) and Herrington (1993). Based on these figures, data is derived to be used in the present survey, and these estimated values are also shown in Table 28.

Table 32 Heavy metal content in Asphalt binder (~bitumen).

Emission component	Lindgren (1996) ppm	Bækken (1993) Ppm	Herrington (1993) ppm	Fauser (1999) ppm	NERI ppm
Cr	< 35		1,7		1,7
Cu	< 17		< 0.4		0.3
Fe	< 24	12-30			
Ni	23	15-100			23
V	336	50-600			
Zn	< 17		10	546	546

The varying value may reflect varying origins of the bitumen and thus varying natural occurrences of metals. Also, it may reflect varying definitions of "bitumen"[7].

In the case of zinc it must be noted that the experimental method of determining the metal content in bitumen is very sensitive to the total results measured.

Fauser (1999) reports three samples of bitumen in Denmark analysing for zinc using a method, which extracts total amount of zinc (divided into an organic and a non organic fraction). The amount of total zinc in bitumen varies from 309 to 948 µg pr g, with an average value of 546 µg pr g. In the organic part, however, the average value was only 21.7 µg pr g. Herrington (1993) and Lindgren (1996) also have measured data close to zero, and hence it becomes unlikely that these latter studies also measure the non organic part. In the present study it is thus decided to rely on the metal content figures measured by Fauser (1999) in the case of zinc.

Granite is the most often used material in Danish asphalt, because of its roughness qualities. SiO_2 composition is about 65-73 %, giving about 35 w.t. % silicon. Table 33 lists the composition of granite from South Sweden based on several analyses (Klint, 2001). Other rock types also used in Danish asphalt may vary in metal content, however compared to other rock composition data in Klint, 2001, quartz and porphyry contains about the same amounts of the listed metals.

Table 33 Metal content of granite from Klint (2001).

Metal content in granite	Co	Cr	Cu	Ni	Pb	V	Zn	Cd	Hg
Mg pr kg	3.9	20.8	10.5	15.5	49.5	26.8	50.8	0.1	0.06

Table 34 Road abrasion metal speciation (mg pr kg).

	Metal speciation		
Emission component	Filler (95 %) Mg pr kg	Binder (5 %) Mg pr kg	Total Mg pr kg
Cr	20.8	1.7	19.8
Cu	10.5	0.3	10.0
Ni	15.5	23	15.9
Pb	49.5	-	47.0
Zn	50.8	546	75.6
Cd	0.10	-	0.10
Hg	0.06	-	0.06

5.2 Airborne particulate fractions of Danish road abrasion

The road abrasion factors for TSP, PM_{10} and $PM_{2.5}$ shown in Table 35 come from the current Danish inventory, based on the EMEP/CORIN-

[7] In the literature, it is not precisely defined if "bitumen" is perceived as only bitumen, or the binding material in asphalt that also may include chalk and sand minerals – this may cause some confusions and errors.

AIR (2007) data and method. The PM_{10} and $PM_{2.5}$ mass fractions of TSP are explicitly shown in Table 36.

Table 35 Airborne particulate fractions of Danish road abrasion (mg pr km) pr vehicle category and particle size class.

Road type	Particle size class	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	MC
All	TSP	0.0150	0.015	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.006	0.006
All	PM_{10}	0.0075	0.0075	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0030	0.0030
All	$PM_{2.5}$	0.0041	0.0041	0.0205	0.0205	0.0205	0.0205	0.0205	0.0205	0.0205	0.0016	0.0016

Table 36 Mass fractions of TSP for road abrasion (from EMEP/CORINAIR (2007)).

Particle size class	Mass fraction of TSP
TSP	1.000
PM_{10}	0.500
$PM_{2.5}$	0.270

5.3 Heavy metal emission factors for Danish road abrasion

The heavy metal emission factors for road abrasion are calculated as the product of the metal contents in asphalt material (Table 34) and the road abrasion particulate emission factors shown in Table 35. The heavy metal emission factors are shown pr vehicle category and road type in Table 37 for total TSP, PM_{10} and $PM_{2.5}$.

Table 37 Heavy metal emission factors for road abrasion (µg pr km) pr vehicle category and road type (total TSP).

Emission component	Particle size class	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	MC
As	TSP	-	-	-	-	-	-	-	-	-	-	-
Cd		0.001	0.001	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.001	0.001
Cr		0.298	0.298	1.508	1.508	1.508	1.508	1.508	1.508	1.508	0.119	0.119
Cu		0.150	0.150	0.759	0.759	0.759	0.759	0.759	0.759	0.759	0.060	0.060
Hg		0.001	0.001	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.000	0.000
Ni		0.238	0.238	1.207	1.207	1.207	1.207	1.207	1.207	1.207	0.095	0.095
Pb		0.705	0.705	3.574	3.574	3.574	3.574	3.574	3.574	3.574	0.282	0.282
Se		-	-	-	-	-	-	-	-	-	-	-
Zn		1.133	1.133	5.743	5.743	5.743	5.743	5.743	5.743	5.743	0.453	0.453
As	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Cd		0.001	0.001	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.000	0.000
Cr		0.149	0.149	0.754	0.754	0.754	0.754	0.754	0.754	0.754	0.060	0.060
Cu		0.075	0.075	0.380	0.380	0.380	0.380	0.380	0.380	0.380	0.030	0.030
Hg		0.000	0.000	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.000	0.000
Ni		0.119	0.119	0.603	0.603	0.603	0.603	0.603	0.603	0.603	0.048	0.048
Pb		0.353	0.353	1.787	1.787	1.787	1.787	1.787	1.787	1.787	0.141	0.141
Se		-	-	-	-	-	-	-	-	-	-	-
Zn		0.567	0.567	2.871	2.871	2.871	2.871	2.871	2.871	2.871	0.227	0.227
As	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Cd		0.000	0.000	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.000	0.000
Cr		0.080	0.080	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.032	0.032
Cu		0.040	0.040	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.016	0.016
Hg		0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000
Ni		0.064	0.064	0.326	0.326	0.326	0.326	0.326	0.326	0.326	0.026	0.026
Pb		0.190	0.190	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.076	0.076
Se		-	-	-	-	-	-	-	-	-	-	-
Zn		0.306	0.306	1.550	1.550	1.550	1.550	1.550	1.550	1.550	0.122	0.122

5.4 Heavy metal emissions for Danish road abrasion

The heavy metal emissions for brake wear are calculated as the product of the total mileage pr vehicle category (Table 16) and the heavy metal emission factors for brake wear shown in Table 37. The heavy metal emissions are shown pr vehicle category and road type in Table 38 for total TSP, PM_{10} and $PM_{2.5}$.

Table 38 Heavy metal emissions (kg) for road abrasion (kg) pr vehicle category and road type for total TSP, PM_{10} and $PM_{2.5}$.

Emission component	Particle size class	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	MC	Total
As	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Cd		0.056	0.018	0.000	0.003	0.002	0.011	0.012	0.004	0.003	0.000	0.001	0.109
Cr		11.602	3.783	0.015	0.522	0.339	2.354	2.484	0.894	0.576	0.028	0.109	22.708
Cu		5.840	1.904	0.008	0.263	0.170	1.185	1.251	0.450	0.290	0.014	0.055	11.431
Hg		0.033	0.011	0.000	0.002	0.001	0.007	0.007	0.003	0.002	0.000	0.000	0.065
Ni		9.281	3.026	0.012	0.418	0.271	1.883	1.987	0.716	0.461	0.023	0.087	18.165
Pb		27.492	8.964	0.036	1.238	0.802	5.578	5.887	2.120	1.366	0.067	0.259	53.809
Se		-	-	-	-	-	-	-	-	-	-	-	-
Zn		44.175	14.403	0.059	1.989	1.289	8.963	9.459	3.406	2.195	0.108	0.416	86.461
As	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Cd		0.010	0.003	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.017
Cr		2.030	0.662	0.002	0.084	0.054	0.224	0.236	0.228	0.092	0.011	0.026	3.650
Cu		1.022	0.333	0.001	0.042	0.027	0.113	0.119	0.115	0.046	0.006	0.013	1.837
Hg		0.006	0.002	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.010
Ni		1.624	0.530	0.002	0.067	0.043	0.179	0.189	0.182	0.074	0.009	0.021	2.920
Pb		4.811	1.569	0.006	0.198	0.128	0.530	0.559	0.541	0.219	0.027	0.061	8.648
Se		-	-	-	-	-	-	-	-	-	-	-	-
Zn		7.731	2.521	0.009	0.318	0.206	0.852	0.899	0.868	0.351	0.044	0.098	13.896
As	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Cd		0.007	0.002	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.014
Cr		1.441	0.511	0.002	0.066	0.043	0.286	0.302	0.099	0.073	0.001	0.011	2.836
Cu		0.725	0.257	0.001	0.033	0.022	0.144	0.152	0.050	0.037	0.001	0.006	1.428
Hg		0.004	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.008
Ni		1.153	0.409	0.002	0.053	0.034	0.229	0.241	0.079	0.059	0.001	0.009	2.269
Pb		3.415	1.210	0.005	0.157	0.102	0.678	0.715	0.235	0.173	0.003	0.027	6.720
Se		-	-	-	-	-	-	-	-	-	-	-	-
Zn		5.487	1.944	0.007	0.252	0.164	1.089	1.149	0.377	0.279	0.006	0.044	10.797

6 Results summary

6.1 Emissions pr source category and vehicle type

The calculated heavy metal emissions for Danish road transport in 2007 are summarised in Table 39 pr emission type and vehicle category.

Table 39 Summary table of heavy metal emissions (kg) pr vehicle category and emission source category (total TSP).

	Emission type	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban Buses	Coaches	Mopeds	Motorcycles	Total
As	Fuel	0.540	0.104	0.001	0.003	0.003	0.033	0.047	0.015	0.009	0.001	0.009	0.763
	Eng. oil	-	-	-	-	-	-	-	-	-	-	-	-
	Tyre wear	0.338	0.174	0.000	0.008	0.008	0.074	0.093	0.030	0.017	0.003	0.013	0.758
	Brake wear	2.968	1.740	0.004	0.135	0.087	0.531	0.560	0.290	0.149	0.015	0.039	6.518
	Road abrasion	-	-	-	-	-	-	-	-	-	-	-	-
Cd	Fuel	0.351	0.056	0.000	0.001	0.002	0.016	0.023	0.007	0.004	0.001	0.006	0.468
	Eng. oil	24.337	7.599	0.015	0.518	0.336	2.333	2.462	0.965	0.622	-	0.194	39.381
	Tyre wear	1.097	0.566	0.001	0.026	0.025	0.240	0.303	0.098	0.056	0.009	0.042	2.463
	Brake wear	2.911	1.707	0.001	0.041	0.027	0.163	0.172	0.088	0.045	0.014	0.038	5.208
	Road abrasion	0.056	0.018	0.000	0.003	0.002	0.011	0.012	0.004	0.003	0.000	0.001	0.109
Cr	Fuel	14.829	7.301	0.011	0.236	0.269	2.783	3.965	1.268	0.728	0.027	0.181	31.599
	Eng. oil	50.218	7.703	0.038	0.466	0.302	2.100	2.216	0.868	0.560	-	0.485	64.957
	Tyre wear	1.520	0.783	0.001	0.035	0.034	0.332	0.420	0.136	0.078	0.012	0.058	3.410
	Brake wear	31.221	18.308	0.065	2.212	1.434	8.703	9.184	1.858	0.953	0.155	0.409	74.502
	Road abrasion	11.602	3.783	0.015	0.522	0.339	2.354	2.484	0.894	0.576	0.028	0.109	22.708
Cu	Fuel	10.389	4.918	0.008	0.158	0.181	1.866	2.659	0.851	0.488	0.019	0.129	21.667
	Eng. oil	55.096	25.677	0.027	1.812	1.175	8.167	8.618	3.377	2.176	-	0.349	106.474
	Tyre wear	6.585	3.395	0.005	0.153	0.149	1.437	1.820	0.590	0.338	0.053	0.253	14.777
	Brake wear	31 181.875	18 285.286	2.997	101.686	65.919	400.039	422.153	397.489	203.850	154.715	408.617	51 624.627
	Road abrasion	5.840	1.904	0.008	0.263	0.170	1.185	1.251	0.450	0.290	0.014	0.055	11.431
Hg	Fuel	16.970	4.925	0.016	0.147	0.168	1.735	2.473	0.791	0.454	0.038	0.249	27.965
	Eng. oil	-	-	-	-	-	-	-	-	-	-	-	-
	Tyre wear	-	-	-	-	-	-	-	-	-	-	-	-
	Brake wear	-	-	-	-	-	-	-	-	-	-	-	-
	Road abrasion	0.033	0.011	0.000	0.002	0.001	0.007	0.007	0.003	0.002	0.000	0.000	0.065
Ni	Fuel	3.832	0.340	0.004	0.006	0.006	0.065	0.093	0.030	0.017	0.010	0.066	4.469
	Eng. oil	24.337	7.599	0.015	0.518	0.336	2.333	2.462	0.965	0.622	-	0.194	39.381
	Tyre wear	10.763	5.550	0.007	0.250	0.243	2.349	2.975	0.964	0.552	0.086	0.414	24.155
	Brake wear	31.250	18.325	0.045	1.538	0.997	6.050	6.384	4.615	2.367	0.155	0.410	72.136

Continued

	Road abrasion	9.281	3.026	0.012	0.418	0.271	1.883	1.987	0.716	0.461	0.023	0.087	18.165
Pb	Fuel	2.215	0.494	0.002	0.014	0.016	0.164	0.233	0.075	0.043	0.005	0.034	3.295
	Eng. oil	126.102	24.417	0.092	1.553	1.007	7.000	7.387	2.894	1.865	-	1.164	173.481
	Tyre wear	33.978	17.519	0.023	0.790	0.768	7.417	9.392	3.044	1.743	0.272	1.307	76.254
	Brake wear	4 111.356	2 410.930	0.162	5.490	3.559	21.598	22.792	21.204	10.874	20.399	53.877	6 682.240
	Road abrasion	27.492	8.964	0.036	1.238	0.802	5.578	5.887	2.120	1.366	0.067	0.259	53.809
Se	Fuel	0.378	0.096	0.000	0.003	0.003	0.033	0.047	0.015	0.009	0.001	0.006	0.590
	Eng. oil	-	-	-	-	-	-	-	-	-	-	-	-
	Tyre wear	8.442	4.353	0.006	0.196	0.191	1.843	2.333	0.756	0.433	0.068	0.325	18.945
	Brake wear	5.935	3.481	0.008	0.270	0.175	1.061	1.120	0.581	0.298	0.029	0.078	13.036
	Road abrasion	-	-	-	-	-	-	-	-	-	-	-	-
Zn	Fuel	63.223	16.995	0.060	0.500	0.570	5.893	8.397	2.686	1.543	0.143	0.946	100.954
	Eng. oil	4 867.441	1 519.768	3.052	103.543	67.123	466.669	492.466	192.962	124.344	-	38.786	7 876.154
	Tyre wear	3 388.959	1 747.364	2.322	143.131	139.180	1 343.947	1 701.887	551.519	315.909	27.106	130.382	9 491.706
	Brake wear	5 984.147	3 509.149	2.987	101.349	65.701	398.715	420.756	270.989	138.975	29.692	78.418	11 000.878
	Road abrasion	44.175	14.403	0.059	1.989	1.289	8.963	9.459	3.406	2.195	0.108	0.416	86.461
As	Total	3.845	2.018	0.005	0.146	0.098	0.637	0.700	0.335	0.175	0.019	0.060	8.038
Cd	Total	28.753	9.946	0.018	0.589	0.390	2.764	2.973	1.163	0.730	0.024	0.281	47.629
Cr	Total	109.389	37.879	0.131	3.472	2.378	16.271	18.270	5.026	2.895	0.223	1.242	197.177
Cu	Total	31 259.785	18 321.180	3.045	104.072	67.594	412.694	436.501	402.757	207.143	154.802	409.404	51 778.976
Hg	Total	17.003	4.936	0.016	0.149	0.169	1.742	2.480	0.793	0.456	0.038	0.250	28.030
Ni	Total	79.464	34.839	0.084	2.729	1.853	12.681	13.902	7.290	4.019	0.274	1.171	158.306
Pb	Total	4 301.144	2 462.325	0.315	9.085	6.152	41.757	45.691	29.336	15.891	20.744	56.640	6 989.079
Se	Total	14.755	7.929	0.014	0.469	0.369	2.937	3.500	1.352	0.739	0.098	0.408	32.570
Zn	Total	14 347.945	6 807.679	8.479	350.512	273.864	2 224.187	2 632.965	1 021.562	582.966	57.048	248.947	28 556.153

6.2 Emissions pr source category

The heavy metal emissions (total TSP) are shown in Figure 4 pr emission source category for Danish road transport in 2007.

Almost all Hg emissions (100 % as a rounded share) come from fuel usage, and for Cr and As the emission shares are 16 and 9 %, respectively. For fuel all other emission shares are insignificant (between 0 % and 3 %).

For engine oil the largest emission shares are noted for Cd (83 %) and engine oil also has substantial emission shares of Cr (33 %), Zn (28 %) and Ni (25 %).

For tyre wear the most important emissions are Se, Zn and Ni. The respective emission shares for these heavy metal components are 58 %, 33 % and 15 %.

Brake wear is the most important source of emissions for Cu (100 %), Pb (96 %), As (82 %), Ni (46 %), Zn (39 %) and Cr (37 %). For Se the brake wear emission share is 40 %.

For road abrasion the most important emission species are Cr and Ni, which have emission shares of 12 and 11 %, respectively. The road abrasion emission shares of other emission components are between 0 % and 1 %.

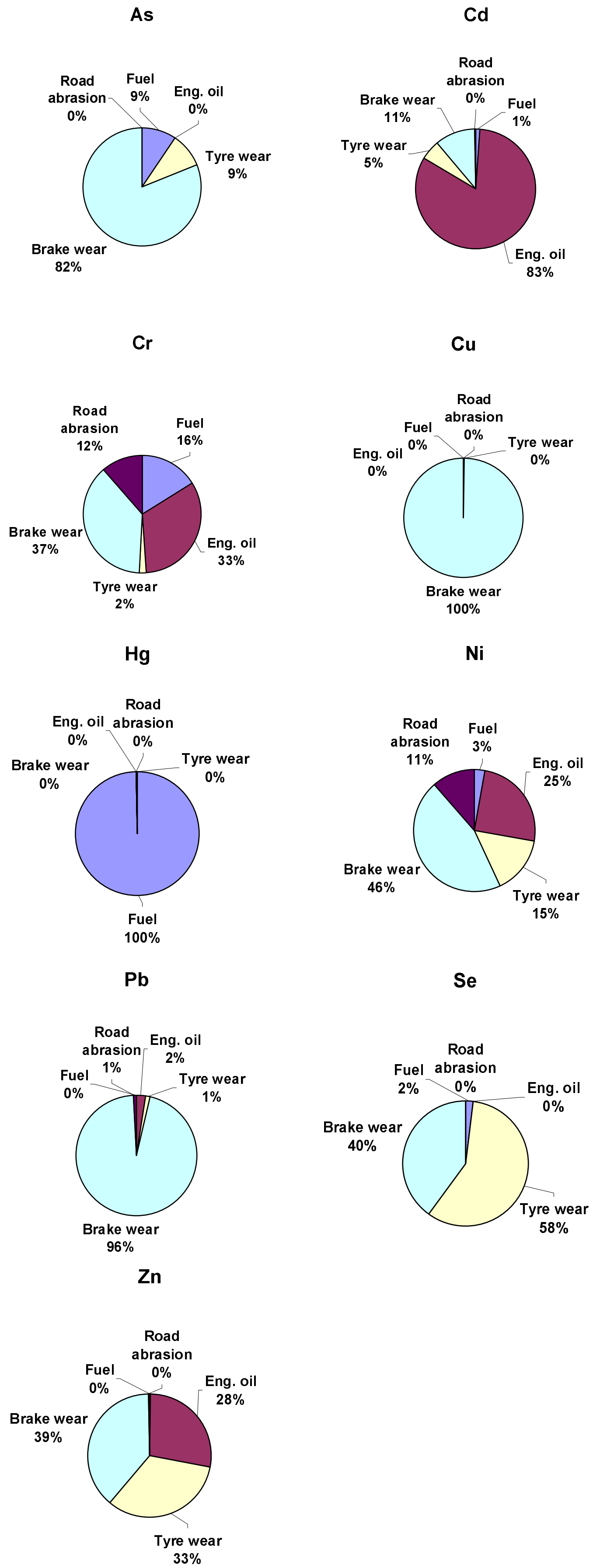

Figure 4 Heavy metal emissions (total TSP) per source category for Danish road transport in 2007.

6.3 Emissions pr vehicle type

Cars are the largest source of emission for all heavy metal species (Figure 5). The emission shares range between 62 % (Pb) and 46 % (Se) for cars are, however, somewhat smaller than the 68 % share of total mileage driven for this vehicle category. For vans, trucks, buses and two-wheelers, the total mileage shares are 22 %, 7 %, 2 % and 2 %, respectively.

The specific vehicle category activity/emission source category combinations and the related emission factors determine the total emissions for each vehicle type/emission source. For most heavy metal species the emission shares for trucks and buses are considerably higher than their share of total mileage. Trucks and buses use more fuel and engine oil and have higher brake, tyre and road wear emissions pr km driven, with Pb and Cu as an exception for brake wear.

The highest emission shares for passenger cars noted for Pb and Cu, 62 % and 61 %, respectively, are due to a relatively high metal content of these two metal species in brake linings. The same type of brake lining is assumed being used for vans also, and hence the van emissions are significant (35 %) for these two emission components also.

In general terms vans are the second most important source of emission. The emissions from vans are slightly higher than the emissions from trucks for all species of heavy metals except for Cr. In the latter case, the total truck emissions are higher than the total emissions from vans. Buses are only a minor source of heavy metal emissions and the emission contributions from two-wheelers are almost insignificant (between 1-2 %).

The major part of Cd emissions stem from engine oil, and the Cd content in engine oil is found to equal gasoline and diesel fuelled engines. The engine oil consumption for trucks and buses are around three times as high as for passenger cars and vans (Figure 2) and thus the Cd emissions shares for trucks (14 %) and buses (4 %) become significantly higher than their actual shares of total mileage.

For Cr, the large engine oil consumption for trucks and the relatively higher emission factors for brake wear and road abrasion for trucks (Table 26) compared to vans, are the major reasons why the emission share for trucks (21 %) is higher than the emission share for vans.

The content of Hg in fuel is higher for gasoline than for diesel, and hence the emission shares pr vehicle category become relatively higher than the share of fuel consumption, for these vehicle categories that have a relatively high gasoline consumption. For cars, vans, trucks and buses the Hg emission shares are 61 %, 18 %, 16 % and 4 %, respectively.

In the case of Se, the tyre wear emission factors for trucks, buses and two-wheelers are relatively higher than the ones for passenger cars. This is also the case for vans, trucks and buses in relation to brake wear. Hence the emission shares for trucks (22 %), buses (6 %) and two-wheelers (2 %) become significantly higher than their total mileage shares.

For As, the relatively higher brake wear emission factors and fuel consumption factors for heavy duty vehicles compared to passenger cars, explain why the emission shares for trucks (20 %) and buses (6 %) become significantly higher than their share of total mileage.

For Ni and Zn, it is the specific vehicle category activity/emission source category combinations and the related emission factors, which explains the emission share values for each individual vehicle type. For cars, vans, trucks and buses, the Ni[Zn] emission shares are 50 %[50 %], 22 %[24 %], 20 %[19 %] and 7 %[6 %], respectively.

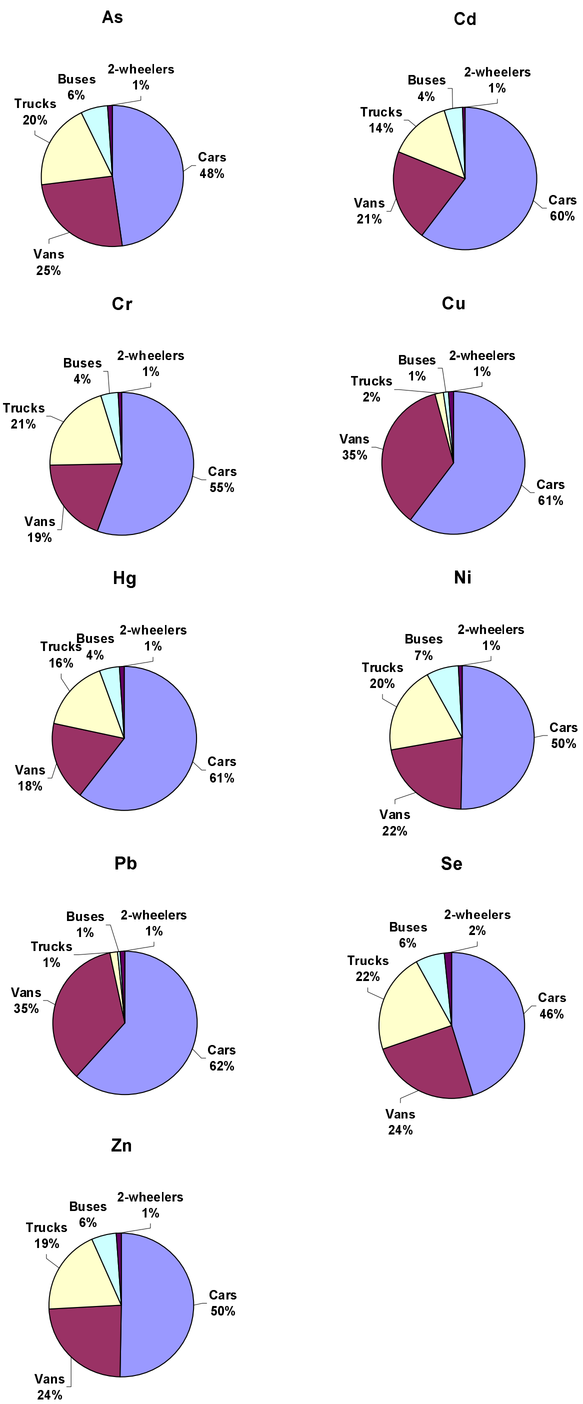

Figure 5 Heavy metal emissions (total TSP) per vehicle type category for Danish road transport in 2007.

6.4 Comparing emission estimates from previous inventory and present study

The previous Danish heavy metal emission inventories for road transport comprise the emission estimates for fuel consumption and engine wear/engine oil (see Chapter 3.6).

The heavy metal emission estimates from the previous inventory and the present study are shown in Table 40, as well as the percentage differences between the new and previous estimates.

The emission difference between the new and the previous inventory for Pb is huge (around 10000 %) due to the emissions from brake wear. For Cu and Zn, large emission differences of around 600 % are noted. Brake wear is a very dominant emission source for Cu also, whereas for Zn, brake and tyre wear and engine oil all are important sources of emissions. For fuel/engine oil alone, the new Zn and Pb estimates would be 91 % and 155 % higher, respectively, and the Cu estimate would be 98 % lower, compared with the previous figures (see Chapter 6.3).

For Cr, Se and Ni, respectively, the new emission estimates are 5 %, 22 % and 46 % lower than the previous ones. To some extent, the emission contribution from the new complimentary sources, tyre wear, brake wear and road abrasion, equals out the emission differences. Zero or relatively small emission contributions are calculated for fuel and engine oil alone.

Table 40 Previous Danish emission estimates and difference in percent between new and previous estimate in 2007.

Emission component	Previous inv.	Fuel	Engine oil	Tyre wear	Brake wear	Road abrasion	Total	New:Previous % diff.
As	0.0	0.8	-	0.8	6.5	-	8.0	-
Cd	41.7	0.5	39.4	2.5	5.2	0.1	47.6	14
Cr	208.3	31.6	65.0	3.4	74.5	22.7	197.2	-5
Cu	7 081.7	21.7	106.5	14.8	51 624.6	11.4	51 779.0	631
Hg	0.0	28.0	-	-	-	0.1	28.0	-
Ni	291.6	4.5	39.4	24.2	72.1	18.2	158.3	-46
Pb	69.3	3.3	173.5	76.3	6 682.2	53.8	6 989.1	9 992
Se	41.7	0.6	-	18.9	13.0	-	32.6	-22
Zn	4 165.7	101.0	7 876.2	9 491.7	11 000.9	86.5	28 556.2	586

6.5 Road transport share of Danish total emissions

The new heavy metal emission estimates for road transport are shown in Table 41, as well as the revised Danish emission total including road transport, and the road transport share of the revised Danish emission total. Road transport is a key source for Cu, Zn and Pb, and of some relevance for Cr. It appears from Table 41 that as much as 95 % of the Danish emissions of Cu originate from road transport activities, and for Zn, Pb and Cr the road transport emission shares are 54 %, 53 % and 15 %, respectively. For the remaining emission components, road transport is merely a small source of emission.

The road transport emissions of Cu and Pb almost solely originate from brake wear, also being the most dominating source for Cr. For Zn, brake and tyre wear are almost equally important sources. Consequently, brake wear, and secondly tyre wear, are the most relevant road transport sources to address, in order to reduce the Danish grand totals.

A remark must be made for Hg. Fuel consumption is the dominant emission source for this emission component, however, seen from a total emissions perspective road transport is a small source of Hg emissions, and hence it becomes less relevant to reduce the emissions of this specific emission component in order to bring down the total Danish emissions.

Table 41 Share of new Danish road transport emissions compared to the revised Danish emission total.

	Danish total Excl. road	Present study Road	Danish total Incl. road	Road share of total, %
As	629	8	637	1
Cd	706	48	753	6
Cr	1 151	197	1 348	15
Cu	2 912	51 779	54 691	95
Hg	1 119	28	1 147	2
Ni	8 431	158	8 590	2
Pb	6 097	6 989	13 086	53
Se	1 948	33	1 981	2
Zn	24 017	28 556	52 574	54

7 Conclusion

This report presents new heavy metal emission factors for cars, vans, trucks, buses, mopeds and motorcycles for each of the emission sources fuel consumption, engine oil, tyre wear, brake wear and road abrasion. The emission components covered are As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn, all of them relevant for emission reporting to the UNECE CLRTAP convention. The report also presents a new Danish inventory for the year 2007.

The specific vehicle category activity/emission source category combinations and the related emission factors determine the total emissions for each vehicle type/emission source. For As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn the calculated emission totals given as TSP are 8 kg, 48 kg, 197 kg, 51 779 kg, 28 kg, 158 kg, 6 989 kg, 33 kg and 28 556 kg.

Set in relation to the previous inventory (comprising fuel and engine oil only), for Pb, the new emission estimates are much higher (around 10 000 %) due to the emissions from brake wear, and for Cu and Zn large emission differences of around 600 % are noted. Brake wear is a very dominant emission source for Cu whereas for Zn, brake and tyre wear and engine oil all are important sources of emissions. This is emphasized by the fact that for fuel/engine oil alone the new Zn and Pb estimates would be 91 % and 155 % higher, respectively, and the Cu estimate would be 98 % lower compared with the previous figures.

For Cr, Se and Ni, respectively, the new emission estimates are 5 %, 22 % and 46 % lower than the previous ones. The emission contribution from the new complimentary sources, tyre wear, brake wear and road abrasion to some extent equals out the emission differences. Zero or relatively small emission contributions are calculated for fuel and engine oil alone.

Set in relation to a revised Danish emission total, road transport is a key source for Cu, Zn and Pb, and of some relevance for Cr. As much as 95 % of the Danish emissions of Cu originate from road transport activities, and for Zn, Pb and Cr the road transport emission shares are 54 %, 53 % and 15 %, respectively. For the remaining emission components, road transport is only a small source of emission.

The road transport emissions of Cu and Pb almost solely originate from brake wear, also being the most dominating source for Cr. For Zn, brake and tyre wear are almost equally important sources. Consequently, brake wear, and secondly tyre wear, are the most relevant road transport sources to address, in order to reduce the Danish grand totals.

Important outcomes of the present project are the proposed heavy metal emission factors and calculated 2007 emission estimates pr fuel type and vehicle type, for each of the five emission sources; fuel and engine oil consumption, vehicle tyre and brake wear and road abrasion. The gathered information of heavy metal content pr unit of consumption/emission has been essential for the establishment of emission factors for each of the five sources of emissions.

For the exhaust based emissions related to fuel and engine oil consumption it is a big improvement to have two separate sets of emission factors based on new information of heavy metal content. Until now, bulk emission factors have been used, related to the total fuel consumption. By treating the sources separately, updates of emission factors and calculated totals become easier, if new emission knowledge become available.

Being the basis for the subsequent heavy metal emission calculations, there is a reasonably good accordance between the new Danish tyre wear particulate emission factors and the factors from the existing Danish non-exhaust emission inventory for cars, vans and trucks between 3.5-7.5 t. and > 16 t. For medium-sized trucks, buses, and 2-wheelers the new emission factors are considerably higher than the previous ones. The wear rate and airborne fraction of the worn material and the associated heavy metal content determine the resulting heavy metal emission factors. The new factors for raw particulate emissions are regarded as being more precise for tyre wear than the ones used in the previous Danish non-exhaust emission inventory, since weight, wear percentage and tyre life times are provided by Danish experts in the tyre business.

The wear rates and airborne fractions of worn material for brakes, especially for heavy duty vehicles and for road abrasion in general are regarded as uncertain. The outcome of the literature study, however, did not bring any new information, which justifies any update of the particulate emission factors from the existing Danish inventory. These latter factors and the associated heavy metal content of worn material determine the heavy metal emission factors proposed in the present report.

For brakes a rough assessment was made of the wear rates for cars, trucks and buses using measured figures from three Danish workshops specialised in cars, trucks and buses. For cars and urban buses this assessment showed a rather fine harmony between the average Danish wear rates and the available literature data. For heavy duty trucks, however, the average Danish wear rates are surprisingly different from the scarce literature data available.

Also in terms of the Cu and Pb content of brake material used by trucks and buses there is a big difference between the figures used in the present study and averages based on other literature values. The metal content values used in this report for trucks and buses are very low, and rely on scarce data. The data differences for brake wear rates and metal contents point out the need for data updates, when new information become available.

By using the detailed emission factors and inventory calculation methods established in the present project estimates of heavy metal emissions can be made for other years than 2007. The emission factors are independent from inventory year and the emissions for each source/fuel/vehicle type combination are calculated as the product of the specific emission factor and the relevant inventory year specific activity data, fuel or engine oil consumption or total mileage.

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Annex 1

Heavy metal emission factors for tyre wear (µg pr km) pr vehicle category and road type for TSP, PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$.

Emission	Road type	Size	Cars	Vans Gasoline	Trucks 3.5-7.5t	Trucks 7.5-16t	Trucks 16-32t	Trucks > 32t	Trucks	Ur. buses	Coaches	Mopeds	MC
As	All	TSP	0.009	0.014	0.023	0.023	0.034	0.047	0.057	0.051	0.045	0.011	0.014
As	Urban	TSP	0.010	0.016	0.026	0.026	0.039	0.056	0.068	0.053	0.052	0.011	0.016
As	Rural	TSP	0.008	0.013	0.022	0.022	0.033	0.049	0.058	0.050	0.045	0.011	0.013
As	Highway	TSP	0.007	0.011	0.019	0.019	0.028	0.041	0.049	0.042	0.037	-	0.011
As	All	PM_{10}	0.005	0.008	0.014	0.014	0.020	0.028	0.034	0.031	0.027	0.007	0.009
As	Urban	PM_{10}	0.006	0.009	0.016	0.016	0.023	0.034	0.041	0.032	0.031	0.007	0.010
As	Rural	PM_{10}	0.005	0.008	0.013	0.013	0.020	0.029	0.035	0.030	0.027	0.007	0.008
As	Highway	PM_{10}	0.004	0.007	0.011	0.011	0.017	0.024	0.029	0.025	0.022	-	0.006
As	All	$PM_{2.5}$	0.004	0.006	0.010	0.010	0.014	0.020	0.024	0.021	0.019	0.005	0.006
As	Urban	$PM_{2.5}$	0.004	0.007	0.011	0.011	0.016	0.024	0.028	0.022	0.022	0.005	0.007
As	Rural	$PM_{2.5}$	0.003	0.005	0.009	0.009	0.014	0.020	0.024	0.021	0.019	0.005	0.005
As	Highway	$PM_{2.5}$	0.003	0.005	0.008	0.008	0.012	0.017	0.020	0.018	0.016	-	0.004
As	All	PM_1	0.001	0.001	0.001	0.001	0.002	0.003	0.003	0.003	0.003	0.001	0.001
As	Urban	PM_1	0.001	0.001	0.002	0.002	0.002	0.003	0.004	0.003	0.003	0.001	0.001
As	Rural	PM_1	0.000	0.001	0.001	0.001	0.002	0.003	0.003	0.003	0.003	0.001	0.001
As	Highway	PM_1	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.002	-	0.001
As	All	$PM_{0.1}$	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.002	0.002	0.001	0.001
As	Urban	$PM_{0.1}$	0.000	0.001	0.001	0.001	0.002	0.003	0.003	0.003	0.002	0.001	0.001
As	Rural	$PM_{0.1}$	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.002	0.002	0.001	0.001
As	Highway	$PM_{0.1}$	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	-	0.001
Cd	All	TSP	0.028	0.045	0.074	0.074	0.111	0.153	0.184	0.166	0.147	0.037	0.046
Cd	Urban	TSP	0.034	0.051	0.084	0.084	0.126	0.184	0.220	0.174	0.168	0.037	0.053
Cd	Rural	TSP	0.027	0.042	0.072	0.072	0.109	0.158	0.189	0.162	0.145	0.037	0.042
Cd	Highway	TSP	0.022	0.037	0.061	0.061	0.091	0.132	0.159	0.137	0.121	-	0.034
Cd	All	PM_{10}	0.017	0.027	0.044	0.044	0.066	0.092	0.111	0.099	0.088	0.022	0.028
Cd	Urban	PM_{10}	0.020	0.031	0.050	0.050	0.076	0.110	0.132	0.104	0.101	0.022	0.032
Cd	Rural	PM_{10}	0.016	0.025	0.043	0.043	0.065	0.095	0.114	0.097	0.087	0.022	0.025
Cd	Highway	PM_{10}	0.013	0.022	0.036	0.036	0.055	0.079	0.095	0.082	0.073	-	0.021
Cd	All	$PM_{2.5}$	0.012	0.019	0.031	0.031	0.046	0.064	0.077	0.070	0.062	0.015	0.019

Continued													
Cd	Urban	$PM_{2.5}$	0.014	0.021	0.035	0.035	0.053	0.077	0.092	0.073	0.071	0.015	0.022
Cd	Rural	$PM_{2.5}$	0.011	0.018	0.030	0.030	0.046	0.066	0.080	0.068	0.061	0.015	0.018
Cd	Highway	$PM_{2.5}$	0.009	0.015	0.025	0.025	0.038	0.055	0.067	0.058	0.051	-	0.014
Cd	All	PM_1	0.002	0.003	0.004	0.004	0.007	0.009	0.011	0.010	0.009	0.002	0.003
Cd	Urban	PM_1	0.002	0.003	0.005	0.005	0.008	0.011	0.013	0.010	0.010	0.002	0.003
Cd	Rural	PM_1	0.002	0.003	0.004	0.004	0.007	0.009	0.011	0.010	0.009	0.002	0.003
Cd	Highway	PM_1	0.001	0.002	0.004	0.004	0.005	0.008	0.010	0.008	0.007	-	0.002
Cd	All	$PM_{0.1}$	0.001	0.002	0.004	0.004	0.005	0.007	0.009	0.008	0.007	0.002	0.002
Cd	Urban	$PM_{0.1}$	0.002	0.002	0.004	0.004	0.006	0.009	0.011	0.008	0.008	0.002	0.003
Cd	Rural	$PM_{0.1}$	0.001	0.002	0.003	0.003	0.005	0.008	0.009	0.008	0.007	0.002	0.002
Cd	Highway	$PM_{0.1}$	0.001	0.002	0.003	0.003	0.004	0.006	0.008	0.007	0.006	-	0.002
Cr	All	TSP	0.039	0.062	0.102	0.102	0.153	0.213	0.255	0.230	0.204	0.051	0.064
Cr	Urban	TSP	0.047	0.071	0.117	0.117	0.175	0.254	0.305	0.240	0.233	0.051	0.073
Cr	Rural	TSP	0.037	0.058	0.100	0.100	0.150	0.219	0.262	0.224	0.200	0.051	0.058
Cr	Highway	TSP	0.030	0.051	0.084	0.084	0.126	0.183	0.220	0.190	0.168	-	0.048
Cr	All	PM_{10}	0.023	0.037	0.061	0.061	0.092	0.128	0.153	0.138	0.122	0.031	0.038
Cr	Urban	PM_{10}	0.028	0.042	0.070	0.070	0.105	0.152	0.183	0.144	0.140	0.031	0.044
Cr	Rural	PM_{10}	0.022	0.035	0.060	0.060	0.090	0.131	0.157	0.134	0.120	0.031	0.035
Cr	Highway	PM_{10}	0.018	0.031	0.050	0.050	0.075	0.110	0.132	0.114	0.101	-	0.029
Cr	All	$PM_{2.5}$	0.016	0.026	0.043	0.043	0.064	0.089	0.107	0.096	0.086	0.021	0.027
Cr	Urban	$PM_{2.5}$	0.020	0.030	0.049	0.049	0.073	0.107	0.128	0.101	0.098	0.021	0.031
Cr	Rural	$PM_{2.5}$	0.015	0.025	0.042	0.042	0.063	0.092	0.110	0.094	0.084	0.021	0.024
Cr	Highway	$PM_{2.5}$	0.013	0.021	0.035	0.035	0.053	0.077	0.092	0.080	0.070	-	0.020
Cr	All	PM_1	0.002	0.004	0.006	0.006	0.009	0.013	0.015	0.014	0.012	0.003	0.004
Cr	Urban	PM_1	0.003	0.004	0.007	0.007	0.010	0.015	0.018	0.014	0.014	0.003	0.004
Cr	Rural	PM_1	0.002	0.004	0.006	0.006	0.009	0.013	0.016	0.013	0.012	0.003	0.003
Cr	Highway	PM_1	0.002	0.003	0.005	0.005	0.008	0.011	0.013	0.011	0.010	-	0.003
Cr	All	$PM_{0.1}$	0.002	0.003	0.005	0.005	0.007	0.010	0.012	0.011	0.010	0.002	0.003
Cr	Urban	$PM_{0.1}$	0.002	0.003	0.006	0.006	0.008	0.012	0.015	0.012	0.011	0.002	0.004
Cr	Rural	$PM_{0.1}$	0.002	0.003	0.005	0.005	0.007	0.010	0.013	0.011	0.010	0.002	0.003
Cr	Highway	$PM_{0.1}$	0.001	0.002	0.004	0.004	0.006	0.009	0.011	0.009	0.008	-	0.002
Cu	All	TSP	0.169	0.267	0.442	0.442	0.663	0.921	1.105	0.995	0.884	0.221	0.276
Cu	Urban	TSP	0.202	0.307	0.505	0.505	0.757	1.101	1.321	1.042	1.010	0.221	0.318
Cu	Rural	TSP	0.160	0.253	0.434	0.434	0.651	0.947	1.137	0.969	0.869	0.221	0.251
Cu	Highway	TSP	0.131	0.221	0.364	0.364	0.545	0.793	0.951	0.823	0.727	-	0.206
Cu	All	PM_{10}	0.101	0.160	0.265	0.265	0.398	0.553	0.663	0.597	0.530	0.133	0.166

Continued

Cu	Urban	PM_{10}	0.121	0.184	0.303	0.303	0.454	0.661	0.793	0.625	0.606	0.133	0.191
Cu	Rural	PM_{10}	0.096	0.152	0.261	0.261	0.391	0.568	0.682	0.581	0.521	0.133	0.151
Cu	Highway	PM_{10}	0.079	0.133	0.218	0.218	0.327	0.476	0.571	0.494	0.436	-	0.124
Cu	All	$PM_{2.5}$	0.071	0.112	0.186	0.186	0.278	0.387	0.464	0.418	0.371	0.093	0.116
Cu	Urban	$PM_{2.5}$	0.085	0.129	0.212	0.212	0.318	0.462	0.555	0.438	0.424	0.093	0.134
Cu	Rural	$PM_{2.5}$	0.067	0.106	0.182	0.182	0.274	0.398	0.477	0.407	0.365	0.093	0.105
Cu	Highway	$PM_{2.5}$	0.055	0.093	0.153	0.153	0.229	0.333	0.400	0.346	0.305	-	0.087
Cu	All	PM_{1}	0.010	0.016	0.027	0.027	0.040	0.055	0.066	0.060	0.053	0.013	0.017
Cu	Urban	PM_{1}	0.012	0.018	0.030	0.030	0.045	0.066	0.079	0.063	0.061	0.013	0.019
Cu	Rural	PM_{1}	0.010	0.015	0.026	0.026	0.039	0.057	0.068	0.058	0.052	0.013	0.015
Cu	Highway	PM_{1}	0.008	0.013	0.022	0.022	0.033	0.048	0.057	0.049	0.044	-	0.012
Cu	All	$PM_{0.1}$	0.008	0.013	0.021	0.021	0.032	0.044	0.053	0.048	0.042	0.011	0.013
Cu	Urban	$PM_{0.1}$	0.010	0.015	0.024	0.024	0.036	0.053	0.063	0.050	0.048	0.011	0.015
Cu	Rural	$PM_{0.1}$	0.008	0.012	0.021	0.021	0.031	0.045	0.055	0.047	0.042	0.011	0.012
Cu	Highway	$PM_{0.1}$	0.006	0.011	0.017	0.017	0.026	0.038	0.046	0.040	0.035	-	0.010
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_{1}	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_{1}	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_{1}	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_{1}	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	0.276	0.437	0.723	0.723	1.084	1.505	1.806	1.626	1.445	0.361	0.452

Continued													
Ni	Urban	TSP	0.330	0.502	0.825	0.825	1.238	1.800	2.160	1.703	1.651	0.361	0.520
Ni	Rural	TSP	0.261	0.414	0.710	0.710	1.065	1.548	1.858	1.584	1.420	0.361	0.410
Ni	Highway	TSP	0.214	0.361	0.594	0.594	0.891	1.296	1.555	1.345	1.188	-	0.337
Ni	All	PM_{10}	0.166	0.262	0.434	0.434	0.650	0.903	1.084	0.975	0.867	0.217	0.271
Ni	Urban	PM_{10}	0.198	0.301	0.495	0.495	0.743	1.080	1.296	1.022	0.990	0.217	0.312
Ni	Rural	PM_{10}	0.156	0.248	0.426	0.426	0.639	0.929	1.115	0.950	0.852	0.217	0.246
Ni	Highway	PM_{10}	0.128	0.217	0.357	0.357	0.535	0.778	0.933	0.807	0.713	-	0.202
Ni	All	$PM_{2.5}$	0.116	0.183	0.303	0.303	0.455	0.632	0.759	0.683	0.607	0.152	0.190
Ni	Urban	$PM_{2.5}$	0.139	0.211	0.347	0.347	0.520	0.756	0.907	0.715	0.693	0.152	0.218
Ni	Rural	$PM_{2.5}$	0.110	0.174	0.298	0.298	0.447	0.650	0.780	0.665	0.596	0.152	0.172
Ni	Highway	$PM_{2.5}$	0.090	0.152	0.250	0.250	0.374	0.544	0.653	0.565	0.499	-	0.142
Ni	All	PM_1	0.017	0.026	0.043	0.043	0.065	0.090	0.108	0.098	0.087	0.022	0.027
Ni	Urban	PM_1	0.020	0.030	0.050	0.050	0.074	0.108	0.130	0.102	0.099	0.022	0.031
Ni	Rural	PM_1	0.016	0.025	0.043	0.043	0.064	0.093	0.111	0.095	0.085	0.022	0.025
Ni	Highway	PM_1	0.013	0.022	0.036	0.036	0.053	0.078	0.093	0.081	0.071	-	0.020
Ni	All	$PM_{0.1}$	0.013	0.021	0.035	0.035	0.052	0.072	0.087	0.078	0.069	0.017	0.022
Ni	Urban	$PM_{0.1}$	0.016	0.024	0.040	0.040	0.059	0.086	0.104	0.082	0.079	0.017	0.025
Ni	Rural	$PM_{0.1}$	0.013	0.020	0.034	0.034	0.051	0.074	0.089	0.076	0.068	0.017	0.020
Ni	Highway	$PM_{0.1}$	0.010	0.017	0.029	0.029	0.043	0.062	0.075	0.065	0.057	-	0.016
Pb	All	TSP	0.872	1.379	2.281	2.281	3.421	4.752	5.702	5.132	4.562	1.140	1.426
Pb	Urban	TSP	1.042	1.584	2.605	2.605	3.908	5.682	6.819	5.376	5.211	1.140	1.641
Pb	Rural	TSP	0.823	1.307	2.241	2.241	3.361	4.887	5.865	5.001	4.482	1.140	1.296
Pb	Highway	TSP	0.676	1.140	1.876	1.876	2.814	4.091	4.909	4.247	3.752	-	1.064
Pb	All	PM_{10}	0.523	0.827	1.369	1.369	2.053	2.851	3.421	3.079	2.737	0.684	0.855
Pb	Urban	PM_{10}	0.625	0.950	1.563	1.563	2.345	3.409	4.091	3.226	3.126	0.684	0.984
Pb	Rural	PM_{10}	0.494	0.784	1.345	1.345	2.017	2.932	3.519	3.000	2.689	0.684	0.778
Pb	Highway	PM_{10}	0.406	0.684	1.125	1.125	1.688	2.455	2.946	2.548	2.251	-	0.639
Pb	All	$PM_{2.5}$	0.366	0.579	0.958	0.958	1.437	1.996	2.395	2.155	1.916	0.479	0.599
Pb	Urban	$PM_{2.5}$	0.438	0.665	1.094	1.094	1.641	2.386	2.864	2.258	2.188	0.479	0.689
Pb	Rural	$PM_{2.5}$	0.346	0.549	0.941	0.941	1.412	2.053	2.463	2.100	1.882	0.479	0.544
Pb	Highway	$PM_{2.5}$	0.284	0.479	0.788	0.788	1.182	1.718	2.062	1.784	1.576	-	0.447
Pb	All	PM_1	0.052	0.083	0.137	0.137	0.205	0.285	0.342	0.308	0.274	0.068	0.086
Pb	Urban	PM_1	0.063	0.095	0.156	0.156	0.234	0.341	0.409	0.323	0.313	0.068	0.098
Pb	Rural	PM_1	0.049	0.078	0.134	0.134	0.202	0.293	0.352	0.300	0.269	0.068	0.078
Pb	Highway	PM_1	0.041	0.068	0.113	0.113	0.169	0.245	0.295	0.255	0.225	-	0.064
Pb	All	$PM_{0.1}$	0.042	0.066	0.109	0.109	0.164	0.228	0.274	0.246	0.219	0.055	0.068

Continued												
Pb	Urban	$PM_{0.1}$	0.050	0.076	0.125	0.125	0.188	0.273	0.327	0.258	0.250	0.055	0.079
Pb	Rural	$PM_{0.1}$	0.040	0.063	0.108	0.108	0.161	0.235	0.282	0.240	0.215	0.055	0.062
Pb	Highway	$PM_{0.1}$	0.032	0.055	0.090	0.090	0.135	0.196	0.236	0.204	0.180	-	0.051
Se	All	TSP	0.217	0.343	0.567	0.567	0.850	1.181	1.417	1.275	1.133	0.283	0.354
Se	Urban	TSP	0.259	0.394	0.647	0.647	0.971	1.412	1.694	1.336	1.295	0.283	0.408
Se	Rural	TSP	0.204	0.325	0.557	0.557	0.835	1.214	1.457	1.242	1.113	0.283	0.322
Se	Highway	TSP	0.168	0.283	0.466	0.466	0.699	1.016	1.220	1.055	0.932	-	0.264
Se	All	PM_{10}	0.130	0.206	0.340	0.340	0.510	0.708	0.850	0.765	0.680	0.170	0.213
Se	Urban	PM_{10}	0.155	0.236	0.388	0.388	0.583	0.847	1.016	0.801	0.777	0.170	0.245
Se	Rural	PM_{10}	0.123	0.195	0.334	0.334	0.501	0.729	0.874	0.745	0.668	0.170	0.193
Se	Highway	PM_{10}	0.101	0.170	0.280	0.280	0.419	0.610	0.732	0.633	0.559	-	0.159
Se	All	$PM_{2.5}$	0.091	0.144	0.238	0.238	0.357	0.496	0.595	0.536	0.476	0.119	0.149
Se	Urban	$PM_{2.5}$	0.109	0.165	0.272	0.272	0.408	0.593	0.711	0.561	0.544	0.119	0.171
Se	Rural	$PM_{2.5}$	0.086	0.136	0.234	0.234	0.351	0.510	0.612	0.522	0.468	0.119	0.135
Se	Highway	$PM_{2.5}$	0.071	0.119	0.196	0.196	0.294	0.427	0.512	0.443	0.391	-	0.111
Se	All	PM_1	0.013	0.021	0.034	0.034	0.051	0.071	0.085	0.077	0.068	0.017	0.021
Se	Urban	PM_1	0.016	0.024	0.039	0.039	0.058	0.085	0.102	0.080	0.078	0.017	0.024
Se	Rural	PM_1	0.012	0.019	0.033	0.033	0.050	0.073	0.087	0.075	0.067	0.017	0.019
Se	Highway	PM_1	0.010	0.017	0.028	0.028	0.042	0.061	0.073	0.063	0.056	-	0.016
Se	All	$PM_{0.1}$	0.010	0.016	0.027	0.027	0.041	0.057	0.068	0.061	0.054	0.014	0.017
Se	Urban	$PM_{0.1}$	0.012	0.019	0.031	0.031	0.047	0.068	0.081	0.064	0.062	0.014	0.020
Se	Rural	$PM_{0.1}$	0.010	0.016	0.027	0.027	0.040	0.058	0.070	0.060	0.053	0.014	0.015
Se	Highway	$PM_{0.1}$	0.008	0.014	0.022	0.022	0.034	0.049	0.059	0.051	0.045	-	0.013
Zn	All	TSP	86.951	137.504	227.488	413.298	619.948	861.038	1 033.246	929.921	826.597	113.744	142.180
Zn	Urban	TSP	103.935	157.977	259.848	472.089	708.133	1 029.624	1 235.549	974.153	944.177	113.744	163.640
Zn	Rural	TSP	82.093	130.311	223.506	406.064	609.096	885.625	1 062.750	906.173	812.128	113.744	129.250
Zn	Highway	TSP	67.426	113.711	187.090	339.904	509.856	741.329	889.595	769.651	679.808	-	106.159
Zn	All	PM_{10}	52.171	82.502	136.493	247.979	371.969	516.623	619.948	557.953	495.958	68.247	85.308
Zn	Urban	PM_{10}	62.361	94.786	155.909	283.253	424.880	617.774	741.329	584.492	566.506	68.247	98.184
Zn	Rural	PM_{10}	49.256	78.186	134.104	243.639	365.458	531.375	637.650	543.704	487.277	68.247	77.550
Zn	Highway	PM_{10}	40.456	68.227	112.254	203.942	305.913	444.798	533.757	461.791	407.885	-	63.695
Zn	All	$PM_{2.5}$	36.519	57.752	95.545	173.585	260.378	361.636	433.963	390.567	347.171	47.773	59.716
Zn	Urban	$PM_{2.5}$	43.653	66.350	109.136	198.277	297.416	432.442	518.930	409.144	396.554	47.773	68.729
Zn	Rural	$PM_{2.5}$	34.479	54.731	93.873	170.547	255.820	371.962	446.355	380.593	341.094	47.773	54.285
Zn	Highway	$PM_{2.5}$	28.319	47.759	78.578	142.760	214.139	311.358	373.630	323.254	285.519	-	44.587
Zn	All	PM_1	5.217	8.250	13.649	24.798	37.197	51.662	61.995	55.795	49.596	6.825	8.531

Continued													
Zn	Urban	PM_1	6.236	9.479	15.591	28.325	42.488	61.777	74.133	58.449	56.651	6.825	9.818
Zn	Rural	PM_1	4.926	7.819	13.410	24.364	36.546	53.137	63.765	54.370	48.728	6.825	7.755
Zn	Highway	PM_1	4.046	6.823	11.225	20.394	30.591	44.480	53.376	46.179	40.788	-	6.370
Zn	All	$PM_{0.1}$	4.174	6.600	10.919	19.838	29.757	41.330	49.596	44.636	39.677	5.460	6.825
Zn	Urban	$PM_{0.1}$	4.989	7.583	12.473	22.660	33.990	49.422	59.306	46.759	45.321	5.460	7.855
Zn	Rural	$PM_{0.1}$	3.940	6.255	10.728	19.491	29.237	42.510	51.012	43.496	38.982	5.460	6.204
Zn	Highway	$PM_{0.1}$	3.236	5.458	8.980	16.315	24.473	35.584	42.701	36.943	32.631	-	5.096

Heavy metal emissions for tyre wear (kg) pr vehicle category and road type for TSP, PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$

Emission	Road type	Size	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5 t.	Trucks 7.5-16 t.	Trucks 16-32 t.	Trucks > 32 t.	Urban buses	Coaches	Mopeds	MC	Total
As	All	TSP	0.338	0.174	0.000	0.008	0.008	0.074	0.093	0.030	0.017	0.003	0.013	0.758
As	Urban	TSP	0.141	0.070	0.000	0.003	0.003	0.017	0.021	0.016	0.006	0.002	0.007	0.287
As	Rural	TSP	0.147	0.082	0.000	0.004	0.004	0.034	0.043	0.012	0.008	0.001	0.005	0.339
As	Highway	TSP	0.050	0.022	0.000	0.001	0.001	0.023	0.029	0.002	0.003	-	0.001	0.132
As	All	PM_{10}	0.203	0.104	0.000	0.005	0.005	0.044	0.056	0.018	0.010	0.002	0.008	0.455
As	Urban	PM_{10}	0.085	0.042	0.000	0.002	0.002	0.010	0.013	0.010	0.004	0.001	0.004	0.172
As	Rural	PM_{10}	0.088	0.049	0.000	0.002	0.002	0.020	0.026	0.007	0.005	0.000	0.003	0.203
As	Highway	PM_{10}	0.030	0.013	0.000	0.001	0.001	0.014	0.017	0.001	0.002	-	0.001	0.079
As	All	$PM_{2.5}$	0.142	0.073	0.000	0.003	0.003	0.031	0.039	0.013	0.007	0.001	0.005	0.318
As	Urban	$PM_{2.5}$	0.059	0.029	0.000	0.001	0.001	0.007	0.009	0.007	0.003	0.001	0.003	0.120
As	Rural	$PM_{2.5}$	0.062	0.035	0.000	0.002	0.001	0.014	0.018	0.005	0.003	0.000	0.002	0.142
As	Highway	$PM_{2.5}$	0.021	0.009	0.000	0.001	0.001	0.010	0.012	0.001	0.001	-	0.001	0.056
As	All	PM_1	0.020	0.010	0.000	0.000	0.000	0.004	0.006	0.002	0.001	0.000	0.001	0.045
As	Urban	PM_1	0.008	0.004	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.017
As	Rural	PM_1	0.009	0.005	0.000	0.000	0.000	0.002	0.003	0.001	0.000	0.000	0.000	0.020
As	Highway	PM_1	0.003	0.001	0.000	0.000	0.000	0.001	0.002	0.000	0.000	-	0.000	0.008
As	All	$PM_{0.1}$	0.016	0.008	0.000	0.000	0.000	0.004	0.004	0.001	0.001	0.000	0.001	0.036
As	Urban	$PM_{0.1}$	0.007	0.003	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.014
As	Rural	$PM_{0.1}$	0.007	0.004	0.000	0.000	0.000	0.002	0.002	0.001	0.000	0.000	0.000	0.016
As	Highway	$PM_{0.1}$	0.002	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.000	-	0.000	0.006
Cd	All	TSP	1.097	0.566	0.001	0.026	0.025	0.240	0.303	0.098	0.056	0.009	0.042	2.463
Cd	Urban	TSP	0.459	0.228	0.000	0.009	0.009	0.054	0.069	0.053	0.021	0.007	0.023	0.932
Cd	Rural	TSP	0.477	0.268	0.000	0.012	0.011	0.111	0.140	0.039	0.026	0.002	0.015	1.102
Cd	Highway	TSP	0.162	0.070	0.000	0.004	0.004	0.074	0.094	0.007	0.010	-	0.004	0.430
Cd	All	PM_{10}	0.658	0.340	0.000	0.015	0.015	0.144	0.182	0.059	0.034	0.005	0.025	1.478
Cd	Urban	PM_{10}	0.275	0.137	0.000	0.006	0.005	0.033	0.041	0.032	0.012	0.004	0.014	0.559
Cd	Rural	PM_{10}	0.286	0.161	0.000	0.007	0.007	0.067	0.084	0.024	0.016	0.001	0.009	0.661
Cd	Highway	PM_{10}	0.097	0.042	0.000	0.003	0.003	0.045	0.056	0.004	0.006	-	0.003	0.258
Cd	All	$PM_{2.5}$	0.461	0.238	0.000	0.011	0.010	0.101	0.127	0.041	0.024	0.004	0.018	1.034
Cd	Urban	$PM_{2.5}$	0.193	0.096	0.000	0.004	0.004	0.023	0.029	0.022	0.009	0.003	0.010	0.391
Cd	Rural	$PM_{2.5}$	0.200	0.113	0.000	0.005	0.005	0.047	0.059	0.016	0.011	0.001	0.006	0.463
Cd	Highway	$PM_{2.5}$	0.068	0.029	0.000	0.002	0.002	0.031	0.039	0.003	0.004	-	0.002	0.180
Cd	All	PM_1	0.066	0.034	0.000	0.002	0.001	0.014	0.018	0.006	0.003	0.001	0.003	0.148
Cd	Urban	PM_1	0.028	0.014	0.000	0.001	0.001	0.003	0.004	0.003	0.001	0.000	0.001	0.056

Continued														
Cd	Rural	PM_1	0.029	0.016	0.000	0.001	0.001	0.007	0.008	0.002	0.002	0.000	0.001	0.066
Cd	Highway	PM_1	0.010	0.004	0.000	0.000	0.000	0.004	0.006	0.000	0.001	-	0.000	0.026
Cd	All	$PM_{0.1}$	0.053	0.027	0.000	0.001	0.001	0.011	0.015	0.005	0.003	0.000	0.002	0.118
Cd	Urban	$PM_{0.1}$	0.022	0.011	0.000	0.000	0.000	0.003	0.003	0.003	0.001	0.000	0.001	0.045
Cd	Rural	$PM_{0.1}$	0.023	0.013	0.000	0.001	0.001	0.005	0.007	0.002	0.001	0.000	0.001	0.053
Cd	Highway	$PM_{0.1}$	0.008	0.003	0.000	0.000	0.000	0.004	0.005	0.000	0.000	-	0.000	0.021
Cr	All	TSP	1.520	0.783	0.001	0.035	0.034	0.332	0.420	0.136	0.078	0.012	0.058	3.410
Cr	Urban	TSP	0.636	0.315	0.000	0.013	0.013	0.075	0.095	0.073	0.028	0.010	0.032	1.290
Cr	Rural	TSP	0.660	0.371	0.000	0.016	0.016	0.154	0.194	0.054	0.036	0.002	0.021	1.525
Cr	Highway	TSP	0.224	0.097	0.000	0.006	0.006	0.103	0.130	0.009	0.013	-	0.006	0.595
Cr	All	PM_{10}	0.912	0.470	0.001	0.021	0.021	0.199	0.252	0.082	0.047	0.007	0.035	2.046
Cr	Urban	PM_{10}	0.381	0.189	0.000	0.008	0.008	0.045	0.057	0.044	0.017	0.006	0.019	0.774
Cr	Rural	PM_{10}	0.396	0.223	0.000	0.010	0.010	0.092	0.117	0.033	0.022	0.001	0.012	0.915
Cr	Highway	PM_{10}	0.134	0.058	0.000	0.004	0.004	0.062	0.078	0.005	0.008	-	0.004	0.357
Cr	All	$PM_{2.5}$	0.638	0.329	0.000	0.015	0.014	0.139	0.176	0.057	0.033	0.005	0.025	1.432
Cr	Urban	$PM_{2.5}$	0.267	0.132	0.000	0.005	0.005	0.032	0.040	0.031	0.012	0.004	0.013	0.542
Cr	Rural	$PM_{2.5}$	0.277	0.156	0.000	0.007	0.007	0.064	0.082	0.023	0.015	0.001	0.009	0.641
Cr	Highway	$PM_{2.5}$	0.094	0.041	0.000	0.003	0.002	0.043	0.055	0.004	0.006	-	0.003	0.250
Cr	All	PM_1	0.091	0.047	0.000	0.002	0.002	0.020	0.025	0.008	0.005	0.001	0.004	0.205
Cr	Urban	PM_1	0.038	0.019	0.000	0.001	0.001	0.005	0.006	0.004	0.002	0.001	0.002	0.077
Cr	Rural	PM_1	0.040	0.022	0.000	0.001	0.001	0.009	0.012	0.003	0.002	0.000	0.001	0.092
Cr	Highway	PM_1	0.013	0.006	0.000	0.000	0.000	0.006	0.008	0.001	0.001	-	0.000	0.036
Cr	All	$PM_{0.1}$	0.073	0.038	0.000	0.002	0.002	0.016	0.020	0.007	0.004	0.001	0.003	0.164
Cr	Urban	$PM_{0.1}$	0.031	0.015	0.000	0.001	0.001	0.004	0.005	0.003	0.001	0.000	0.002	0.062
Cr	Rural	$PM_{0.1}$	0.032	0.018	0.000	0.001	0.001	0.007	0.009	0.003	0.002	0.000	0.001	0.073
Cr	Highway	$PM_{0.1}$	0.011	0.005	0.000	0.000	0.000	0.005	0.006	0.000	0.001	-	0.000	0.029
Cu	All	TSP	6.585	3.395	0.005	0.153	0.149	1.437	1.820	0.590	0.338	0.053	0.253	14.777
Cu	Urban	TSP	2.755	1.365	0.002	0.056	0.054	0.327	0.414	0.315	0.123	0.043	0.137	5.590
Cu	Rural	TSP	2.860	1.609	0.002	0.071	0.069	0.665	0.842	0.236	0.156	0.010	0.090	6.609
Cu	Highway	TSP	0.970	0.421	0.001	0.026	0.026	0.445	0.564	0.039	0.058	-	0.026	2.578
Cu	All	PM_{10}	3.951	2.037	0.003	0.092	0.089	0.862	1.092	0.354	0.203	0.032	0.152	8.866
Cu	Urban	PM_{10}	1.653	0.819	0.001	0.034	0.033	0.196	0.248	0.189	0.074	0.026	0.082	3.354
Cu	Rural	PM_{10}	1.716	0.965	0.001	0.042	0.041	0.399	0.505	0.141	0.094	0.006	0.054	3.965
Cu	Highway	PM_{10}	0.582	0.253	0.000	0.016	0.015	0.267	0.338	0.023	0.035	-	0.016	1.547
Cu	All	$PM_{2.5}$	2.766	1.426	0.002	0.064	0.063	0.604	0.764	0.248	0.142	0.022	0.106	6.206
Cu	Urban	$PM_{2.5}$	1.157	0.573	0.001	0.023	0.023	0.137	0.174	0.132	0.052	0.018	0.058	2.348

Continued

Cu	Rural	$PM_{2.5}$	1.201	0.676	0.001	0.030	0.029	0.279	0.354	0.099	0.066	0.004	0.038	2.776
Cu	Highway	$PM_{2.5}$	0.407	0.177	0.000	0.011	0.011	0.187	0.237	0.016	0.025	-	0.011	1.083
Cu	All	PM_1	0.395	0.204	0.000	0.009	0.009	0.086	0.109	0.035	0.020	0.003	0.015	0.887
Cu	Urban	PM_1	0.165	0.082	0.000	0.003	0.003	0.020	0.025	0.019	0.007	0.003	0.008	0.335
Cu	Rural	PM_1	0.172	0.097	0.000	0.004	0.004	0.040	0.051	0.014	0.009	0.001	0.005	0.397
Cu	Highway	PM_1	0.058	0.025	0.000	0.002	0.002	0.027	0.034	0.002	0.004	-	0.002	0.155
Cu	All	$PM_{0.1}$	0.316	0.163	0.000	0.007	0.007	0.069	0.087	0.028	0.016	0.003	0.012	0.709
Cu	Urban	$PM_{0.1}$	0.132	0.066	0.000	0.003	0.003	0.016	0.020	0.015	0.006	0.002	0.007	0.268
Cu	Rural	$PM_{0.1}$	0.137	0.077	0.000	0.003	0.003	0.032	0.040	0.011	0.007	0.000	0.004	0.317
Cu	Highway	$PM_{0.1}$	0.047	0.020	0.000	0.001	0.001	0.021	0.027	0.002	0.003	-	0.001	0.124
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	10.763	5.550	0.007	0.250	0.243	2.349	2.975	0.964	0.552	0.086	0.414	24.155
Ni	Urban	TSP	4.503	2.232	0.003	0.091	0.089	0.534	0.676	0.515	0.202	0.070	0.224	9.138
Ni	Rural	TSP	4.674	2.630	0.003	0.116	0.112	1.087	1.377	0.385	0.255	0.016	0.147	10.803
Ni	Highway	TSP	1.586	0.688	0.001	0.043	0.042	0.728	0.922	0.064	0.095	-	0.043	4.214
Ni	All	PM_{10}	6.458	3.330	0.004	0.150	0.146	1.410	1.785	0.578	0.331	0.052	0.248	14.493
Ni	Urban	PM_{10}	2.702	1.339	0.002	0.055	0.053	0.320	0.406	0.309	0.121	0.042	0.134	5.483

Continued

Ni	Rural	PM_{10}	2.805	1.578	0.002	0.069	0.067	0.652	0.826	0.231	0.153	0.010	0.088	6.482
Ni	Highway	PM_{10}	0.951	0.413	0.001	0.026	0.025	0.437	0.553	0.038	0.057	-	0.026	2.528
Ni	All	$PM_{2.5}$	4.521	2.331	0.003	0.105	0.102	0.987	1.250	0.405	0.232	0.036	0.174	10.145
Ni	Urban	$PM_{2.5}$	1.891	0.937	0.001	0.038	0.037	0.224	0.284	0.216	0.085	0.029	0.094	3.838
Ni	Rural	$PM_{2.5}$	1.963	1.104	0.001	0.049	0.047	0.457	0.578	0.162	0.107	0.007	0.062	4.537
Ni	Highway	$PM_{2.5}$	0.666	0.289	0.001	0.018	0.018	0.306	0.387	0.027	0.040	-	0.018	1.770
Ni	All	PM_1	0.646	0.333	0.000	0.015	0.015	0.141	0.179	0.058	0.033	0.005	0.025	1.449
Ni	Urban	PM_1	0.270	0.134	0.000	0.005	0.005	0.032	0.041	0.031	0.012	0.004	0.013	0.548
Ni	Rural	PM_1	0.280	0.158	0.000	0.007	0.007	0.065	0.083	0.023	0.015	0.001	0.009	0.648
Ni	Highway	PM_1	0.095	0.041	0.000	0.003	0.003	0.044	0.055	0.004	0.006	-	0.003	0.253
Ni	All	$PM_{0.1}$	0.517	0.266	0.000	0.012	0.012	0.113	0.143	0.046	0.027	0.004	0.020	1.159
Ni	Urban	$PM_{0.1}$	0.216	0.107	0.000	0.004	0.004	0.026	0.032	0.025	0.010	0.003	0.011	0.439
Ni	Rural	$PM_{0.1}$	0.224	0.126	0.000	0.006	0.005	0.052	0.066	0.018	0.012	0.001	0.007	0.519
Ni	Highway	$PM_{0.1}$	0.076	0.033	0.000	0.002	0.002	0.035	0.044	0.003	0.005	-	0.002	0.202
Pb	All	TSP	33.978	17.519	0.023	0.790	0.768	7.417	9.392	3.044	1.743	0.272	1.307	76.254
Pb	Urban	TSP	14.215	7.045	0.009	0.289	0.281	1.685	2.134	1.626	0.637	0.220	0.707	28.848
Pb	Rural	TSP	14.757	8.301	0.011	0.365	0.355	3.433	4.347	1.216	0.805	0.052	0.463	34.104
Pb	Highway	TSP	5.006	2.173	0.004	0.136	0.133	2.299	2.911	0.202	0.301	-	0.137	13.302
Pb	All	PM_{10}	20.387	10.512	0.014	0.474	0.461	4.450	5.635	1.826	1.046	0.163	0.784	45.752
Pb	Urban	PM_{10}	8.529	4.227	0.005	0.173	0.168	1.011	1.280	0.976	0.382	0.132	0.424	17.309
Pb	Rural	PM_{10}	8.854	4.981	0.006	0.219	0.213	2.060	2.608	0.730	0.483	0.031	0.278	20.463
Pb	Highway	PM_{10}	3.004	1.304	0.002	0.082	0.080	1.379	1.747	0.121	0.181	-	0.082	7.981
Pb	All	$PM_{2.5}$	14.271	7.358	0.010	0.332	0.323	3.115	3.945	1.278	0.732	0.114	0.549	32.027
Pb	Urban	$PM_{2.5}$	5.970	2.959	0.004	0.121	0.118	0.708	0.896	0.683	0.268	0.092	0.297	12.116
Pb	Rural	$PM_{2.5}$	6.198	3.487	0.005	0.153	0.149	1.442	1.826	0.511	0.338	0.022	0.195	14.324
Pb	Highway	$PM_{2.5}$	2.103	0.913	0.002	0.057	0.056	0.966	1.223	0.085	0.126	-	0.057	5.587
Pb	All	PM_1	2.039	1.051	0.001	0.047	0.046	0.445	0.564	0.183	0.105	0.016	0.078	4.575
Pb	Urban	PM_1	0.853	0.423	0.001	0.017	0.017	0.101	0.128	0.098	0.038	0.013	0.042	1.731
Pb	Rural	PM_1	0.885	0.498	0.001	0.022	0.021	0.206	0.261	0.073	0.048	0.003	0.028	2.046
Pb	Highway	PM_1	0.300	0.130	0.000	0.008	0.008	0.138	0.175	0.012	0.018	-	0.008	0.798
Pb	All	$PM_{0.1}$	1.631	0.841	0.001	0.038	0.037	0.356	0.451	0.146	0.084	0.013	0.063	3.660
Pb	Urban	$PM_{0.1}$	0.682	0.338	0.000	0.014	0.013	0.081	0.102	0.078	0.031	0.011	0.034	1.385
Pb	Rural	$PM_{0.1}$	0.708	0.398	0.001	0.018	0.017	0.165	0.209	0.058	0.039	0.002	0.022	1.637
Pb	Highway	$PM_{0.1}$	0.240	0.104	0.000	0.007	0.006	0.110	0.140	0.010	0.014	-	0.007	0.638
Se	All	TSP	8.442	4.353	0.006	0.196	0.191	1.843	2.333	0.756	0.433	0.068	0.325	18.945
Se	Urban	TSP	3.532	1.750	0.002	0.072	0.070	0.419	0.530	0.404	0.158	0.055	0.176	7.167

Continued

Se	Rural	TSP	3.666	2.062	0.003	0.091	0.088	0.853	1.080	0.302	0.200	0.013	0.115	8.473
Se	Highway	TSP	1.244	0.540	0.001	0.034	0.033	0.571	0.723	0.050	0.075	-	0.034	3.305
Se	All	PM_{10}	5.065	2.612	0.003	0.118	0.114	1.106	1.400	0.454	0.260	0.041	0.195	11.367
Se	Urban	PM_{10}	2.119	1.050	0.001	0.043	0.042	0.251	0.318	0.242	0.095	0.033	0.105	4.300
Se	Rural	PM_{10}	2.200	1.237	0.002	0.054	0.053	0.512	0.648	0.181	0.120	0.008	0.069	5.084
Se	Highway	PM_{10}	0.746	0.324	0.001	0.020	0.020	0.343	0.434	0.030	0.045	-	0.020	1.983
Se	All	$PM_{2.5}$	3.546	1.828	0.002	0.082	0.080	0.774	0.980	0.318	0.182	0.028	0.136	7.957
Se	Urban	$PM_{2.5}$	1.483	0.735	0.001	0.030	0.029	0.176	0.223	0.170	0.066	0.023	0.074	3.010
Se	Rural	$PM_{2.5}$	1.540	0.866	0.001	0.038	0.037	0.358	0.454	0.127	0.084	0.005	0.048	3.559
Se	Highway	$PM_{2.5}$	0.522	0.227	0.000	0.014	0.014	0.240	0.304	0.021	0.031	-	0.014	1.388
Se	All	PM_1	0.507	0.261	0.000	0.012	0.011	0.111	0.140	0.045	0.026	0.004	0.019	1.137
Se	Urban	PM_1	0.212	0.105	0.000	0.004	0.004	0.025	0.032	0.024	0.009	0.003	0.011	0.430
Se	Rural	PM_1	0.220	0.124	0.000	0.005	0.005	0.051	0.065	0.018	0.012	0.001	0.007	0.508
Se	Highway	PM_1	0.075	0.032	0.000	0.002	0.002	0.034	0.043	0.003	0.004	-	0.002	0.198
Se	All	$PM_{0.1}$	0.405	0.209	0.000	0.009	0.009	0.088	0.112	0.036	0.021	0.003	0.016	0.909
Se	Urban	$PM_{0.1}$	0.170	0.084	0.000	0.003	0.003	0.020	0.025	0.019	0.008	0.003	0.008	0.344
Se	Rural	$PM_{0.1}$	0.176	0.099	0.000	0.004	0.004	0.041	0.052	0.015	0.010	0.001	0.006	0.407
Se	Highway	$PM_{0.1}$	0.060	0.026	0.000	0.002	0.002	0.027	0.035	0.002	0.004	-	0.002	0.159
Zn	All	TSP	3 388.959	1 747.364	2.322	143.131	139.180	1 343.947	1 701.887	551.519	315.909	27.106	130.382	9 491.706
Zn	Urban	TSP	1 417.825	702.636	0.849	52.317	50.873	305.346	386.670	294.654	115.471	21.956	70.528	3 419.125
Zn	Rural	TSP	1 471.818	827.977	1.072	66.094	64.270	622.045	787.717	220.348	145.878	5.150	46.225	4 258.595
Zn	Highway	TSP	499.316	216.751	0.401	24.720	24.037	416.556	527.499	36.517	54.560	-	13.629	1 813.986
Zn	All	PM_{10}	2 033.376	1048.418	1.393	85.879	83.508	806.368	1 021.132	330.912	189.546	16.264	78.229	5 695.024
Zn	Urban	PM_{10}	850.695	421.582	0.509	31.390	30.524	183.207	232.002	176.792	69.282	13.174	42.317	2 051.475
Zn	Rural	PM_{10}	883.091	496.786	0.643	39.656	38.562	373.227	472.630	132.209	87.527	3.090	27.735	2 555.157
Zn	Highway	PM_{10}	299.589	130.051	0.241	14.832	14.422	249.934	316.500	21.910	32.736	-	8.177	1 088.392
Zn	All	$PM_{2.5}$	1 423.363	733.893	0.975	60.115	58.456	564.458	714.792	231.638	132.682	11.385	54.760	3 986.517
Zn	Urban	$PM_{2.5}$	595.487	295.107	0.356	21.973	21.367	128.245	162.401	123.755	48.498	9.221	29.622	1 436.032
Zn	Rural	$PM_{2.5}$	618.164	347.750	0.450	27.760	26.993	261.259	330.841	92.546	61.269	2.163	19.414	1 788.610
Zn	Highway	$PM_{2.5}$	209.713	91.035	0.168	10.382	10.096	174.953	221.550	15.337	22.915	-	5.724	761.874
Zn	All	PM_1	203.338	104.842	0.139	8.588	8.351	80.637	102.113	33.091	18.955	1.626	7.823	569.502
Zn	Urban	PM_1	85.070	42.158	0.051	3.139	3.052	18.321	23.200	17.679	6.928	1.317	4.232	205.147
Zn	Rural	PM_1	88.309	49.679	0.064	3.966	3.856	37.323	47.263	13.221	8.753	0.309	2.773	255.516
Zn	Highway	PM_1	29.959	13.005	0.024	1.483	1.442	24.993	31.650	2.191	3.274	-	0.818	108.839
Zn	All	$PM_{0.1}$	162.670	83.873	0.111	6.870	6.681	64.509	81.691	26.473	15.164	1.301	6.258	455.602
Zn	Urban	$PM_{0.1}$	68.056	33.727	0.041	2.511	2.442	14.657	18.560	14.143	5.543	1.054	3.385	164.118

Continued														
Zn	Rural	$PM_{0.1}$	70.647	39.743	0.051	3.173	3.085	29.858	37.810	10.577	7.002	0.247	2.219	204.413
Zn	Highway	$PM_{0.1}$	23.967	10.404	0.019	1.187	1.154	19.995	25.320	1.753	2.619	-	0.654	87.071

Heavy metal emission factors for brake wear (µg pr km) pr vehicle category and road type for TSP, PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$

Emission	Road type	Size	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5t.	Trucks 7.5-16t.	Trucks 16-32t.	Trucks >32t.	Urban buses	Coaches	Mopeds	MC
As	All	TSP	0.076	0.137	0.390	0.390	0.390	0.340	0.340	0.489	0.390	0.062	0.042
As	Urban	TSP	0.125	0.195	0.547	0.547	0.547	0.547	0.547	0.547	0.547	0.062	0.062
As	Rural	TSP	0.065	0.116	0.370	0.370	0.370	0.370	0.370	0.458	0.370	0.062	0.032
As	Highway	TSP	0.014	0.069	0.193	0.193	0.193	0.193	0.193	0.282	0.193	-	0.007
As	All	PM_{10}	0.075	0.134	0.382	0.382	0.382	0.333	0.333	0.480	0.382	0.061	0.042
As	Urban	PM_{10}	0.123	0.191	0.536	0.536	0.536	0.536	0.536	0.536	0.536	0.061	0.061
As	Rural	PM_{10}	0.063	0.114	0.363	0.363	0.363	0.363	0.363	0.449	0.363	0.061	0.031
As	Highway	PM_{10}	0.014	0.068	0.189	0.189	0.189	0.189	0.189	0.276	0.189	-	0.007
As	All	$PM_{2.5}$	0.030	0.053	0.152	0.152	0.152	0.133	0.133	0.191	0.152	0.024	0.017
As	Urban	$PM_{2.5}$	0.049	0.076	0.213	0.213	0.213	0.213	0.213	0.213	0.213	0.024	0.024
As	Rural	$PM_{2.5}$	0.025	0.045	0.144	0.144	0.144	0.144	0.144	0.179	0.144	0.024	0.012
As	Highway	$PM_{2.5}$	0.005	0.027	0.075	0.075	0.075	0.075	0.075	0.110	0.075	-	0.003
As	All	PM_1	0.008	0.014	0.039	0.039	0.039	0.034	0.034	0.049	0.039	0.006	0.004
As	Urban	PM_1	0.013	0.020	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.006	0.006
As	Rural	PM_1	0.006	0.012	0.037	0.037	0.037	0.037	0.037	0.046	0.037	0.006	0.003
As	Highway	PM_1	0.001	0.007	0.019	0.019	0.019	0.019	0.019	0.028	0.019	-	0.001
As	All	$PM_{0.1}$	0.006	0.011	0.031	0.031	0.031	0.027	0.027	0.039	0.031	0.005	0.003
As	Urban	$PM_{0.1}$	0.010	0.016	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.005	0.005
As	Rural	$PM_{0.1}$	0.005	0.009	0.030	0.030	0.030	0.030	0.030	0.037	0.030	0.005	0.003
As	Highway	$PM_{0.1}$	0.001	0.006	0.015	0.015	0.015	0.015	0.015	0.023	0.015	-	0.001
Cd	All	TSP	0.075	0.134	0.120	0.120	0.120	0.104	0.104	0.148	0.118	0.061	0.042
Cd	Urban	TSP	0.123	0.192	0.168	0.168	0.168	0.168	0.168	0.165	0.165	0.061	0.061
Cd	Rural	TSP	0.063	0.114	0.114	0.114	0.114	0.114	0.114	0.138	0.112	0.061	0.031
Cd	Highway	TSP	0.014	0.068	0.059	0.059	0.059	0.059	0.059	0.085	0.058	-	0.007
Cd	All	PM_{10}	0.073	0.132	0.117	0.117	0.117	0.102	0.102	0.145	0.115	0.059	0.041
Cd	Urban	PM_{10}	0.120	0.188	0.165	0.165	0.165	0.165	0.165	0.162	0.162	0.059	0.059
Cd	Rural	PM_{10}	0.062	0.112	0.111	0.111	0.111	0.111	0.111	0.136	0.110	0.059	0.031
Cd	Highway	PM_{10}	0.013	0.066	0.058	0.058	0.058	0.058	0.058	0.083	0.057	-	0.007
Cd	All	$PM_{2.5}$	0.029	0.052	0.047	0.047	0.047	0.041	0.041	0.058	0.046	0.024	0.016
Cd	Urban	$PM_{2.5}$	0.048	0.075	0.066	0.066	0.066	0.066	0.066	0.064	0.064	0.024	0.024
Cd	Rural	$PM_{2.5}$	0.025	0.045	0.044	0.044	0.044	0.044	0.044	0.054	0.044	0.024	0.012
Cd	Highway	$PM_{2.5}$	0.005	0.026	0.023	0.023	0.023	0.023	0.023	0.033	0.023	-	0.003
Cd	All	PM_1	0.007	0.013	0.012	0.012	0.012	0.010	0.010	0.015	0.012	0.006	0.004
Cd	Urban	PM_1	0.012	0.019	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.006	0.006
Cd	Rural	PM_1	0.006	0.011	0.011	0.011	0.011	0.011	0.011	0.014	0.011	0.006	0.003
Cd	Highway	PM_1	0.001	0.007	0.006	0.006	0.006	0.006	0.006	0.009	0.006	-	0.001
Cd	All	$PM_{0.1}$	0.006	0.011	0.010	0.010	0.010	0.008	0.008	0.012	0.009	0.005	0.003
Cd	Urban	$PM_{0.1}$	0.010	0.015	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.005	0.005
Cd	Rural	$PM_{0.1}$	0.005	0.009	0.009	0.009	0.009	0.009	0.009	0.011	0.009	0.005	0.002
Cd	Highway	$PM_{0.1}$	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.007	0.005	-	0.001
Cr	All	TSP	0.801	1.441	6.388	6.388	6.388	5.576	5.576	3.133	2.494	0.650	0.446
Cr	Urban	TSP	1.318	2.056	8.969	8.969	8.969	8.969	8.969	3.501	3.501	0.650	0.650
Cr	Rural	TSP	0.679	1.225	6.069	6.069	6.069	6.069	6.069	2.935	2.369	0.650	0.335
Cr	Highway	TSP	0.146	0.726	3.169	3.169	3.169	3.169	3.169	1.803	1.237	-	0.072
Cr	All	PM_{10}	0.785	1.412	6.260	6.260	6.260	5.464	5.464	3.071	2.444	0.637	0.437
Cr	Urban	PM_{10}	1.291	2.014	8.790	8.790	8.790	8.790	8.790	3.431	3.431	0.637	0.637
Cr	Rural	PM_{10}	0.665	1.200	5.947	5.947	5.947	5.947	5.947	2.877	2.322	0.637	0.328

Continued

Cr	Highway	PM_{10}	0.143	0.712	3.105	3.105	3.105	3.105	3.105	1.767	1.212	-	0.071
Cr	All	$PM_{2.5}$	0.312	0.562	2.491	2.491	2.491	2.175	2.175	1.222	0.973	0.254	0.174
Cr	Urban	$PM_{2.5}$	0.514	0.802	3.498	3.498	3.498	3.498	3.498	1.366	1.366	0.254	0.254
Cr	Rural	$PM_{2.5}$	0.265	0.478	2.367	2.367	2.367	2.367	2.367	1.145	0.924	0.254	0.131
Cr	Highway	$PM_{2.5}$	0.057	0.283	1.236	1.236	1.236	1.236	1.236	0.703	0.482	-	0.028
Cr	All	PM_1	0.080	0.144	0.639	0.639	0.639	0.558	0.558	0.313	0.249	0.065	0.045
Cr	Urban	PM_1	0.132	0.206	0.897	0.897	0.897	0.897	0.897	0.350	0.350	0.065	0.065
Cr	Rural	PM_1	0.068	0.122	0.607	0.607	0.607	0.607	0.607	0.294	0.237	0.065	0.033
Cr	Highway	PM_1	0.015	0.073	0.317	0.317	0.317	0.317	0.317	0.180	0.124	-	0.007
Cr	All	$PM_{0.1}$	0.064	0.115	0.511	0.511	0.511	0.446	0.446	0.251	0.200	0.052	0.036
Cr	Urban	$PM_{0.1}$	0.105	0.164	0.718	0.718	0.718	0.718	0.718	0.280	0.280	0.052	0.052
Cr	Rural	$PM_{0.1}$	0.054	0.098	0.486	0.486	0.486	0.486	0.486	0.235	0.190	0.052	0.027
Cr	Highway	$PM_{0.1}$	0.012	0.058	0.253	0.253	0.253	0.253	0.253	0.144	0.099	-	0.006
Cu	All	TSP	800.039	1 438.911	293.623	293.623	293.623	256.297	256.297	670.210	533.387	649.224	445.593
Cu	Urban	TSP	1 315.995	2 052.953	412.267	412.267	412.267	412.267	412.267	748.913	748.913	649.224	649.224
Cu	Rural	TSP	677.698	1 223.167	278.959	278.959	278.959	278.959	278.959	627.831	506.750	649.224	334.331
Cu	Highway	TSP	145.784	725.295	145.651	145.651	145.651	145.651	145.651	385.668	264.586	-	71.920
Cu	All	PM_{10}	784.038	1 410.133	287.750	287.750	287.750	251.171	251.171	656.806	522.720	636.240	436.682
Cu	Urban	PM_{10}	1 289.676	2 011.894	404.021	404.021	404.021	404.021	404.021	733.935	733.935	636.240	636.240
Cu	Rural	PM_{10}	664.144	1 198.703	273.380	273.380	273.380	273.380	273.380	615.275	496.615	636.240	327.645
Cu	Highway	PM_{10}	142.868	710.789	142.738	142.738	142.738	142.738	142.738	377.954	259.294	-	70.482
Cu	All	$PM_{2.5}$	312.015	561.175	114.513	114.513	114.513	99.956	99.956	261.382	208.021	253.198	173.781
Cu	Urban	$PM_{2.5}$	513.238	800.652	160.784	160.784	160.784	160.784	160.784	292.076	292.076	253.198	253.198
Cu	Rural	$PM_{2.5}$	264.302	477.035	108.794	108.794	108.794	108.794	108.794	244.854	197.632	253.198	130.389
Cu	Highway	$PM_{2.5}$	56.856	282.865	56.804	56.804	56.804	56.804	56.804	150.410	103.189	-	28.049
Cu	All	PM_1	80.004	143.891	29.362	29.362	29.362	25.630	25.630	67.021	53.339	64.922	44.559
Cu	Urban	PM_1	131.600	205.295	41.227	41.227	41.227	41.227	41.227	74.891	74.891	64.922	64.922
Cu	Rural	PM_1	67.770	122.317	27.896	27.896	27.896	27.896	27.896	62.783	50.675	64.922	33.433
Cu	Highway	PM_1	14.578	72.529	14.565	14.565	14.565	14.565	14.565	38.567	26.459	-	7.192
Cu	All	$PM_{0.1}$	64.003	115.113	23.490	23.490	23.490	20.504	20.504	53.617	42.671	51.938	35.647
Cu	Urban	$PM_{0.1}$	105.280	164.236	32.981	32.981	32.981	32.981	32.981	59.913	59.913	51.938	51.938
Cu	Rural	$PM_{0.1}$	54.216	97.853	22.317	22.317	22.317	22.317	22.317	50.226	40.540	51.938	26.746
Cu	Highway	$PM_{0.1}$	11.663	58.024	11.652	11.652	11.652	11.652	11.652	30.853	21.167	-	5.754
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_{10}	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_1	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_1	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_1	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_1	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-

Continued

Hg	Rural	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	0.802	1.442	4.440	4.440	4.440	3.876	3.876	7.782	6.193	0.651	0.447
Ni	Urban	TSP	1.319	2.057	6.234	6.234	6.234	6.234	6.234	8.695	8.695	0.651	0.651
Ni	Rural	TSP	0.679	1.226	4.219	4.219	4.219	4.219	4.219	7.290	5.884	0.651	0.335
Ni	Highway	TSP	0.146	0.727	2.203	2.203	2.203	2.203	2.203	4.478	3.072	-	0.072
Ni	All	PM_{10}	0.786	1.413	4.351	4.351	4.351	3.798	3.798	7.626	6.069	0.638	0.438
Ni	Urban	PM_{10}	1.293	2.016	6.110	6.110	6.110	6.110	6.110	8.522	8.522	0.638	0.638
Ni	Rural	PM_{10}	0.666	1.201	4.134	4.134	4.134	4.134	4.134	7.144	5.766	0.638	0.328
Ni	Highway	PM_{10}	0.143	0.712	2.159	2.159	2.159	2.159	2.159	4.388	3.011	-	0.071
Ni	All	$PM_{2.5}$	0.313	0.562	1.732	1.732	1.732	1.512	1.512	3.035	2.415	0.254	0.174
Ni	Urban	$PM_{2.5}$	0.514	0.802	2.431	2.431	2.431	2.431	2.431	3.391	3.391	0.254	0.254
Ni	Rural	$PM_{2.5}$	0.265	0.478	1.645	1.645	1.645	1.645	1.645	2.843	2.295	0.254	0.131
Ni	Highway	$PM_{2.5}$	0.057	0.283	0.859	0.859	0.859	0.859	0.859	1.746	1.198	-	0.028
Ni	All	PM_1	0.080	0.144	0.444	0.444	0.444	0.388	0.388	0.778	0.619	0.065	0.045
Ni	Urban	PM_1	0.132	0.206	0.623	0.623	0.623	0.623	0.623	0.870	0.870	0.065	0.065
Ni	Rural	PM_1	0.068	0.123	0.422	0.422	0.422	0.422	0.422	0.729	0.588	0.065	0.034
Ni	Highway	PM_1	0.015	0.073	0.220	0.220	0.220	0.220	0.220	0.448	0.307	-	0.007
Ni	All	$PM_{0.1}$	0.064	0.115	0.355	0.355	0.355	0.310	0.310	0.623	0.495	0.052	0.036
Ni	Urban	$PM_{0.1}$	0.106	0.165	0.499	0.499	0.499	0.499	0.499	0.696	0.696	0.052	0.052
Ni	Rural	$PM_{0.1}$	0.054	0.098	0.337	0.337	0.337	0.337	0.337	0.583	0.471	0.052	0.027
Ni	Highway	$PM_{0.1}$	0.012	0.058	0.176	0.176	0.176	0.176	0.176	0.358	0.246	-	0.006
Pb	All	TSP	105.486	189.722	15.853	15.853	15.853	13.837	13.837	35.752	28.453	85.601	58.752
Pb	Urban	TSP	173.515	270.684	22.258	22.258	22.258	22.258	22.258	39.950	39.950	85.601	85.601
Pb	Rural	TSP	89.355	161.276	15.061	15.061	15.061	15.061	15.061	33.491	27.032	85.601	44.082
Pb	Highway	TSP	19.222	95.631	7.864	7.864	7.864	7.864	7.864	20.573	14.114	-	9.483
Pb	All	PM_{10}	103.376	185.927	15.536	15.536	15.536	13.561	13.561	35.037	27.884	83.889	57.577
Pb	Urban	PM_{10}	170.045	265.270	21.813	21.813	21.813	21.813	21.813	39.151	39.151	83.889	83.889
Pb	Rural	PM_{10}	87.568	158.050	14.760	14.760	14.760	14.760	14.760	32.821	26.491	83.889	43.200
Pb	Highway	PM_{10}	18.837	93.718	7.706	7.706	7.706	7.706	7.706	20.162	13.832	-	9.293
Pb	All	$PM_{2.5}$	41.139	73.991	6.183	6.183	6.183	5.397	5.397	13.943	11.097	33.384	22.913
Pb	Urban	$PM_{2.5}$	67.671	105.567	8.681	8.681	8.681	8.681	8.681	15.580	15.580	33.384	33.384
Pb	Rural	$PM_{2.5}$	34.848	62.897	5.874	5.874	5.874	5.874	5.874	13.061	10.542	33.384	17.192
Pb	Highway	$PM_{2.5}$	7.496	37.296	3.067	3.067	3.067	3.067	3.067	8.023	5.504	-	3.698
Pb	All	PM_1	10.549	18.972	1.585	1.585	1.585	1.384	1.384	3.575	2.845	8.560	5.875
Pb	Urban	PM_1	17.352	27.068	2.226	2.226	2.226	2.226	2.226	3.995	3.995	8.560	8.560
Pb	Rural	PM_1	8.936	16.128	1.506	1.506	1.506	1.506	1.506	3.349	2.703	8.560	4.408
Pb	Highway	PM_1	1.922	9.563	0.786	0.786	0.786	0.786	0.786	2.057	1.411	-	0.948
Pb	All	$PM_{0.1}$	8.439	15.178	1.268	1.268	1.268	1.107	1.107	2.860	2.276	6.848	4.700
Pb	Urban	$PM_{0.1}$	13.881	21.655	1.781	1.781	1.781	1.781	1.781	3.196	3.196	6.848	6.848
Pb	Rural	$PM_{0.1}$	7.148	12.902	1.205	1.205	1.205	1.205	1.205	2.679	2.163	6.848	3.527
Pb	Highway	$PM_{0.1}$	1.538	7.650	0.629	0.629	0.629	0.629	0.629	1.646	1.129	-	0.759
Se	All	TSP	0.152	0.274	0.779	0.779	0.779	0.680	0.680	0.979	0.779	0.124	0.085
Se	Urban	TSP	0.251	0.391	1.094	1.094	1.094	1.094	1.094	1.094	1.094	0.124	0.124
Se	Rural	TSP	0.129	0.233	0.740	0.740	0.740	0.740	0.740	0.917	0.740	0.124	0.064
Se	Highway	TSP	0.028	0.138	0.386	0.386	0.386	0.386	0.386	0.563	0.386	-	0.014
Se	All	PM_{10}	0.149	0.268	0.763	0.763	0.763	0.666	0.666	0.959	0.763	0.121	0.083
Se	Urban	PM_{10}	0.245	0.383	1.072	1.072	1.072	1.072	1.072	1.072	1.072	0.121	0.121
Se	Rural	PM_{10}	0.126	0.228	0.725	0.725	0.725	0.725	0.725	0.899	0.725	0.121	0.062
Se	Highway	PM_{10}	0.027	0.135	0.379	0.379	0.379	0.379	0.379	0.552	0.379	-	0.013
Se	All	$PM_{2.5}$	0.059	0.107	0.304	0.304	0.304	0.265	0.265	0.382	0.304	0.048	0.033

Continued

Se	Urban	$PM_{2.5}$	0.098	0.152	0.427	0.427	0.427	0.427	0.427	0.427	0.427	0.048	0.048
Se	Rural	$PM_{2.5}$	0.050	0.091	0.289	0.289	0.289	0.289	0.289	0.358	0.289	0.048	0.025
Se	Highway	$PM_{2.5}$	0.011	0.054	0.151	0.151	0.151	0.151	0.151	0.220	0.151	-	0.005
Se	All	PM_1	0.015	0.027	0.078	0.078	0.078	0.068	0.068	0.098	0.078	0.012	0.008
Se	Urban	PM_1	0.025	0.039	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.012	0.012
Se	Rural	PM_1	0.013	0.023	0.074	0.074	0.074	0.074	0.074	0.092	0.074	0.012	0.006
Se	Highway	PM_1	0.003	0.014	0.039	0.039	0.039	0.039	0.039	0.056	0.039	-	0.001
Se	All	$PM_{0.1}$	0.012	0.022	0.062	0.062	0.062	0.054	0.054	0.078	0.062	0.010	0.007
Se	Urban	$PM_{0.1}$	0.020	0.031	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.010	0.010
Se	Rural	$PM_{0.1}$	0.010	0.019	0.059	0.059	0.059	0.059	0.059	0.073	0.059	0.010	0.005
Se	Highway	$PM_{0.1}$	0.002	0.011	0.031	0.031	0.031	0.031	0.031	0.045	0.031	-	0.001
Zn	All	TSP	153.536	276.143	292.651	292.651	292.651	255.448	255.448	456.916	363.637	124.593	85.514
Zn	Urban	TSP	252.554	393.984	410.902	410.902	410.902	410.902	410.902	510.572	510.572	124.593	124.593
Zn	Rural	TSP	130.058	234.739	278.036	278.036	278.036	278.036	278.036	428.025	345.477	124.593	64.162
Zn	Highway	TSP	27.978	139.192	145.169	145.169	145.169	145.169	145.169	262.929	180.382	-	13.802
Zn	All	PM_{10}	150.466	270.620	286.798	286.798	286.798	250.339	250.339	447.778	356.365	122.101	83.804
Zn	Urban	PM_{10}	247.503	386.105	402.684	402.684	402.684	402.684	402.684	500.361	500.361	122.101	122.101
Zn	Rural	PM_{10}	127.457	230.044	272.475	272.475	272.475	272.475	272.475	419.464	338.567	122.101	62.879
Zn	Highway	PM_{10}	27.418	136.408	142.266	142.266	142.266	142.266	142.266	257.671	176.774	-	13.526
Zn	All	$PM_{2.5}$	59.879	107.696	114.134	114.134	114.134	99.625	99.625	178.197	141.819	48.591	33.351
Zn	Urban	$PM_{2.5}$	98.496	153.654	160.252	160.252	160.252	160.252	160.252	199.123	199.123	48.591	48.591
Zn	Rural	$PM_{2.5}$	50.723	91.548	108.434	108.434	108.434	108.434	108.434	166.930	134.736	48.591	25.023
Zn	Highway	$PM_{2.5}$	10.911	54.285	56.616	56.616	56.616	56.616	56.616	102.542	70.349	-	5.383
Zn	All	PM_1	15.354	27.614	29.265	29.265	29.265	25.545	25.545	45.692	36.364	12.459	8.551
Zn	Urban	PM_1	25.255	39.398	41.090	41.090	41.090	41.090	41.090	51.057	51.057	12.459	12.459
Zn	Rural	PM_1	13.006	23.474	27.804	27.804	27.804	27.804	27.804	42.802	34.548	12.459	6.416
Zn	Highway	PM_1	2.798	13.919	14.517	14.517	14.517	14.517	14.517	26.293	18.038	-	1.380
Zn	All	$PM_{0.1}$	12.283	22.091	23.412	23.412	23.412	20.436	20.436	36.553	29.091	9.967	6.841
Zn	Urban	$PM_{0.1}$	20.204	31.519	32.872	32.872	32.872	32.872	32.872	40.846	40.846	9.967	9.967
Zn	Rural	$PM_{0.1}$	10.405	18.779	22.243	22.243	22.243	22.243	22.243	34.242	27.638	9.967	5.133
Zn	Highway	$PM_{0.1}$	2.238	11.135	11.614	11.614	11.614	11.614	11.614	21.034	14.431	-	1.104

Heavy metal emissions for brake wear (kg) pr vehicle category and road type for TSP, PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$

Emission	Road type	Size	Cars	Vans	Trucks Gasoline	Trucks 3.5-7.5t.	Trucks 7.5-16t.	Trucks 16-32t.	Trucks >32t.	Urban buses	Coaches	Mopeds	MC	Total
As	All	TSP	2.968	1.740	0.004	0.135	0.087	0.531	0.560	0.290	0.149	0.015	0.039	6.518
As	Urban	TSP	1.709	0.869	0.002	0.061	0.039	0.162	0.171	0.165	0.067	0.012	0.027	3.283
As	Rural	TSP	1.156	0.740	0.002	0.060	0.039	0.260	0.274	0.111	0.066	0.003	0.011	2.723
As	Highway	TSP	0.103	0.132	0.000	0.014	0.009	0.109	0.115	0.013	0.016	-	0.001	0.511
As	All	PM_{10}	2.908	1.705	0.004	0.132	0.086	0.520	0.549	0.284	0.146	0.014	0.038	6.387
As	Urban	PM_{10}	1.674	0.852	0.002	0.059	0.039	0.159	0.168	0.162	0.066	0.012	0.026	3.218
As	Rural	PM_{10}	1.133	0.725	0.002	0.059	0.038	0.255	0.269	0.109	0.065	0.003	0.011	2.669
As	Highway	PM_{10}	0.101	0.129	0.000	0.014	0.009	0.106	0.112	0.013	0.015	-	0.001	0.501
As	All	$PM_{2.5}$	1.157	0.679	0.002	0.053	0.034	0.207	0.218	0.113	0.058	0.006	0.015	2.542
As	Urban	$PM_{2.5}$	0.666	0.339	0.001	0.024	0.015	0.063	0.067	0.065	0.026	0.005	0.010	1.281
As	Rural	$PM_{2.5}$	0.451	0.288	0.001	0.023	0.015	0.101	0.107	0.043	0.026	0.001	0.004	1.062
As	Highway	$PM_{2.5}$	0.040	0.051	0.000	0.005	0.004	0.042	0.045	0.005	0.006	-	0.000	0.199
As	All	PM_1	0.297	0.174	0.000	0.013	0.009	0.053	0.056	0.029	0.015	0.001	0.004	0.652
As	Urban	PM_1	0.171	0.087	0.000	0.006	0.004	0.016	0.017	0.017	0.007	0.001	0.003	0.328
As	Rural	PM_1	0.116	0.074	0.000	0.006	0.004	0.026	0.027	0.011	0.007	0.000	0.001	0.272
As	Highway	PM_1	0.010	0.013	0.000	0.001	0.001	0.011	0.011	0.001	0.002	-	0.000	0.051
As	All	$PM_{0.1}$	0.237	0.139	0.000	0.011	0.007	0.042	0.045	0.023	0.012	0.001	0.003	0.521
As	Urban	$PM_{0.1}$	0.137	0.070	0.000	0.005	0.003	0.013	0.014	0.013	0.005	0.001	0.002	0.263
As	Rural	$PM_{0.1}$	0.093	0.059	0.000	0.005	0.003	0.021	0.022	0.009	0.005	0.000	0.001	0.218
As	Highway	$PM_{0.1}$	0.008	0.011	0.000	0.001	0.001	0.009	0.009	0.001	0.001	-	0.000	0.041
Cd	All	TSP	2.911	1.707	0.001	0.041	0.027	0.163	0.172	0.088	0.045	0.014	0.038	5.208
Cd	Urban	TSP	1.676	0.853	0.001	0.019	0.012	0.050	0.053	0.050	0.020	0.012	0.026	2.770
Cd	Rural	TSP	1.134	0.726	0.001	0.019	0.012	0.080	0.084	0.034	0.020	0.003	0.011	2.123
Cd	Highway	TSP	0.101	0.129	0.000	0.004	0.003	0.033	0.035	0.004	0.005	-	0.001	0.315
Cd	All	PM_{10}	2.853	1.673	0.001	0.041	0.026	0.160	0.169	0.086	0.044	0.014	0.037	5.104
Cd	Urban	PM_{10}	1.643	0.835	0.001	0.018	0.012	0.049	0.052	0.049	0.020	0.011	0.026	2.715
Cd	Rural	PM_{10}	1.112	0.711	0.001	0.018	0.012	0.078	0.083	0.033	0.020	0.003	0.011	2.080
Cd	Highway	PM_{10}	0.099	0.127	0.000	0.004	0.003	0.033	0.034	0.004	0.005	-	0.001	0.309
Cd	All	$PM_{2.5}$	1.135	0.666	0.000	0.016	0.010	0.064	0.067	0.034	0.018	0.006	0.015	2.031
Cd	Urban	$PM_{2.5}$	0.654	0.332	0.000	0.007	0.005	0.019	0.021	0.019	0.008	0.005	0.010	1.080
Cd	Rural	$PM_{2.5}$	0.442	0.283	0.000	0.007	0.005	0.031	0.033	0.013	0.008	0.001	0.004	0.828
Cd	Highway	$PM_{2.5}$	0.039	0.050	0.000	0.002	0.001	0.013	0.014	0.002	0.002	-	0.000	0.123
Cd	All	PM_1	0.291	0.171	0.000	0.004	0.003	0.016	0.017	0.009	0.004	0.001	0.004	0.521
Cd	Urban	PM_1	0.168	0.085	0.000	0.002	0.001	0.005	0.005	0.005	0.002	0.001	0.003	0.277
Cd	Rural	PM_1	0.113	0.073	0.000	0.002	0.001	0.008	0.008	0.003	0.002	0.000	0.001	0.212
Cd	Highway	PM_1	0.010	0.013	0.000	0.000	0.000	0.003	0.004	0.000	0.000	-	0.000	0.032
Cd	All	$PM_{0.1}$	0.233	0.137	0.000	0.003	0.002	0.013	0.014	0.007	0.004	0.001	0.003	0.417
Cd	Urban	$PM_{0.1}$	0.134	0.068	0.000	0.001	0.001	0.004	0.004	0.004	0.002	0.001	0.002	0.222
Cd	Rural	$PM_{0.1}$	0.091	0.058	0.000	0.001	0.001	0.006	0.007	0.003	0.002	0.000	0.001	0.170
Cd	Highway	$PM_{0.1}$	0.008	0.010	0.000	0.000	0.000	0.003	0.003	0.000	0.000	-	0.000	0.025
Cr	All	TSP	31.221	18.308	0.065	2.212	1.434	8.703	9.184	1.858	0.953	0.155	0.409	74.502
Cr	Urban	TSP	17.974	9.142	0.029	0.994	0.644	2.660	2.807	1.059	0.428	0.125	0.280	36.144
Cr	Rural	TSP	12.165	7.781	0.029	0.988	0.640	4.263	4.498	0.714	0.426	0.029	0.120	31.653
Cr	Highway	TSP	1.081	1.384	0.007	0.230	0.149	1.780	1.879	0.086	0.099	-	0.009	6.705
Cr	All	PM_{10}	30.596	17.942	0.064	2.168	1.405	8.529	9.000	1.821	0.934	0.152	0.401	73.012
Cr	Urban	PM_{10}	17.615	8.959	0.029	0.974	0.631	2.607	2.751	1.038	0.420	0.123	0.275	35.421
Cr	Rural	PM_{10}	11.922	7.626	0.029	0.968	0.628	4.177	4.408	0.699	0.417	0.029	0.117	31.020
Cr	Highway	PM_{10}	1.059	1.357	0.007	0.226	0.146	1.745	1.841	0.084	0.097	-	0.009	6.571

Continued

Cr	All	$PM_{2.5}$	12.176	7.140	0.025	0.863	0.559	3.394	3.582	0.725	0.372	0.060	0.160	29.056
Cr	Urban	$PM_{2.5}$	7.010	3.565	0.011	0.388	0.251	1.037	1.095	0.413	0.167	0.049	0.109	14.096
Cr	Rural	$PM_{2.5}$	4.744	3.035	0.011	0.385	0.250	1.662	1.754	0.278	0.166	0.011	0.047	12.345
Cr	Highway	$PM_{2.5}$	0.422	0.540	0.003	0.090	0.058	0.694	0.733	0.033	0.039	-	0.004	2.615
Cr	All	PM_1	3.122	1.831	0.007	0.221	0.143	0.870	0.918	0.186	0.095	0.015	0.041	7.450
Cr	Urban	PM_1	1.797	0.914	0.003	0.099	0.064	0.266	0.281	0.106	0.043	0.013	0.028	3.614
Cr	Rural	PM_1	1.217	0.778	0.003	0.099	0.064	0.426	0.450	0.071	0.043	0.003	0.012	3.165
Cr	Highway	PM_1	0.108	0.138	0.001	0.023	0.015	0.178	0.188	0.009	0.010	-	0.001	0.671
Cr	All	$PM_{0.1}$	2.498	1.465	0.005	0.177	0.115	0.696	0.735	0.149	0.076	0.012	0.033	5.960
Cr	Urban	$PM_{0.1}$	1.438	0.731	0.002	0.080	0.052	0.213	0.225	0.085	0.034	0.010	0.022	2.892
Cr	Rural	$PM_{0.1}$	0.973	0.623	0.002	0.079	0.051	0.341	0.360	0.057	0.034	0.002	0.010	2.532
Cr	Highway	$PM_{0.1}$	0.086	0.111	0.001	0.018	0.012	0.142	0.150	0.007	0.008	-	0.001	0.536
Cu	All	TSP	31 181.875	18 285.286	2.997	101.686	65.919	400.039	422.153	397.489	203.850	154.715	408.617	51 624.627
Cu	Urban	TSP	17 952.038	9 130.927	1.347	45.688	29.618	122.262	129.021	226.525	91.590	125.319	279.815	28 134.148
Cu	Rural	TSP	12 150.258	7 771.832	1.338	45.405	29.435	195.935	206.766	152.666	91.025	29.396	119.569	20 793.626
Cu	Highway	TSP	1 079.579	1 382.527	0.312	10.593	6.867	81.842	86.366	18.299	21.235	-	9.233	2 696.853
Cu	All	PM_{10}	30 558.238	17 919.580	2.937	99.652	64.601	392.038	413.710	389.539	199.773	151.621	400.445	50 592.135
Cu	Urban	PM_{10}	17 592.997	8 948.308	1.320	44.774	29.025	119.817	126.440	221.995	89.759	122.813	274.218	27 571.465
Cu	Rural	PM_{10}	11 907.253	7 616.396	1.311	44.497	28.846	192.017	202.631	149.612	89.204	28.808	117.178	20 377.754
Cu	Highway	PM_{10}	1 057.988	1 354.876	0.306	10.381	6.729	80.205	84.639	17.933	20.810	-	9.049	2 642.916
Cu	All	$PM_{2.5}$	12 160.931	7 131.262	1.169	39.657	25.708	156.015	164.640	155.021	79.502	60.339	159.361	20 133.605
Cu	Urban	$PM_{2.5}$	7 001.295	3 561.061	0.525	17.818	11.551	47.682	50.318	88.345	35.720	48.875	109.128	10 972.318
Cu	Rural	$PM_{2.5}$	4 738.601	3 031.015	0.522	17.708	11.480	76.415	80.639	59.540	35.500	11.464	46.632	8 109.514
Cu	Highway	$PM_{2.5}$	421.036	539.186	0.122	4.131	2.678	31.918	33.683	7.136	8.282	-	3.601	1 051.773
Cu	All	PM_1	3 118.188	1 828.529	0.300	10.169	6.592	40.004	42.215	39.749	20.385	15.472	40.862	5 162.463
Cu	Urban	PM_1	1 795.204	913.093	0.135	4.569	2.962	12.226	12.902	22.653	9.159	12.532	27.981	2 813.415
Cu	Rural	PM_1	1 215.026	777.183	0.134	4.541	2.943	19.594	20.677	15.267	9.102	2.940	11.957	2 079.363
Cu	Highway	PM_1	107.958	138.253	0.031	1.059	0.687	8.184	8.637	1.830	2.124	-	0.923	269.685
Cu	All	$PM_{0.1}$	2 494.550	1 462.823	0.240	8.135	5.274	32.003	33.772	31.799	16.308	12.377	32.689	4 129.970
Cu	Urban	$PM_{0.1}$	1 436.163	730.474	0.108	3.655	2.369	9.781	10.322	18.122	7.327	10.026	22.385	2 250.732
Cu	Rural	$PM_{0.1}$	972.021	621.747	0.107	3.632	2.355	15.675	16.541	12.213	7.282	2.352	9.566	1 663.490
Cu	Highway	$PM_{0.1}$	86.366	110.602	0.025	0.847	0.549	6.547	6.909	1.464	1.699	-	0.739	215.748
Hg	All	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	TSP	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_{10}	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	$PM_{2.5}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Highway	PM_1	-	-	-	-	-	-	-	-	-	-	-	-
Hg	All	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Urban	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-
Hg	Rural	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-

Continued

Hg	Highway	$PM_{0.1}$	-	-	-	-	-	-	-	-	-	-	-	-
Ni	All	TSP	31.250	18.325	0.045	1.538	0.997	6.050	6.384	4.615	2.367	0.155	0.410	72.136
Ni	Urban	TSP	17.991	9.151	0.020	0.691	0.448	1.849	1.951	2.630	1.063	0.126	0.280	36.201
Ni	Rural	TSP	12.177	7.789	0.020	0.687	0.445	2.963	3.127	1.773	1.057	0.029	0.120	30.186
Ni	Highway	TSP	1.082	1.386	0.005	0.160	0.104	1.238	1.306	0.212	0.247	-	0.009	5.748
Ni	All	PM_{10}	30.625	17.959	0.044	1.507	0.977	5.929	6.256	4.523	2.320	0.152	0.401	70.693
Ni	Urban	PM_{10}	17.632	8.968	0.020	0.677	0.439	1.812	1.912	2.578	1.042	0.123	0.275	35.477
Ni	Rural	PM_{10}	11.933	7.633	0.020	0.673	0.436	2.904	3.064	1.737	1.036	0.029	0.117	29.583
Ni	Highway	PM_{10}	1.060	1.358	0.005	0.157	0.102	1.213	1.280	0.208	0.242	-	0.009	5.633
Ni	All	$PM_{2.5}$	12.188	7.147	0.018	0.600	0.389	2.359	2.490	1.800	0.923	0.060	0.160	28.133
Ni	Urban	$PM_{2.5}$	7.017	3.569	0.008	0.269	0.175	0.721	0.761	1.026	0.415	0.049	0.109	14.118
Ni	Rural	$PM_{2.5}$	4.749	3.038	0.008	0.268	0.174	1.156	1.219	0.691	0.412	0.011	0.047	11.773
Ni	Highway	$PM_{2.5}$	0.422	0.540	0.002	0.062	0.040	0.483	0.509	0.083	0.096	-	0.004	2.242
Ni	All	PM_{1}	3.125	1.833	0.005	0.154	0.100	0.605	0.638	0.462	0.237	0.016	0.041	7.214
Ni	Urban	PM_{1}	1.799	0.915	0.002	0.069	0.045	0.185	0.195	0.263	0.106	0.013	0.028	3.620
Ni	Rural	PM_{1}	1.218	0.779	0.002	0.069	0.045	0.296	0.313	0.177	0.106	0.003	0.012	3.019
Ni	Highway	PM_{1}	0.108	0.139	0.000	0.016	0.010	0.124	0.131	0.021	0.025	-	0.001	0.575
Ni	All	$PM_{0.1}$	2.500	1.466	0.004	0.123	0.080	0.484	0.511	0.369	0.189	0.012	0.033	5.771
Ni	Urban	$PM_{0.1}$	1.439	0.732	0.002	0.055	0.036	0.148	0.156	0.210	0.085	0.010	0.022	2.896
Ni	Rural	$PM_{0.1}$	0.974	0.623	0.002	0.055	0.036	0.237	0.250	0.142	0.085	0.002	0.010	2.415
Ni	Highway	$PM_{0.1}$	0.087	0.111	0.000	0.013	0.008	0.099	0.104	0.017	0.020	-	0.001	0.460
Pb	All	TSP	4 111.356	2 410.930	0.162	5.490	3.559	21.598	22.792	21.204	10.874	20.399	53.877	6 682.240
Pb	Urban	TSP	2 366.991	1 203.920	0.073	2.467	1.599	6.601	6.966	12.084	4.886	16.523	36.894	3 659.003
Pb	Rural	TSP	1 602.022	1 024.722	0.072	2.451	1.589	10.579	11.163	8.144	4.856	3.876	15.765	2 685.239
Pb	Highway	TSP	142.343	182.287	0.017	0.572	0.371	4.419	4.663	0.976	1.133	-	1.217	337.998
Pb	All	PM_{10}	4 029.129	2 362.711	0.159	5.380	3.488	21.166	22.336	20.780	10.657	19.991	52.799	6 548.596
Pb	Urban	PM_{10}	2 319.651	1 179.842	0.071	2.417	1.567	6.469	6.826	11.842	4.788	16.193	36.156	3 585.823
Pb	Rural	PM_{10}	1 569.981	1 004.228	0.071	2.402	1.557	10.367	10.940	7.981	4.759	3.798	15.450	2 631.535
Pb	Highway	PM_{10}	139.497	178.642	0.017	0.560	0.363	4.330	4.570	0.957	1.110	-	1.193	331.238
Pb	All	$PM_{2.5}$	1 603.429	940.263	0.063	2.141	1.388	8.423	8.889	8.269	4.241	7.956	21.012	2 606.074
Pb	Urban	$PM_{2.5}$	923.126	469.529	0.028	0.962	0.624	2.574	2.717	4.713	1.905	6.444	14.389	1 427.011
Pb	Rural	$PM_{2.5}$	624.788	399.642	0.028	0.956	0.620	4.126	4.354	3.176	1.894	1.512	6.148	1 047.243
Pb	Highway	$PM_{2.5}$	55.514	71.092	0.007	0.223	0.145	1.723	1.819	0.381	0.442	-	0.475	131.819
Pb	All	PM_{1}	411.136	241.093	0.016	0.549	0.356	2.160	2.279	2.120	1.087	2.040	5.388	668.224
Pb	Urban	PM_{1}	236.699	120.392	0.007	0.247	0.160	0.660	0.697	1.208	0.489	1.652	3.689	365.900
Pb	Rural	PM_{1}	160.202	102.472	0.007	0.245	0.159	1.058	1.116	0.814	0.486	0.388	1.577	268.524
Pb	Highway	PM_{1}	14.234	18.229	0.002	0.057	0.037	0.442	0.466	0.098	0.113	-	0.122	33.800
Pb	All	$PM_{0.1}$	328.908	192.874	0.013	0.439	0.285	1.728	1.823	1.696	0.870	1.632	4.310	534.579
Pb	Urban	$PM_{0.1}$	189.359	96.314	0.006	0.197	0.128	0.528	0.557	0.967	0.391	1.322	2.952	292.720
Pb	Rural	$PM_{0.1}$	128.162	81.978	0.006	0.196	0.127	0.846	0.893	0.652	0.388	0.310	1.261	214.819
Pb	Highway	$PM_{0.1}$	11.387	14.583	0.001	0.046	0.030	0.353	0.373	0.078	0.091	-	0.097	27.040
Se	All	TSP	5.935	3.481	0.008	0.270	0.175	1.061	1.120	0.581	0.298	0.029	0.078	13.036
Se	Urban	TSP	3.417	1.738	0.004	0.121	0.079	0.324	0.342	0.331	0.134	0.024	0.053	6.567
Se	Rural	TSP	2.313	1.479	0.004	0.120	0.078	0.520	0.549	0.223	0.133	0.006	0.023	5.447
Se	Highway	TSP	0.205	0.263	0.001	0.028	0.018	0.217	0.229	0.027	0.031	-	0.002	1.022
Se	All	PM_{10}	5.817	3.411	0.008	0.264	0.171	1.040	1.098	0.569	0.292	0.029	0.076	12.775
Se	Urban	PM_{10}	3.349	1.703	0.004	0.119	0.077	0.318	0.335	0.324	0.131	0.023	0.052	6.436
Se	Rural	PM_{10}	2.267	1.450	0.003	0.118	0.077	0.509	0.538	0.219	0.130	0.005	0.022	5.338
Se	Highway	PM_{10}	0.201	0.258	0.001	0.028	0.018	0.213	0.225	0.026	0.030	-	0.002	1.001
Se	All	$PM_{2.5}$	2.315	1.357	0.003	0.105	0.068	0.414	0.437	0.226	0.116	0.011	0.030	5.084
Se	Urban	$PM_{2.5}$	1.333	0.678	0.001	0.047	0.031	0.127	0.133	0.129	0.052	0.009	0.021	2.561

Continued

Se	Rural	$PM_{2.5}$	0.902	0.577	0.001	0.047	0.030	0.203	0.214	0.087	0.052	0.002	0.009	2.124
Se	Highway	$PM_{2.5}$	0.080	0.103	0.000	0.011	0.007	0.085	0.089	0.010	0.012	-	0.001	0.398
Se	All	PM_1	0.594	0.348	0.001	0.027	0.017	0.106	0.112	0.058	0.030	0.003	0.008	1.304
Se	Urban	PM_1	0.342	0.174	0.000	0.012	0.008	0.032	0.034	0.033	0.013	0.002	0.005	0.657
Se	Rural	PM_1	0.231	0.148	0.000	0.012	0.008	0.052	0.055	0.022	0.013	0.001	0.002	0.545
Se	Highway	PM_1	0.021	0.026	0.000	0.003	0.002	0.022	0.023	0.003	0.003	-	0.000	0.102
Se	All	$PM_{0.1}$	0.475	0.278	0.001	0.022	0.014	0.085	0.090	0.046	0.024	0.002	0.006	1.043
Se	Urban	$PM_{0.1}$	0.273	0.139	0.000	0.010	0.006	0.026	0.027	0.026	0.011	0.002	0.004	0.525
Se	Rural	$PM_{0.1}$	0.185	0.118	0.000	0.010	0.006	0.042	0.044	0.018	0.011	0.000	0.002	0.436
Se	Highway	$PM_{0.1}$	0.016	0.021	0.000	0.002	0.001	0.017	0.018	0.002	0.002	-	0.000	0.082
Zn	All	TSP	5 984.147	3 509.149	2.987	101.349	65.701	398.715	420.756	270.989	138.975	29.692	78.418	11 000.878
Zn	Urban	TSP	3 445.195	1 752.326	1.342	45.536	29.520	121.857	128.594	154.434	62.442	24.050	53.700	5 818.995
Zn	Rural	TSP	2 331.769	1 491.501	1.334	45.255	29.337	195.287	206.082	104.080	62.056	5.641	22.947	4 495.289
Zn	Highway	TSP	207.183	265.322	0.311	10.558	6.844	81.571	86.080	12.475	14.477	-	1.772	686.594
Zn	All	PM_{10}	5 864.464	3 438.966	2.927	99.322	64.387	390.741	412.341	265.569	136.196	29.098	76.850	10 780.860
Zn	Urban	PM_{10}	3 376.291	1 717.279	1.315	44.626	28.929	119.420	126.022	151.345	61.193	23.569	52.626	5 702.615
Zn	Rural	PM_{10}	2 285.134	1 461.671	1.307	44.350	28.751	191.381	201.960	101.998	60.815	5.529	22.488	4 405.383
Zn	Highway	PM_{10}	203.040	260.016	0.305	10.346	6.707	79.940	84.359	12.226	14.188	-	1.737	672.862
Zn	All	$PM_{2.5}$	2 333.817	1 368.568	1.165	39.526	25.623	155.499	164.095	105.686	54.200	11.580	30.583	4 290.342
Zn	Urban	$PM_{2.5}$	1 343.626	683.407	0.523	17.759	11.513	47.524	50.151	60.229	24.352	9.380	20.943	2 269.408
Zn	Rural	$PM_{2.5}$	909.390	581.685	0.520	17.650	11.442	76.162	80.372	40.591	24.202	2.200	8.949	1 753.163
Zn	Highway	$PM_{2.5}$	80.801	103.476	0.121	4.117	2.669	31.813	33.571	4.865	5.646	-	0.691	267.772
Zn	All	PM_1	598.415	350.915	0.299	10.135	6.570	39.872	42.076	27.099	13.898	2.969	7.842	1 100.088
Zn	Urban	PM_1	344.519	175.233	0.134	4.554	2.952	12.186	12.859	15.443	6.244	2.405	5.370	581.899
Zn	Rural	PM_1	233.177	149.150	0.133	4.526	2.934	19.529	20.608	10.408	6.206	0.564	2.295	449.529
Zn	Highway	PM_1	20.718	26.532	0.031	1.056	0.684	8.157	8.608	1.248	1.448	-	0.177	68.659
Zn	All	$PM_{0.1}$	478.732	280.732	0.239	8.108	5.256	31.897	33.660	21.679	11.118	2.375	6.273	880.070
Zn	Urban	$PM_{0.1}$	275.616	140.186	0.107	3.643	2.362	9.749	10.287	12.355	4.995	1.924	4.296	465.520
Zn	Rural	$PM_{0.1}$	186.542	119.320	0.107	3.620	2.347	15.623	16.487	8.326	4.965	0.451	1.836	359.623
Zn	Highway	$PM_{0.1}$	16.575	21.226	0.025	0.845	0.548	6.526	6.886	0.998	1.158	-	0.142	54.927

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