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Aerosol particle and trace gas emissions from earthworks, road construction, and asphalt paving in Germany: Emission factors and influence on local air quality

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HIGHLIGHTS

- Construction site emissions are characterized by modern online techniques.
- These emissions have significant effects on local air quality.
- The influence of meteorological conditions on mineral dust emissions is shown.
- An emission inventory is calculated based on fuel-based emission factors.
- Construction site emissions contribute to 17% of total PM_{10} emissions in Germany.

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ABSTRACT

Aerosol emissions from construction sites have a strong impact on local air quality. The chemical and physical characteristics of particles and trace gases emitted by earthworks (excavation and loading of soil as well as traffic on unpaved roads) and road works (asphalt sawing, smashing, soil compacting, asphalt paving) have therefore been addressed in this study by using a mobile set-up of numerous modern online aerosol and trace gas instruments including a high-resolution aerosol mass spectrometer.

Fuel-based emission factors for several variables have been determined, showing that earthwork activities and compacting by use of a plate compactor revealed the highest median emission factors for PM_{10} (up to 54 g l^{-1}). Construction activities were assigned to contribute about 17% (36 000 t a^{-1}) to total PM_{10} emissions and 3% (13 500 t a^{-1}) to total traffic-related NO_x emissions in Germany. In particular, calculated PM_{10} emissions by earthworks are about 15 800 t a^{-1} corresponding to 44% of total PM_{10} emissions by construction activities in Germany.

Mechanical processes such as asphalt sawing ($PM_1/PM_{10} = 18 \pm 31\%$), soil compacting by a plate compactor ($PM_1/PM_{10} = 5 \pm 6\%$) and earthworks ($PM_1/PM_{10} = 2 \pm 5\%$) emit predominantly coarse mineral dust particles. Contrary to that, particle emissions by thermal construction processes (asphalt paving: $PM_1/PM_{10} = 62 \pm 14\%$) and by the internal combustion engines of heavy machinery (e.g. road roller $PM_1/PM_{10} = 94 \pm 9\%$) are mostly in the submicron range. These particles were mainly composed of organics containing non-polar saturated and unsaturated hydrocarbons (e.g. asphalting: O:C < 0.01, H:C = 2.01). Besides construction activities, mineral dust is also emitted over cleared land by wind-driven resuspension depending on wind speed. PM_{10} emissions by construction activities often result in local concentrations > 100 μg m^{-3} and can easily breach the European limit level of PM_{10}. This study also shows that particulate mineral dust emissions are strongly dependent on soil moisture and can thus successfully be reduced to a high percentage by wetting the ground (for PM_{10} up to 95 ± 34%) showing the importance of potential mitigation strategies.

1. Introduction

Construction activities have been identified as dynamic sources for the input of aerosol particles and harmful trace gases into the

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atmosphere and can therefore temporarily affect the local air quality (Heidari and Marr, 2015; Kong et al., 2015; Font et al., 2014; Fu et al., 2012). In particular, high PM emissions from building and demolition operations resulting in ambient mass concentrations of >100 μg m^{-3} are of special interest as those can easily exceed the European limit level of PM_{10} (e.g. Font et al., 2014; Fuller and Green, 2004) which means a daily mean concentration of 50 μg m^{-3} that should not be exceeded on more than 35 days per year. Adverse health effects of PM have already been confirmed in many scientific studies (Kim et al., 2015) and pose a risk of premature mortality (Lelieveld et al., 2015). Negative effects of particulate and gaseous construction site emissions on the health of construction workers (Ulvestad et al., 2015; Torén and Järvholm, 2014) as well as on public health can therefore not be excluded (Chauhan et al., 2010). Construction activities are likely to increase with the stage of urbanization on a global scale (Azarmi et al., 2014; Guttikunda et al., 2014) and their relative importance as emission source is rising as other anthropogenic aerosol sources get more and more regulated (Fuller and Green, 2004). Although construction sites appear to be highly localized and isolated, their vast number throughout the whole year makes them a major source of anthropogenic particles contributing significantly to the ambient aerosol (e.g. Guttikunda and Jawahar, 2012).

The chemical and physical characteristics of the gaseous and particulate emissions from construction sites differ strongly depending on the variety of specific activities, materials, machines and tools that are used (Font et al., 2014; Muleski et al., 2005; Abolhasani et al., 2008). On the one hand, emissions are caused by various mechanical processes including e.g. the transport and handling of bulk material, drilling, sawing, milling, compacting and grading of the ground (Muleski et al., 2005; Azarmi et al., 2014, and references therein). Particles generated by such operations are emitted over a large size range (Azarmi et al., 2014; Chen et al., 2011; Muleski et al., 2005) and are mainly composed of crustal elements and silicates from mineral fragments (Amato et al., 2009; Kaegi, 2004), of concrete and cement (Chueinta et al., 2000) as well as of metals from mechanical abrasion of tools and machines (Kaegi, 2004). Significant PM_{10} emissions of several grams per vehicle and kilometer are also released by traffic on dirty (Kinsey et al., 2004) or unpaved and temporary roads (Gillies et al., 1999) in the vicinity of construction sites (Guttikunda et al., 2014). These emissions can be in the same order of magnitude or even higher than those by construction operations (Kinsey et al., 2004; Muleski et al., 2005). On the other hand, gases and particles are generated by thermal construction processes such as heating bitumen for paving and roofing (Wang et al., 2001). Bitumen has become an essential material in road works after the legal ban on the use of tar-containing products in many European states. Besides gases, large masses of fine particles (PM_1) are emitted by thermal evaporation of semi- and low-volatile compounds and subsequent nucleation and condensation after cooling in the atmosphere. Bitumen aerosols have shown to pose a threat to workers and public health (e.g. Chauhan et al., 2010; Herrick et al., 2007). In addition to the mechanical and thermal building processes, combustion exhaust of the machinery contributes to the total particle and trace gas emissions from construction sites (Millstein and Harley, 2009; Ketchman and Bilec, 2013). Most construction machinery is diesel-powered with less strictly regulated emissions compared to road traffic (Fu et al., 2012; Abolhasani et al., 2008). Diesel-powered vehicles generally have larger emission ratios of PM_1 to CO_2 (Canagaratna et al., 2004) and significantly higher emission factors of black carbon (BC) (Dallmann et al., 2014) compared to gasoline-fueled or gas-powered vehicles. The tailpipe emissions from construction machinery varies strongly with engine power demand und thus with working mode (Fu et al., 2012; Abolhasani et al., 2008). Helms and Heidt (2014) found that up to 6% of NO_x and up to 10% of traffic related PM emissions in Germany are caused by mobile construction machinery. Similar numbers for particle emissions from construction activities (up to 10% of total annual PM_{10}) have been modeled for six Indian cities (Guttikunda and Jawahar, 2012). Millstein and Harley (2009) assigned 11% of NO_x and 14% of total $PM_{2.5}$ emissions from mobile machinery in California (USA) to be released by off-road engines that are typically dominated by construction machines (Abolhasani et al., 2008). Construction emissions have also attracted political attention. For instance, London has recently introduced new emission standards for NO_x and PM from construction machinery by implementing a low emission zone that has come into force on 1st September 2015.

Detailed information on the emissions from various construction operations are needed for an appropriate risk assessment as every construction site can be assumed to comprise several activities that can significantly differ in their emission characteristics (Heidari and Marr, 2015). However, only very few research papers on real-world emissions from construction sites exist resulting in sparse data of such emissions. Construction site emissions are therefore poorly quantified and very uncertain (Font et al., 2014). Several studies focused exclusively on the exhaust emissions of the construction machinery (e.g. Fu et al., 2012). Others investigated the influence of construction site emissions on local air quality (e.g. Fuller and Green, 2004) or calculated emission factors to assess emission inventories for all construction activities (e.g. Muleski et al., 2005). Comprehensive studies that take all these objectives into account and that consider various construction activities are very scarce. A mobile set-up of various instruments for online measurements of the physical and chemical aerosol particle and trace gas characteristics was therefore operated in several field studies to investigate the real-world emissions from different construction activities including earthworks, road works and asphalt paving. Fuel-based emission factors have been calculated for all building operations under investigation. Based on these values, we estimated total annual emissions from construction activities in Germany. The impact of these activities on the ambient air quality was also examined considering meteorological conditions such as wind speed and soil moisture. In addition, the efficiency of wetting the ground for reducing PM emissions as a common mitigation strategy was investigated for the application of a plate compactor. The chemical composition of the non-refractory PM_1 was studied in detail by high-resolution aerosol mass spectrometry. The results of this study enable the prioritization of different construction activities towards several emission characteristics and provide the starting point for an emission based risk assessment.

2. Experimental

2.1. Sampling site

The field measurements took place in the outskirts of the city of Mainz, Germany. Earthworks have been investigated in a distance of 50–100 m at the same site for three days (26.06., 27.06. and 30.06.2014). The construction activities included the excavation, loading and transport of soil by an excavator and several dump trucks. Emissions from earthworks have been overlaid by dust events due to the traffic on unpaved temporary roads within the construction area. Other machinery has not been used. Additional measurements were performed at different road construction sites on 03.07., 07.07. and 17.07.2014. Specific activities were smashing and removing of asphalt by a saw and an excavator with a hydraulic hammer as well as renewal of asphalt pavement by an asphalt finisher and a road roller. The emissions of a plate compactor