Air pollution on urban areas and impact of local environment and vehicles on particle number concentrations

Generalities

Air quality in urbans areas is the effect of a complex relations between natural and anthropogenic environmental states. Air pollution has become one of the most important threats to human health because of the developing increase in the use of vehicles powered by fossil fuels. Most cities world-wide endure from serious air-quality problems, which have established increasing attention in the past decade. (Holgate 2017)

The air pollution path of the urban atmosphere consists of emission and transmission of air pollutants resulting in the ambient air pollution. Each part of the path is influenced by different factors. Emissions from motor trafic are a very important source group throughout the world. During transmission, air pollutants are dispersed, diluted and subjected to photochemical reactions. Ambient air pollution shows temporal and spatial variability.(Mayer 1999)

The urban population evolution is produced by (1) drift to the cities and (2) excess of births over deaths in the cities themselves especially due to high birthrates in the developing countries. Principally in charge for the migration to the cities is a deep structural change, especially in non-industrialised countries. This structural change is the significance of (1) economic opening-up, (2) new trading partners, and (3) change of political conditions, e.g. democratisation. Structural change takes a rapid course in some countries, dubbed ”tigers”. It is not surprising that the predictable urban population growth from 1992 until 2010 is much higher for Lagos, Bombay or Dhaka than for Tokyo or New York (Table 1). Urban population progress has many significances. One of them is higher emission of air pollutants. Even though for most air pollutants, the emission rate per inhabitant is at present higher in industrialised countries, the predisposition is clear that this rate will in future be higher in the so-called developing countries.(Mayer 1999)

While the risks of air pollution to health were thought to have been brought under control by the Clean Air Acts of the 1950s and 1960s, the situation of air pollution in the UK has now deteriorated to a point where it is contributing to 40,000 excess deaths each year.(Holgate 2017)

Table 1. Estimated population (in millions) of certain megacities in 1992, projected population (in millions) in 2010, and projected population increase after UN, 1993

Megacity	1992	2010	2010-1992
Lagos	8,7	21,1	12,4
Bombay	13,3	24,4	11,1
Dhaka	7,4	17,6	10,2
Delhi	8,0	15,6	7,6
Jakarta	10,0	17,2	7,2
Beijing	11,4	18,0	6,6
Sao Paulo	19,2	25,0	5,8
Tokyo	25,8	28,9	3,1
Los Angeles	11,9	13,9	2,0
New York	16,2	17,2	1,0

Studies

In this exploratory study our research questions were (1) what factors influence particle number concentrations that we are exposed to? (2) can we quantify the amount of influence such factors have on exposure during transit through urban environments using bicycle measurements? To address these questions we developed new methods for application to this dataset of diverse bicycle routes to systematically and quantitatively evaluate the variables that lead to higher or lower levels of particle number concentration, in a manner that is directly relevant to exposure in urban environments. This study includes variables such as amount of traffic, but goes beyond to evaluate variables such as road type, presence of different vehicle types, and local environment, among others. Such information is valuable for citizens who may want to reduce their exposure when moving through a city, but also for city governments and others who make or influence infrastructure decisions, to be able to reduce exposure and better protect human health, while progress is made to reduce air pollution levels overall.

Methods

The data were collected in the metropolitan area of Berlin and Potsdam in the context of a larger measurement campaign including stationary and mobile measurements carried out in the summer (June through August) of 2014. Measurements of particle number concentration were collected during bicycle trips, many of which were morning or evening commutes on commonly used cycling routes through the two cities. In addition to the PNC(particle number concentration) measurements, video documentation of the routes was collected, which allowed for evaluation and identification of the suite of variables. The unique combination of information allowed for a number of questions to be addressed including the importance of local areas (park, residential neighborhoods, etc.) and the proximity to specific potential sources of pollution including buses, trucks, and cars. Techniques were developed to analyze the data which included video analysis and statistical methods to identify average ambient concentrations. Variations in these analytical methods were applied to assess the robustness of the results.

Results

This exploratory work is one of the first studies (and the first in Germany) that investigated the differences in environmental variables affecting the PNC that a cyclist is exposed to quantitatively. Many of these results confirm what we may intuitively hypothesize, e.g., higher traffic density leads to higher PNC or cycling through green spaces reduces the PNC that a cyclist is exposed to; but show surprisingly large variations due to very local factors. For example, the presence of one or more buses, mopeds, or trucks leads to increases in PNC of N30% relative to the ambient average. Factors such as traffic density and the event variables are mutually reinforcing, more so than street type and the event variables which are also related. An evaluation of the relative frequency of event occurrences by traffic density classification shows that, considering the total number of counts within a traffic density category, there tends to be an increasing presence of buses, mopeds, medium vehicles, and trucks as traffic density increases. For example, from low to high traffic density, the relative amount of total counts for one or more buses increases from 6.7% to 24%. For mopeds and trucks the increase is 1.3 to 3.8% and 6.8% to 22%, respectively for low to high traffic density. Cycle paths that are located on the street also result in a 32% higher PNC than the ambient average, while cycle paths removed from the street and located on a shared pedestrian-cyclist sidewalk reduce PNC by 11% relative to the ambient average. The proximity to traffic and the overall amount and type of vehicular traffic have a significant influence on PNCs.

The magnitude of influence of these types of factors should be considered when planning infrastructure, but could also be used by individuals to plan transit routes to minimize exposure to PM. To compare with this work, a study that evaluated exposure to particles in 11 cities in the Netherlands cited an overall mean of 24,329 particles cm^{-3} for their bicycle measurements, with large variations observed within and between cities and sampling days (particle number concentration measured with a TSI CPC). The mean value in this study was 7680 particles cm^{-3} (standard deviation: 3260 to 18,070 particles cm^{-3}) (PNC measured with a DiSCmini). Average bicycle trip PNCs were 22,660 particles cm^{3} for a study conducted in Basel, Switzerland also using a DiSC mini. A study in Christchurch, NZ reported median PNC of 31,414 particles cm^{-3} and 16,641 particles cm^{-3} for on road and off road cyclists, respectively, using a TSI CPC. The median PNC of this study was substantially lower at 7020 particles cm^{-3}. These comparisons show that overall mean and median particle number concentrations in Berlin were somewhat lower than those recorded in other cities. Our results indicate that even for cities with relatively moderate particulate levels, the specific location and proximity to vehicles makes a measurable difference to exposure rates. A limited number of studies evaluated the effect of different variables, such as environment or cycling location and the effect these had on particle number concentrations. In a study evaluating the difference of bicycle commuting routes in Basel, Switzerland – one along main roads, and the other away from main roads – results showed that daily UFP exposure could be reduced by half if main roads were avoided. While we do not evaluate daily exposure in this study, we can compare the relative percent difference in PNC residuals between cycling on main roads (ST_MAINRD) to cycling on residential streets (ST_RESID), for which we found a decrease of ca. 36%. While this is similar to Ragettli et al. (2013), these values reflect only differences in PNC during cycling, whereas their measurements spanned 24 h, of which the commuting routes were only a small contribution in terms of time, although likely a large contribution to overall exposure.(Ragettli et al. 2013) The 11 cities study from the Netherlands evaluated the percent change in particle number concentration for a variety of predictor variables during their occurrence relative to the total observation period. This is most similar to the approach taken here among existing studies, and one of the only other studies to quantitatively assess the effect of multiple variables influencing PNC. They observed an 11% increase for cycling on an on-road bicycle lane (lane separated from road vehicles by line marking only), and a smaller increase of 8% for cycling on a bike path for cyclists that is parallel but unattached to the road(Boogaard et al. 2009). In our study, we observed an increase of 32% in the cycling location variables for a cycle path on the street (CL_STRPATH), and a decrease of −11% for a cycle path on sidewalk (CL_SIDEWK) relative to the average ambient level. The larger increase relative to the estimated background in our results may reflect the difference in methods, but could also be attributed to the amount of traffic on those routes where the cycle path is located on the street. That we see a decrease for cycle paths located on the sidewalk, whereby Boogaard et al. (2009) see a similar magnitude increase could be attributed to a number of factors, including differences in infrastructure between the countries/cities in terms of the distance of the sidewalk from the road, a variation in the type of road and/or traffic density for which cycle paths are placed on the sidewalk, etc.(Boogaard et al. 2009) Among other comparable variables that they investigated were the increase resulting from passing mopeds (58%) and while waiting for traffic lights (10%)(Boogaard et al. 2009). Here we observed an increase of 38% owing to presence of mopeds (MOPED_1) and a 35% increase for waiting at traffic lights relative to the ambient average (ENV_TRAFLIGHT). The general consistency in these results fromdifferent cities indicates that such factors are likely to have similar effects in other cities as well. These results, highlight the substantial differences in particle number concentrations that exist over small scales, both temporally and spatially. These variations have significant implications for cyclists, but also for other urban citizens and both their activity and their transport choices. From these results we can conclude that infrastructure choices – for example, in terms of where and how cycling lanes are built – as well as their proximity to traffic (emissions sources) will have a large effect on the particle number concentrations that cyclists are exposed to. Furthermore, the traffic mix in the city and the proximity of these vehicles to cyclists can exacerbate short-term exposure to higher concentrations. The extensive number of variables investigated and quantified provides a wealth of information for possible consideration in urban planning. Results, while collected by bicycle, have direct implications for city dwellers' exposure rates due to local sources for a full range of activities, including walking and a range of recreational activities. While the general conclusions from this study are likely applicable in other cities given the general consistency of limited comparisons available, with variations in magnitude owing to local conditions, such as built environment and local geography expected, further such studies would allow for a better understanding of the full transferability of the results among cities. In terms of the built environment, the differences in the width and height of street canyons from the surrounding buildings would affect dispersion and thereby the PNC measured. This was not a variable that was classified in this study but could add additional information to future work. The lack of nearby stationary measurement site(s) with equivalent measurements was a limitation that was overcome by the development of an alternative background assessment method. However, future studies would be served by having such measurements available. The rapid changes in ultra-fine particle concentrations should be taken into account if a stationary site is used. The approach of non-prescribed bicycling routes and the resulting broad variability in locations for the different days measured results in a less consistent dataset. The local background correction also limits any comparisons across regions of the city. This research is therefore a more exploratory study. Furthermore, the evaluation of video data is time consuming and may include some inaccurate classifications or subjectivity as it is carried out by individuals. This will likely not influence the outcome with a sufficiently large data set and clear classification guidelines, as was the aim here. Other options to address these issues would be automated video evaluation or possible crowd-sourcing. Finally, similar measurements carried out during other seasons would add value to such a dataset.

Conclusions

This exploratory study quantifies the effect of nearby pollution sources in urban areas,with a particular focus on quantifying the effects of a wide range of variables – cycling location, environment, presence and density traffic and vehicle types – on the particle number concentrations bicyclists are exposed to. These results have implications, not just for cyclists, but also for pedestrians and urban infrastructure more generally because the differences in local pollution levels are found to be quite large.(von Schneidemesser et al. 2019)

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