Science of the Total Environment 538 (2015) 458–467

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A method to estimate spatiotemporal air quality in an urban traffic corridor

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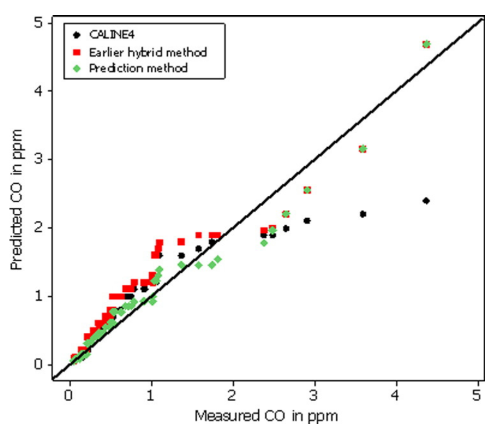
HIGHLIGHTS

- The method predicts spatiotemporal air quality in an urban traffic corridor.
- The prediction method is based on one monitoring station in the traffic corridor.
- The method predicts spatial probability of exceedances of CO reasonably well.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 April 2015
Received in revised form 21 July 2015
Accepted 12 August 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Urban air quality
Human exposure
Spatiotemporal
Concentration
CO
Traffic emission

ABSTRACT

Air quality exposure assessment using personal exposure sampling or direct measurement of spatiotemporal air pollutant concentrations has difficulty and limitations. Most statistical methods used for estimating spatiotemporal air quality do not account for the source characteristics (e.g. emissions). In this study, a prediction method, based on the lognormal probability distribution of hourly-average-spatial concentrations of carbon monoxide (CO) obtained by a CALINE4 model, has been developed and validated in an urban traffic corridor. The data on CO concentrations were collected at three locations and traffic and meteorology within the urban traffic corridor.[1] The method has been developed with the data of one location and validated at other two locations. The method estimated the CO concentrations reasonably well (correlation coefficient, $r \geq 0.96$). Later, the method has been applied to estimate the probability of occurrence [$P(C \geq C_{std}$] of the spatial CO concentrations in the corridor. The results have been promising and, therefore, may be useful to quantifying spatiotemporal air quality within an urban area.

1. Introduction

Road traffic is the main cause of poor air quality in urban areas (Colvile et al., 2001; Ghose et al., 2004; Ramachandra and Shwetmala, 2009). This

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[1] Traffic corridor encompasses the entire passage bounded by the buildings on both sides including roadway with sidewalks.

http://dx.doi.org/10.1016/j.scitotenv.2015.08.065
0048-9697/

fact has forced researchers around the world to focus on the association of traffic-related air pollution and its impact on human health, along or in the close-proximity of traffic corridors. Several studies have reported that negative health impacts such as heart attacks, cancers, asthma, decreased lung function, etc. are closely associated with traffic induced air pollution (Gasana et al., 2012; Lipfert et al., 2006; Newman et al., 2014; Wilker et al., 2013). For this reason, evaluating human exposure in traffic corridors is of growing concern to assess human health risks.

Since air quality changes spatially and temporally, exposure also varies in space and time (Dons et al., 2011; Steinle et al., 2013). It is, therefore, essential that spatiotemporal concentrations are known for accurate assessment of human exposure in traffic corridors. Ambient air quality measurements at fixed multi locations to indirectly estimate the exposure, or direct measurement of exposure at the breathing level of a few voluntary individuals using corridors (i.e. personal monitoring) or using mobile monitoring vans (Durant et al., 2010; Padró-Martínez et al., 2012) is laborious and expensive (Carr et al., 2002). Several studies are carried out on modeling of spatiotemporal concentrations, but most have employed statistical methods, which do not capture temporal trends (i.e. changes over time) in sources and meteorology. For example, approaches such as spatial interpolation, land-use regression (LUR), hierarchical method and spatial proximity are widely used to estimate spatial concentrations (Chen et al., 2010; Crouse et al., 2009; Dons et al., 2013; Li et al., 2013; McAdam et al., 2011; O'Leary and Lemke, 2014; Wheeler et al., 2008). These methods have been the preferred methods for estimating intra-urban and fine scale concentration gradients. While these approaches are common, other methods including dispersion models and hybrid modeling approaches have also been used to estimate spatial concentrations. For example, several dispersion models are used to evaluate roadside air quality (Sharma and Khare, 2001; Vardoulakis et al., 2003), which incorporate emission and meteorology. CALINE4 (California line source dispersion model, version4) (Benson, 1984) is one such model, which is well evaluated and validated air quality model for modeling pollutant concentrations from vehicular sources and is commonly used (Heist et al., 2013; Levitin et al., 2005; Zhang and Batterman, 2010); A hybrid modeling approach using CAL3QHCR dispersion model was developed to produce spatiotemporal concentrations based on long-term spatial, temporal means and residuals (Keller et al., 2015). A similar study was carried out by Wilton et al. (2010), in which CAL3QHCR dispersion model was combined with LUR model to improve the spatial concentrations. Spatial interpolation technique, such as kriging, uses observed concentrations of many locations to predict concentrations at unknown locations. The number of available stations and their locations limits the spatial resolution (Whitworth et al., 2011). The method produces unbiased estimates if expanded routine monitoring of spatial pollutant concentrations is available. The LUR models require observed concentrations as response variables with surrounding land features, population density and traffic characteristics as predictor variables. Similarly, the hierarchical model needs a high spatiotemporal resolution of observed concentrations, as demonstrated by Li et al. (2013) on nitrogen dioxide (NO_2), and Pirani et al. (2014) on particulate concentrations.

In traffic corridors, a direct measurement or adopting any of these methods is even more complicated due to limited spatial domain and turbulent wind flow pattern. In this study, we combined a line-source-dispersion model with a probability distribution model to develop a method for calculating spatial concentrations in a highly trafficked urban traffic corridor. Line-source-dispersion models are used for estimating roadside air quality that relates traffic emissions with the pollutant concentrations under a specified meteorological condition. However, dispersion models predict average concentrations well, i.e. middle range of the concentration distribution and poorly predict the extreme ranges (Gokhale and Khare, 2005, 2007). Further, these models predict spatial concentrations well for a single source (de Hoogh et al., 2014). On the other hand, probability distribution models capture the dispersion of concentration values resulting from the dilution of the pollutant, which remains nearly same at any spatial point within the corridor and fit well to the larger concentration distribution range. However, they are data based and do not take into account the emissions and meteorology (Gokhale and Khare, 2005, 2007). Therefore, dispersion models are reasonably good in predicting average concentrations and probability models represent extreme concentrations well as they capture stochastic variability (Gokhale and Khare, 2005, 2007; Jakeman et al., 1988; Marani et al., 1986; Ott, 1995). This attribute of the probability distribution models may eliminate large deviations between estimated and measured concentrations. Therefore, a suitable probability distribution model combined with the well suited line-source-dispersion model can provide better estimates of concentration distributions.

We developed a prediction method by combining CALINE4 with a lognormal distribution model to estimate hourly average spatiotemporal carbon monoxide (CO) concentrations at one location and validated at two spatial locations. The method has been applied in an urban traffic corridor to determine spatial concentrations and to identify locations of higher probability of occurrences of pollutant concentration exceeding national standards within the corridor.

2. Methods

A suitable probability distribution model for the concentrations measured at three locations has been identified by standard goodness-of-fit tests of which the location parameter has been calibrated with the output of the widely used CALINE4 model. The calibration factor was empirically estimated from the dispersion model output and the location parameter of the identified probability distribution model. This factor accounts for the average deviation of estimated from the measured concentrations and, thus, considerably reduces uncertainty. The step-by-step procedure of the method has been described below:

i) identification of three suitable locations in the traffic corridor for monitoring of pollutant concentrations, meteorological parameters and traffic volume, ii) identification of the suitable probability distribution model from a range of probability models at all the selected locations, iii) concentration estimation with CALINE4 model, iv) development of the prediction method by combining the CALINE4 model output with the identified probability distribution model output using a calibration factor at one location v) validation of the prediction method at other two locations, and vi) application of the prediction method to estimate the probability of exceedances at spatial locations within the traffic corridor.

2.1. Urban traffic corridor, monitoring locations and measurements

A highly trafficked 400 m long urban traffic corridor in Guwahati, India was selected. It houses numerous commercial activities, offices, public utilities and attracts about 100,000 of traffic volume daily. Three monitoring locations (L1, L2 and L3 as shown in Fig. 1) were selected. The distance between L1 and L3 was 296 m, between L1 and L2 was 127 m, and 176 m between L3 and L2. The road was 16 m wide with a separator of 1 m in between two lanes each side and the width of each lane was 3.75 m. Another location on a building rooftop, 18 m high and 69 m from the road, was selected within the corridor for installing weather station. Videotaping for recording traffic volume was done near L1 along with the measurement of pollutant concentrations.

The CO concentrations were measured during daytime from 7 am to 7 pm at all the locations for a period of one week including weekdays and weekend days in March 2014. The measurements at L1 were carried out from March 1 to March 7, at L2 from March 8 to March 15, and at L3 from March 18 to March 24, 2014. The CO meter (make: Delta Ohm,