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Vehicular road influence areas

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HIGHLIGHTS

- A simplified methodology to evaluate vehicular road impact areas was proposed.
- Multiple AERMOD simulations of pollutant dispersion around roads was conducted.
- TSP and PM_{10} concentration vs. distance to road measurements were performed.
- Beta distribution functions fit well pollutant concentrations vs. distance to road edge data.

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ABSTRACT

Vehicle operation over paved and unpaved roads is an emission source that significantly contributes to air pollution. Emissions are derived from vehicle exhaust pipes and re-suspension of particulate matter generated by wind erosion and tire to road surface interactions.

Environmental authorities require a methodology to evaluate road impact areas, which enable managers to initiate counter-measures, particularly under circumstances where historic meteorological and/or air quality data is unavailable. The present study describes an analytical and experimental work developed to establish a simplified methodology to estimate the area influenced by vehicular roads. AERMOD was chosen to model pollutant dispersion generated by two roads of common attributes (straight road over flat terrain) under the effects of several arbitrary chosen weather conditions. The resulting pollutant concentration vs. Distance curves collapsed into a single curve when concentration and distance were expressed as dimensionless numbers and this curve can be described by a beta distribution function. This result implied that average concentration at a given distance was proportional to emission intensity and that it showed minor sensitivity to meteorological conditions. Therefore, road influence was defined by the area adjacent to the road limited by distance at which the beta distribution function equaled the limiting value specified by the national air quality standard for the pollutant under consideration.

1. Introduction

Vehicle operation over paved and unpaved roads represents a substantial air pollutant emission source. This source is composed of emissions from vehicle exhaust pipes (traditionally termed emissions from mobile sources), tire wear and re-suspension of particulate matter generated by wheels interaction with road surface and wind erosion.

Vehicle tires pulverize road materials, which are re-suspended into the atmosphere by air-flow generated from moving vehicles (Nicholson et al., 1989; USEPA, 2007). Approximately 20% of particulate matter present in the atmosphere of several western United States cities is derived from paved and unpaved roads (Kuhns et al., 2001).

Current environmental regulations demand compensation from companies using vehicles and road types that cause environmental damage. For example, environmental authorities demand implement counter-measures of mitigation and adaptation to mining companies engaged in open pit mining exploitation activities, where materials transport over unpaved roads is the primary emission source of particulate matter (Chakraborty et al., 2002; Huertas et al., 2012). However, systematic and recognized

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Symbols and acronyms

	Description	units
a, b	Minimum and maximum distances of dispersion	m
C_i	Pollutant i concentration	µg m^{-3}
C^*	Normalized pollutant concentration	–
L	Road width	m
l_i^*	Distance to the edge road where the average annual concentration of the pollutant (i) equals the respective maximum value recommended by the local air quality standard ($NAAQS_i$).	m
E	Particulate matter emission	g s^{-1} m^{-2}
E_{fj}	Emission factor for vehicles of with size j	g/VKT
E_t	Particulate matter emission from the exhaust pipe	kg s^{-1}
F_i	Dispersion factor for pollutant i	s m^{-1}
k	Intensity of the applications	l m-^{2}
T_j	Kilometers traveled by vehicle j	
N_j	Number of vehicles with size j	–
s	Road surface silt content	%
s_L	Road surface silt loading	g m^{-2}
t	Average time between spray applications	h
i	Index for pollutant	–
j	Index for vehicle type	–
n	Number of days in the period	–
m	Number of rainy days in the period with precipitation levels exceeding 0.254 mm	–
p	Average daytime evaporation rate	mm h^{-1}
r	Average daily traffic	vehicles h^{-1}
V	Wind speed	m s^{-1}
W	Average weight of the vehicles traveling in the road	tons
x	Distance to the edge of the road	m
β	Beta distribution function	–
α_1, α_2	Parameters of the beta distribution function	–
η_r	Efficiency of the emission control measures	–
η_{rn}	Efficiency of particulate matter emission control through natural rain	–
TSP	Total suspended particles	
PM_{10}	Particles with aerodynamic diameter less than 10 microns	
VKT	Vehicle kilometers traveled	
CFD	Computational Fluid Dynamics	
NAAQS	National atmospheric air quality standard	
UTM	Universal Transverse Mercator	
GRG	Generalized Reduced Gradient algorithm	

methodologies to identify road influence areas, where companies and institutions should implement decontamination actions are not currently available.

The influence area can be experimentally assessed by monitoring pollutant concentrations at different distances from roads for periods of time >1 year. Subsequently, the distance where the pollutant concentration ceases to exceed local air quality standards is determined. This methodology is expensive because it requires at least one year of monitoring. Few studies have reported this type of measurements (Venkatram et al., 2007).

Alternatively, influence area can be determined through numerical simulation. Pollutant dispersion is calculated by using the mass and energy conservation equation along with the chemical reaction equations. These equations do not have a known analytical solution. Therefore, heuristic models, which estimate pollutant concentration downwind, have been applied. Steady state Gaussian models are used most frequently. CALINE is the Gaussian model traditionally employed to estimate pollutant dispersion emitted by vehicles (Levitin et al., 2005; Yura et al., 2007). However, studies that quantitatively examine areas impacted by road use have not been published.

Some studies focused in the development of algorithms or approximations to estimate pollutant concentrations around roads (Barrett and Britter, 2009; Venkatram and Horst, 2006). Godoy et al. (2009) developed a stochastic model to evaluate particle deposition distance as a function of meteorological conditions, physical parameters of the emission source and particle size distribution. Furthermore, numerical models based on physics have been used to estimate pollutant dispersion emitted from vehicles. For example, Sahlodin et al. (2007) applied Computational Fluid Dynamics (CFD) to examine pollutant dispersion around roads. Recently, Huertas et al. (2016) used CFD to model particulate matter dispersion around unpaved roads. These studies reported that distance for particle deposition decreased with wind speed and that it was independent of particle size distribution.

In each case described above, meteorological and other input data measurements, i.e. site-specific variables were required for the models. However in practice, it is rarely possible to have all this information available. The present document proposes a simplified methodology to estimate the influence area of roads, based only on pollutant emission estimates. The proposed methodology is presented first and subsequently the empirical work used to develop the method is described.

2. Simplified methodology to determine vehicular road influence areas

This section presents a simplified methodology to determine vehicular road influence areas. The methodology was developed for roads constructed in flat regions, with weather conditions without high frequency of calms. The approach is limited to circumstances where pollutants do not exhibit chemical reactions during the dispersion process. In practice it can be used for any pollutant.

2.1. Input data

Emissions estimates: Vehicle exhaust pipe emissions and particulate matter re-suspension need to be considered. Both emission sources are of fugitive nature and therefore must be estimated