Vehicular traffic as a method to evaluate air pollution in large cities

Tráfego veicular como método de avaliação da exposição à poluição atmosférica nas grandes metrópoles

Abstract

Air pollution is a major concern for public health. Among the studies conducted to evaluate the association between air pollution and a wide variety of outcomes, some have used motor vehicle traffic data as a method for exposure assessment. This paper intends to revise and discuss some of the methodological aspects of studies that used this method, especially in areas where vehicles are the main generating source of pollutants. We performed a literature search with keywords related to air pollution and vehicle traffic, and selected articles published between the years 2000 to 2009. We noted different approaches for assessing the exposure among the studies using vehicle traffic, with emphasis on the method named Distance Weighted Traffic Density, which considers the number of roads, the distance from the location of interest and traffic itself. Moreover, we highlight the importance of using techniques such as geographic information systems (GIS) to measure this exposure.

Keywords: Air pollution. Motor vehicle traffic. Vehicle emissions. Environmental exposure. Geographic information system.

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Resumo

A poluição atmosférica é uma das maiores preocupações para a saúde pública. Entre os estudos conduzidos para testar a associação entre poluição do ar e os mais diversos desfechos em saúde, alguns utilizaram dados viários e de tráfego veicular como avaliação da exposição. O presente trabalho pretende revisar e discutir alguns dos aspectos metodológicos dos estudos que utilizaram este método, principalmente em áreas onde a fonte veicular é uma grande geradora de poluentes. Realizou-se uma busca bibliográfica com palavras-chave relacionadas à poluição atmosférica e tráfego veicular, e foram selecionados artigos publicados entre os anos de 2000 e 2009. Foram constatadas várias abordagens para avaliar a exposição, enfatizando-se o método da Densidade de Tráfego Ponderada pela Distância, que considera as vias e a distância das mesmas em relação ao local de interesse e o tráfego. Além disso, destaca-se a importância do uso de técnicas de sistemas de informação geográfica (SIG) como instrumento na construção de modelos para mensurar a exposição.

Palavras-chave: Poluição atmosférica. Tráfego veicular, Emissões de veículos. Exposição ambiental. Sistema de informação geográfica.

Introduction

Several epidemiological studies have found an association between exposure to atmospheric pollutants and adverse health effects, such as the increase in the number of hospitalizations and mortality, and decrease in life expectancy[1]. These studies are usually performed in urban areas, where automotive vehicles are the main source of air pollution. According to a study that examined seven Brazilian cities, approximately 5% of the total number of deaths from respiratory causes between elderly individuals (aged ≥65 years) and children (aged ≤05 years) that occur every year can be attributed to atmospheric pollution, with a significant amount coming from automotive engine exhaust[2].

In the last decades, a reduction in the emission of pollutants emitted by vehicles has been observed[3]. However, mobile sources are one of the main producers of atmospheric pollutants in urban areas. In Brazil, the three greatest metropolitan areas – São Paulo, Rio de Janeiro and Belo Horizonte – comprise 45% of the total number of vehicles in this country[1].

The increase in the number of vehicles also causes traffic to flow more slowly, leading to longer times spent in congestions[1] and, consequently, increasing fossil fuel burning and pollution.

Certain studies evaluate atmospheric pollution using a direct measure, such as data on the mean concentration of pollutants measured by air quality monitoring stations. However, the distribution of these stations in urban areas evaluates local pollutant concentration and they may not be sufficiently dense to detect the spatial heterogeneity of pollutants dispersed by mobile sources[4], which could result in exposure classification errors among individuals.

For this reason, several studies have analyzed the effects of atmospheric pollution on health, using an indirect measure based on exposure to vehicular traffic. This approach has been employed concomitantly to or in place of the direct measure obtained from mean pollutant concentration in monitoring stations. Interest in the use of an indirect measure in certain studies is explained by the fact that this enables exposure of a specific location to be estimated.

The availability of data on vehicle flow is a factor that promotes the performance of research that evaluates the association between this exposure and several health outcomes. Geographic information systems (GIS) are an important instrument applied in such studies, serving to map and outline environmental problems, polluted areas, and pollutant dispersion, among other things.

In view of the importance of this theme for public health, the present study aimed to review epidemiological studies that used vehicular traffic as an indirect measure of evaluation of exposure to atmospheric pollution.

Methodology

A literature search on atmospheric pollution and vehicular traffic was conducted on the PubMed database, using the terms *"air pollution", "health, traffic"," road traffic"*, "*vehicular traffic*" or "*traffic density*", with the following search parameters:

("air pollution"[MeSH Terms] OR "air pollution"[All Fields]) AND "health"[All Fields] AND ("traffic"[Title/Abstract] OR "road traffic"[Title/Abstract] OR "vehicular traffic"[Title/Abstract] OR "Traffic density"[title/abstract])

The search for articles was limited to those published between 2000 and 2009 and these were subsequently separated, according to the types of methods to evaluate exposure that were used. The following articles were not considered: those that reported experiments in laboratory, those that evaluated exposure to atmospheric pollution without any association with health data, or those that only took into consideration the pollution of indoor environments (indoor pollution). There was a previous selection by title, subsequently by abstract reading, and, whenever necessary, by complete article reading. Certain studies on this theme were included, based on the bibliographical references of articles obtained in the previous search.

This review is part of a study approved by the *Comissão de Ética para Análise de Projetos de Pesquisa* (Research Project Analysis Ethics Committee – CAPPesq) of the *Diretoria Clínica do Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo* (Clinical Management of the São Paulo University School of Medicine Clinical Hospital), under number 0662/09.

Results

Of all 513 articles identified from the search parameter, 35 were eligible for review.

It could be observed that different indicators of vehicular traffic were used to characterize atmospheric pollution. Some studies, for example, analyzed the distances of certain locations as indicator, such as that from one's residence or school to the streets, or the density of vehicles or length and density of streets in census tracts or buffers, while others used the flow of vehicles on streets of interest, or used a combination of several indicators.

The outcomes evaluated in these studies varied between heart diseases[5-9], respiratory diseases[5,10-23], gestational outcomes[24-28], allergies and changes in the immunological system[29-31], thrombosis[32], cancer and leukemia[33-37], lead contamination[38] and mortality in general[39].

Studies on the exposure to vehicular traffic using distance as the only indicator

This method consisted in the use of GIS to map a place of interest and its distance to one or more streets. The majority of studies evaluated the exposure from the home or school address[11], or from a certain point of reference, such as the census tract centroid[6].

Exposure was based on the distance from these points to the streets and it served as parameter to infer the level of exposure experienced by individuals. Certain studies only considered the nearest road[7-9,11,12,25,32]; others used the main road (arterial roads, collector streets) considered to have high traffic intensity[6,18,20,26,28]; yet others were based on the distance of both types of road – road or main road[5,14,17,19,31,39].

Certain authors used the shortest distance from the point of interest to a road to evaluate the exposure of individuals in their studies[6,9,25,26,32]. Other authors considered individuals whose distance was lower than a certain value to be exposed, a value that ranged from 50 m[5,12,39], 100 m[5,18,20,31,39], 150 m[18,19,23,31], 200 m[7,20,28,31], 300 m[17,19] up to 400 m[11].

Some studies evaluated certain distances according to road classification: Hoek et al.[5] and Finkelstein et al.[39] considered individuals living as far as 100 m from a road or as far as 50 m from a main road (arterial or collector) to be exposed, whereas other authors adopted several values for distance, such as in the study conducted by Roselund et al.[20], which was based on 100 m and 200 m, and by Williams et al.[31], based on 100 m, 150 m and 200 m.

Kim et al.[19] adopted, in their analyses, 150 and 300 m of distances of roads and, additionally, distinguished individuals into those who lived leeward and windward of roads, thus being able to analyze the influence of the predominant wind direction in their analyses.

Studies on the exposure to vehicular traffic using its intensity as the only indicator

Many studies used exposure to vehicular traffic intensity as their method to evaluate exposure, understood as the number of vehicles passing through a certain road, during a specific period of time. The majority considered the annual mean of daily traffic and only Wyler et al.[30] and Furman and Laleli[38] used car/hour counts to estimate exposure.

According to the objective proposed in each study, the following were considered: the traffic of the nearest main road[29,30,35,38], the traffic of the nearest road[10,11] or the traffic of roads (main ones or not) included in distances (buffers) of up to 50 m[25], 100 m[8,9,25], 150 m/500 feet[16,19,21,37] and 300 m[9,19]. The majority were based on vehicular traffic in relation to the homes of individuals. One study considered the place of work[38] and another one, schools[11].

The values of vehicle flow were obtained by general count, not specifying the type of vehicle, except for the studies by Janssen et al.[11] and Wyler et al.[30], which distinguished the flow of cars from that of trucks. A total of three studies applied questionnaires and obtained the self-reported traffic intensity on the street of residence[15,20,22].

In another methodological approach, the measure of traffic was obtained by multiplying the length of roads close to the homes of the population studied by the daily mean of vehicle flow on such roads[16,21,35,37].

Studies on vehicular traffic exposure using only density of roads/vehicles as indicator

There were two studies, obtained in the review, that were not limited exclusively to data on the distance of roads or vehicular traffic to evaluate exposure, but they also calculated the density of roads and vehicles in the polygon that surrounded the home.

Based on the individual's geocoded address and census data, Reynolds et al.[36] calculated the density of vehicles, obtained by dividing the total number of vehicles of the census tract by its area (in square miles). The density of vehicles referred to the number of vehicle owners in a census tract, rather than its circulation on the roads of this area.

The density of vehicles provides an estimate of the potential of exposure to emissions from fuel evaporation when vehicles are parked at night, once such evaporation is an important source of organic volatile gases, such as benzene[36].

For the calculation of the density of roads, the total length of roads of an area unit known as buffered blocks was divided by its area. These buffered blocks consisted of an additional frontier of 200 m around each census tract. According to authors, the increase in the frontier of census tracts prevented a discrepancy in the size of the area and roads of such sectors in the calculation of this measure.

In another study conducted by Reynolds et al.[37], the length of the streets in a buffer of 150 m/500 feet around an individual' geocoded address was added and this value was subsequently divided by the buffer area.

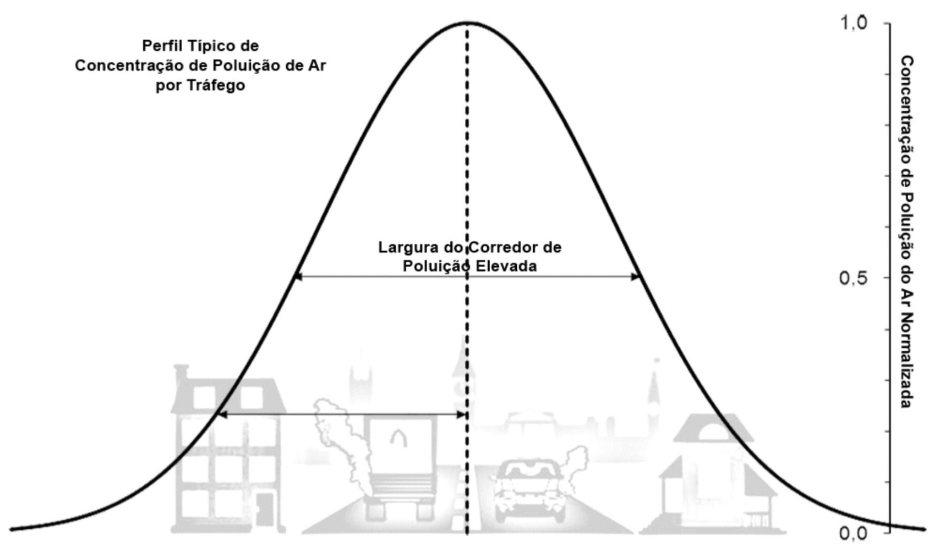
Utilization of more than one indirect measure of exposure to vehicular traffic in the same study

Many studies used the combination of several indicators of exposure to vehicular traffic to indirectly estimate atmospheric pollution. One methodology which was repeatedly observed is based on the combination of data on the flow of vehicles and the distance of roads around the point of interest (representing the dispersion of pollutants resulting from vehicles, from the street center). This model is known as Distance Weighted Traffic Density – DWTD[13,17-19,24-27,33-35]. In this model, it is assumed that the dispersion of vehicle emissions on the roads is closer to a Gaussian (normal) distribution and that 96% of pollutants emitted by vehicular traffic were dispersed as far as 500 feet/150 m of the center of the road[33], as observed in Figure 1. The higher the flow on the road, the greater the emission of vehicle pollutants, increasing the concentrations of such pollutants in the urban space, especially in the homes close to busier roads.

For each individual studied, the DWTD is calculated according to a varying distance around their home or another geocoded place of interest (Figure 2), where *W* is the buffer width and *D* is the shortest distance from one's home to each road within the buffer. *Y* is the value used to weigh the vehicle flow obtained for each road within this area.

$$Y = \left(\frac{1}{0,4\sqrt{2\pi}}\right) \times \exp\left[\left(\frac{(0,5)\left(\frac{D}{L}\right)^2}{(0,4)^2}\right)\right]$$

Then, the vehicle flow of such street is divided by the *Y* value, generating an *X* value. Next, the weighted values of traffic (*X*) of all roads included in the buffer (*n*) are added, thus obtaining the DWTD.



Adapted from Pearson et al.[23]

Figur1 1 – Profile of the concentration of pollutants emitted by vehicular traffic as the model of distance weighted traffic density

$$X = \frac{fluxo\ veicular}{Y} \qquad DTPD = \sum_{i=1}^{n} X_i$$

As the density and characteristics of constructions, predominant wind direction, altitude, and turbulence caused the flow of vehicles to affect the dispersion of pollutants generated by traffic, various buffer widths could be assumed to calculate the DWTD. This reduces lack of accuracy in the measure of exposure.

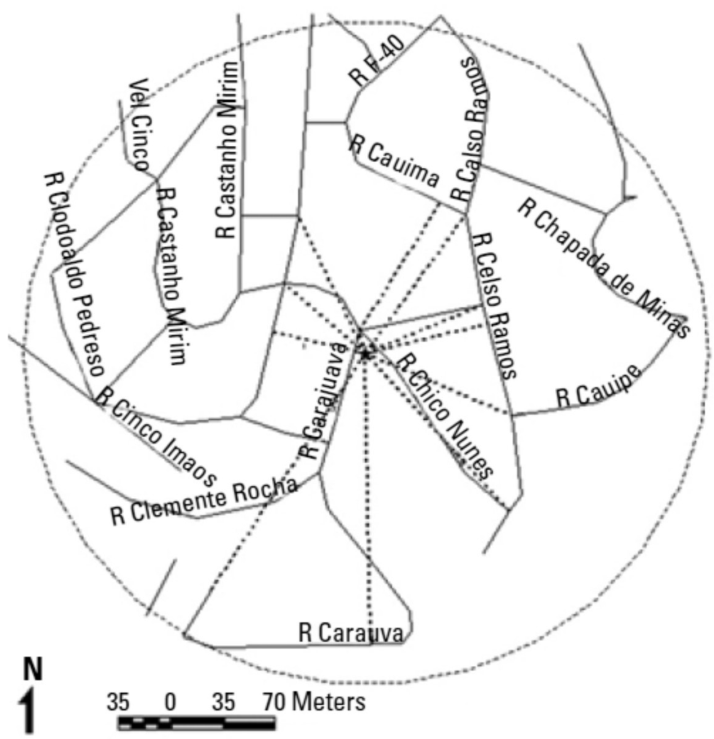
Studies used buffers with a radius varying from 300 m[13,17,18], 750 feet (228.4 m)[33,34], 165 m[35], to 500 feet / 150 m[19,24-26,33].

Discussion

As observed in the literature search, the road network and its respective vehicle flow is an important indicator of atmospheric pollution, once mobile sources are the main producers of emissions of such pollutants in urban areas.

However, when the distance of roads or the volume of traffic represent only the road that is closest to one's home, the evaluation of exposure may have limitations, because a more distant road with heavy traffic could be important for the analysis. Thus, the weighting of vehicle flow by the distance enables a more reliable evaluation, as it considers the set of roads that surround one's home.

Only some studies were based on a single method of evaluation of exposure, the majority of authors sought to use several or to combine them. Despite this variety and combinations, few studies considered more detailed traffic information, such as the mean speed of vehicles[38], the type of vehicle (cars or trucks) and what could characterize the fuel used[40], and none considered the year the vehicle was manufactured. It was observed that only two reviewed studies included the discrimination between truck traffic and that of the remaining vehicles during data analysis[11,30]. All types of auto-



Source: Medeiros et al.[27]

Figure 2 – Representation of a 750 feet (228.4 m) radius buffer, bordering a residence of a subject in an epidemiological study.

motive vehicles produce pollutants that affect the quality of air; however, the type of fuel used by these vehicles determines a higher or lower concentration of different pollutants, which, in different ways, lead to adverse effects on health.

The majority of articles shown did not include the residential mobility variable in the analyses, nor the time spent by individuals in their residence, place of work or when going from their residence to work. Time/residential mobility and daily exposure situations are important variables, because they use the measure of exposure at the moment when the study is conducted, and people often move or spend most of the day in a place other than their residence, thus causing errors in the classification of exposure.

Residential mobility was analyzed by Hooven et al.[26], in Rotterdam, Holland, in the period comprised by the seven months preceding the date of birth and the 5th month of pregnancy. Of all the 7,339 pregnant women participating in this study, only 1,118 (15.2%) had not moved during this period. One limitation pointed out by Reynolds et al.[37], in a study conducted in California, USA, was that the maternal residential address in the birth certificate was different from that recorded in the cancer database in 50% of cases (in a period of up to five years between birth and the diagnosis).

On the other hand, Miyake et al.[28] found a low residential mobility in Neyagawa, Japan. A total of two interviews were conducted with the pregnant women, one in the prenatal period and the other between the 2nd and 9th months after birth. Of all women, 90.2% reported the same address in the interval of time between the first and second interviews.

Shima et al.[12] gathered information about the time of residence of the population studied in Shiba, Japan, only including individuals who had been living in such location for at least three years. Of all the 3,184 individuals who responded the first questionnaire, 655 (20.6%) were excluded because they had not lived there during the established time.

In the Netherlands Cohort Study (NLCS), Hoek et al.[5] also found a great percentage (89.8%) of participants living ≥10 years at the same address, with a mean time of residence of 35 years.

Another limitation in several reviewed articles is the temporal resolution of traffic data. Pearson et al.[33] reported that the fact that vehicle counts are conducted every ten years and only for one specific area of Denver, USA, was one of the limitations in the analysis of vehicular traffic. Thus, the estimates could not correspond to the period before the diagnosis of cancer for each child, and these may have moved from their home during the period of study. Authors stated that this last fact could be confirmed in a previous study, which indicated that many children had in fact moved. Langholz et al.[34] also observed a similar difficulty. The traffic count that was closest to the period of selection of individuals (cases) occurred between 1990 and 1994, and the most etiologically relevant period for the study was before the date of diagnosis (exposure of children between 1978 and 1984, before the diagnosis of leukemia), i.e. data referred to a time of approximately 10 to 20 years after such date.

Wilhelm and Ritz[24] and Hooven et al.[26] reported in their studies that they used the mean annual values of vehicle count of 24 hours, although the daily and monthly values and seasonal fluctuations were ignored. One advantage of the study performed in France by Zmirou et al.[13], when compared to the others, was due to the inclusion of seasonal traffic variations, enabling better detailing of the level of exposure to atmospheric pollution in different periods of the year.

When road classification (roads, arterial and collection roads) is the only factor taken into consideration to evaluate exposure, it is not possible to identify, for example, possible variations in the same classification, once estimated traffic values are standardized within ranges of values.

Larger roads with heavier traffic, such as highways and main roads, have been exhaustively considered in studies[10,11,17,24-26].

However, local roads were not so frequently included, and when such roads were analyzed, the values of their vehicle flows were not observed in a more detailed way, with the adoption of a single value. In these cases, the variations that such roads could have in the area where they were included were not distinguished, as observed in two studies that attributed a flow of 100 vehicles/day for local roads[33,34].

Information about the proportion of local roads, when compared to others, is important, because it enables the identification of the actual need for such roads to be analyzed or not, especially when it comes to a residential area. Only one study considered all types of roads, including the traffic of local roads[27]. Differently from other authors, who did not analyze local roads or attributed a single value to them all, Medeiros et al.[27] estimated vehicle flow on each of them by the total flow of each polygon (used by the local traffic company), proportionately to each road, according to their length in the area.

The difference in concentration of pollutants inside and outside of a home could be questioned as a limiting factor of studies that estimate the exposure of the population, based on an indicator of vehicular traffic. However, Hoek et al.[5] reported that a relevant part of the exposure to pollutants coming from an external environment probably occur inside the homes. Cançado et al.[41] observed that personal PM_{10} monitors, placed inside and outside homes, detected the presence of such pollutant, showing that approximately 50% of particulate material in the homes come from the external environment and that the remaining 50% originate from tobacco combustion, gas stove or an unknown source. Another aspect that could be questioned is whether the type of road or even its vehicle flow is an adequate indicator of the level of pollution in the area. In this sense, certain studies aimed to validate an indirect traffic measure with a specific pollutant, identified by the direct measure of its concentration. These studies are important, because authors confirm and emphasize the fact that a mobile source plays a key role in affecting the quality of air and that this could serve as a point of reference to estimate the exposure of a population to atmospheric pollutants.

Kramer et al. [29] used data on the concentration of NO_2 and the density of traffic in three areas of a city of Germany and showed that the exposure to traffic was an important proxy for NO_2 concentration (annual mean estimate).

The relationship between $PM_{2,5}$, elemental carbon and truck traffic in the Bronx, New York, USA, was analyzed by Lena et al.[40]. The results pointed out that the concentration of elemental carbon varied according to truck traffic (an increase of 1.69 µg/m³ in elemental carbon for each 100 trucks/hour).

Reynolds et al.[36] compared the values of density of vehicles, roads and traffic to data on the concentration of several pollutants (CO, NO_2, PM_{10}, benzene and 1,3-butadiene). The density of traffic showed a statistically significant positive correlation with CO (r=0.70), benzene (r=0.69), 1,3 butadiene (r=0.57) and, to a lesser degree, NO_2 (r=0.30). The density of roads showed a statistically significant positive correlation with CO (r=0.62) and, to a lesser degree, NO_2 (r=0.32) and PM_{10} (r=0.31).

Zhu et al.[4] measured particulate material and black carbon at distances of between 30 and 300 m from the sides of a highway in Los Angeles, USA. One of the sides of this highway was windward, the other, leeward. Measurements showed that the closer to the leeward side of a highway, the higher the concentration of ultrafine particles. Only when the distance was longer than 300 m, did this concentration become equal on both sides of the highway, indicating the influence of such particles within such distance.

The study conducted by Roosbroeck et al.[42] sought to validate the intensity of traffic as an estimate of exposure to particulate material, soot and NO_x in Holland. The exposure of individuals living on streets with heavy traffic (>10.000 vehicles/day) was compared to that on streets with low traffic.

The relationship between the intensity of traffic close to homes and concentrations outside of such homes was significant and explained between 5% and 50% of the variation in pollutants. The time spent in traffic and external environments significantly increased the exposure to soot and $PM_{2,5}$.

Meteorological factors, such as wind direction and speed, were dealt with in only one study, which considered the predominant wind direction[19]. The models developed usually assume an isotropic dispersion of pollutants in space. Wind direction could be less important for streets (arterial and collection) than highways, once homes are usually surrounded by the former, whereas the latter are often found along one side of these homes. As a result, it could be suggested that the lack of information about wind direction does not significantly influence the results of studies that were based on data on arterial, collection and, in some cases, local roads.

Finally, another trend which is beginning to appear more frequently in the literature on atmospheric pollution is the method known as Land Use Regression (LUR), used to evaluate exposure. This method predicts concentrations of pollution in a certain location, combining data on the road network or vehicular traffic with other factors that could influence exposure, such as land use, topography and population characteristics[43]. However, the creation of models based on regression involves complex statistical tests and the availability of all data necessary to create such models could prevent its implementation.

Final Considerations

As the economic development and urbanization process grow in developing countries, a fast increase in the number of vehicles is observed. These vehicles are frequently in poor conditions, running on low quality fuels, and including precarious engines and gas filter mechanisms, thus causing an increase in the levels of concentration of atmospheric pollution.

This article reviewed studies that used data on the road network and/or vehicular traffic as an indirect measure to evaluate atmospheric pollution in urban areas. These measures have been used more frequently in the international literature and applied to the investigation of several outcomes, thus having an important role in the context of environmental epidemiology. In addition, there is the unquestionable fact that procedures inherent to the analyses of such evaluations of exposure are facilitated and enriched by the use of the GIS to store, process and geocode data.

In summary, indicators of exposure based on vehicular traffic have been applied in several studies, because they are relatively easy to interpret and they describe how exposed to vehicle emissions residents are, especially those living near busy roads. As observed, studies have shown that the concentrations of pollutants close to roads are well correlated to traffic, so that these indicators can be used as an indicator of exposure of the population to urban atmospheric pollutants.

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