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REGULATED AIR POLLUTANT EMISSIONS FROM HIGHER EMITTERS STATIONARY SOURCES IN BELO HORIZONTE, MINAS GERAIS, BRAZIL

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Abstract - Belo Horizonte, capital of Minas Gerais state, is a highly urbanized city located in the third largest metropolitan area of Brazil, being one of the most important cities in the country. There are several potential air pollutant emission sources in the studied area, such as industry and the vehicular fleet (1,669,884 vehicles in 2015). These can affect the air quality, which can have an impact on population health. Despite this critical scenario, few studies have been developed with the objective of evaluating the air quality in this city, especially regarding the identification of pollutant emission sources. Thus, the aim of this study was to identify and quantify atmospheric emissions by stationary sources of significant environmental impact in Belo Horizonte. The quantification of emissions was preferably performed based on chimneys monitoring data. However, in the absence of these data, estimates were made based on AP-42 guidelines. As a result, 75 chimneys were identified, belonging to 28 companies. Pollutant emission rates of 305, 235, 234, 224, 206, 180 and 63 t year^{-1} were observed for NO_X, CO, TSP, PM_{10}, $PM_{2.5}$, SO_2 and VOC, respectively. The results obtained can contribute to the diagnosis, modeling and management of air quality in Belo Horizonte.
Keywords: Air pollution; Emission source; Emission inventory; Chimneys.

INTRODUCTION

Belo Horizonte, capital of Minas Gerais state, is a highly urbanized city located in the third largest metropolitan area of Brazil, which receives the city's name. This municipality has a population of over 2.5 million inhabitants, an area of 331 km^2, resulting in a population density of 7,167 inhabitants km^{-2}. Its Human Development Index (HDI) is 0.810 and the Gross Domestic Product (GDP) is 81.43 billion reais (R$), which represents 16.7 % of the state GDP and 1.53 % of the national GDP. In an economic view, Belo Horizonte is one of the most important cities in Brazil (IBGE, 2016).

In Belo Horizonte, there are many potential emission sources of atmospheric pollutants, such as the steel industry, several industrial boilers, for example, in hospitals, hotels and laundries, and pollutants related to the high growth of the vehicular fleet, which increased from 659,672 to 1,669,884 vehicles (growth of 153 %) between 2000 and 2015 (DENATRAN, 2016). Associated with the urban network expansion, these emission sources can affect the air quality, causing damage to the population health, as observed in Freitas et al. (2013) and Radicchi (2012), as well as to the environment. Despite this critical scenario, few studies have been carried out focusing on atmospheric

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pollution for this city, especially in relation to identification of emission sources and evaluation of dispersion and environmental contamination processes. For example, the only atmospheric emission inventory for Belo Horizonte (Table 1) was published by the state environmental agency (Fundação Estadual de Meio Ambiente) in 2003 (FEAM, 2003), but the aspect of emissions distribution over time was not considered. This scenario is very common in other Brazilian areas, where few studies have reported atmospheric emissions and there is a lack of data updating (Table 1).

Although on-road vehicles are reported as the main sources of air pollutants in urban environments, stationary sources, such as chimneys from industry, boilers and furnaces, may still make significant contributions to air pollution on these areas. According to Carvalho et al. (2015), industry still plays an important role for air pollution problems in some urban cities, as observed in the Metropolitan Area of São Paulo. Furthermore, Bhanarkar et al. (2005) showed that fossil fuel combustion in boilers is a significant source of sulfur dioxide, particles and toxic metals that can deteriorate air quality in urban areas. It is also important to consider that the major problems related to air pollution are due to the synergism of sources, it being necessary to know the main types of sources and emitted pollutants in a given study area. All of these issues are problems related to air quality that may be occurring in Belo Horizonte.

In order to define strategies and policies to mitigate the adverse effects of exposure to atmospheric pollutants, it is necessary to have a full comprehension of its characteristics and dynamics in urban environments. One of the most important steps to achieve this goal, is to identify the sources and quantify the pollutant emission rates, which is realized through an emission inventory (González et al., 2017). Through this tool, it is possible to identify the predominant emission sources and understand the main sectors and types of pollutants that contribute to the air quality deterioration in a given locality (Qiu et al., 2014; Ueda and Tomaz, 2011; Zhou et al., 2014).

In this context, the identification of stationary sources of air pollutants, in conjunction with their emission profiles in space and time, can provide a better understanding of their contribution to atmospheric emissions in Belo Horizonte nowadays. Pollutant emission quantification in these sources is also a fundamental subsidy for atmospheric dispersion studies, with models such as AERMOD (American Meteorological Society and Environmental Protection Agency Regulatory Model), and for assessing air quality through photochemical models, such as CMAQ (Community Multi-Scale Air Quality) (Albuquerque et al., 2018, Borge et al., 2008, 2014, Kim et al., 2008).

Thus, the aim of this study was to identify and quantify atmospheric emissions by stationary sources (chimneys) from companies of significant environmental impact in Belo Horizonte, with 2015 as the baseline year. Moreover, this study aimed to allocate these atmospheric emissions in space and time, and to evaluate the uncertainties associated with the use of emission factors for atmospheric emissions estimates.

METHODOLOGY

Selection of companies and data acquisition

The first stage to identify and quantify atmospheric emissions from stationary sources consisted in the selection of companies with significant potential air pollution impact, which are licensed and located in Belo Horizonte and whose environmental licenses were granted by the municipality or by the state. For this, research was carried out at the Municipal Secretariat of Environment of Belo Horizonte (SEMMA) and at the State Secretariat of Environment and Sustainable Development of Minas Gerais (SEMAD).

The polluting potential classification was made according to the guidelines of the Normative Deliberation 74/2004 of the Conselho Estadual de Política Ambiental (State Council of Environmental Policy) (COPAM) (MINAS GERAIS, 2004) and according to the Normative Deliberation 74/2012 of the Conselho Municipal de Meio Ambiente (Municipal Council of the Environment) (COMAM) (BELO

Table 1. Atmospheric emissions by stationary sources in Brazilian areas.

Local	Reference	Baseline year	Emission [t year^{-1} km^{-2}]				
			TSP	SO_2	CO	NO_X	VOC
Belo Horizonte	(FEAM, 2003)	2002	1.0	0.1	1.9	5.2	0.1
Contagem	(FEAM, 2003)	2002	3.6	2.2	9.5	41.7	1.3
Betim	(FEAM, 2003)	2002	6.1	21.9	4.8	45.8	1.2
MASP	(CETESB, 2016)	2014	0.4	0.7	0.5	3.3	0.7
MAV	(IEMA, 2011)	2010	3.9	9.7	60.0	9.1	2.0
MARJ	(Pires, 2005)	2004	1.9	9.8	1.1	5.3	4.5
MAS	(Lyra, 2008)	2006	0.9	4.3	5.8	5.9	2.8
Curitiba	(Grauer et al., 2013)	2013	4.4	0.3	22.0	2.7	NA[1]

[1]NA: Not Available; MASP = Metropolitan Area of São Paulo; MAV = Metropolitan Area of Vitória; MARJ = Metropolitan Area of Rio de Janeiro; MAS = Metropolitan Area of Salvador.

HORIZONTE, 2012), state and municipal legislations, respectively. These legislations establish criteria for classifying companies and activities that may be subject to environmental licensing, according to their size and polluting potential of air, soil and water. The polluting potential is a function of the intrinsic activity characteristics, considering mainly effluent flow rates and types of pollutants emitted.

At SEMMA, the identification of companies with significant air polluting potential was done with the assistance of technicians from the sector of Industrial Activities Licensing, who listed these companies according to the environmental licensing protocols. After the identification phase, consultations were carried out on the environmental licensing processes of the companies, such as environmental impact studies, environmental performance evaluation reports and environmental monitoring and compliance reports.

Considering that SEMAD provides the environmental information of companies licensed in the state, in electronic format, on the portal of the Integrated Environmental Information System (SIAM, 2017), searches in this database were then performed by linking the activity code and the name of the municipality. Through this, it was possible to identify the companies on which more refined searches were made in order to collect their respective environmental information.

At SEMMA and SEMAD, consultations of the environmental licensing processes were necessary to collect the following information: types, names and quantities of the emission sources; physical parameters such as location, diameter and height of the source; monitoring data of emitted pollutants, such as flow, velocity, temperature, concentration and emission rates. Information was also necessary on the production processes, such as daily operating time, raw materials used, fuel consumption rates, and whether or not emission control systems existed. It is important to emphasize that the monitoring data came from certified laboratories, whose methods of collection and analysis are recommended by technical standards, such as the Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards) (ABNT), the United States Environmental Protection Agency (US EPA) and the Companhia Ambiental do Estado de São Paulo (Environmental Company of São Paulo State) (CETESB).

Atmospheric emissions estimates

After the data acquisition for each company to be inventoried, air pollutant emissions estimates were carried out in two ways. In the first one, emission rates were extracted directly from the monitoring data. However, not all companies had monitoring data on their pollutants and / or not all pollutants that could be emitted were monitored. In those cases, estimates were made following the guidelines of the *Compilation of Air Pollutant Emission Factors* (AP-42) from the United States Environmental Protection Agency (US EPA, 1995). This methodology follows the emission factor (EF) approach, as demonstrated in Equation 1:

$$E = A \times EF \times \left(1 - \frac{RE}{100}\right) \tag{1}$$

where E is pollutant emission (kg h^{-1}); A is the activity, which can be, for example, the fuel consumption, the activity duration or the amount of produced material; EF is the emission factor, which relates the mass of pollutant emitted with the activity; and RE is the removal efficiency of the control equipment adopted at the emission source (%).

Emission factors were taken from the AP-42 (US EPA, 1995), European Environmental Agency (EEA, 2016) and UK National Emissions Inventory (JONES et al., 2017). Although the EFs used are from the US EPA database or from European Union countries, in the absence of local EFs, their use has been recurrent and accepted in several studies developed worldwide, such as Pires (2005) (Rio de Janeiro, Brazil), Sadavarte and Venkataraman (2014) (India), Kawashima (2015) (Brazil) and González et al. (2017) (Colombia).

Spatial and temporal allocation of emissions

The spatial allocation of the emission sources was done according to their geographical coordinates in ArcGIS (version 10.3). The temporal distribution was based on data for the productive processes. Thus, for continuous processes, constant emission rates (24 hours per day) were used throughout the reference year. For cases where production was interrupted or changed according to the hours of the day or to the days of the week, the emission rates were distributed according to these periods. In cases where information on the production process was unavailable, the most conservative scenario was adopted, with emission rates constant 24 hours a day, 7 days a week.

Assessment of uncertainties associated with the use of emission factors

Considering the intrinsic uncertainties related to the use of emission factors, an evaluation of the existence of differences between the data obtained from the monitoring and those estimated from these emission factors was performed. Thus, for those sources estimated from monitoring data, where data were also available to estimate their emissions based on emission factors if their pollutants had not been monitored, these two methodologies were used.

Subsequently, the percentage error observed in the estimate based on the emission factor was calculated in comparison to the data obtained from the monitoring, as presented in Equation 2. This process allowed a preliminary evaluation of uncertainties arising from the use of emission factors.

$$\text{Error}(\%) = \left[\frac{\left(E_{EF} - E_{Monitoring}\right)}{E_{Monitoring}}\right] \times 100 \qquad (2)$$

where *Error (%)* is the percentage error observed in the estimate based on the emission factor; E_{EF} is emission rate of a given pollutant obtained from the emission factors; $E_{Monitoring}$ is the emission rate of a given pollutant obtained from the monitoring data.

RESULTS AND DISCUSSIONS

Atmospheric emissions from stationary sources in Belo Horizonte

Based on the methodologies outlined, 75 stationary sources of atmospheric pollutants were identified in Belo Horizonte, distributed over 28 companies. Among these sources, there are 21 boiler chimneys supplied with low flash point fuel oil (BPF A1 oil) (9), firewood (5), natural gas (3) and liquefied petroleum gas (LPG) (1), and 36 chimneys from a single steel industry. These results represented a significant change compared to the local official inventory (FEAM, 2003), with the inclusion of 25 new companies and maintenance of only 3 of the previously reported.

The inventoried air pollutants considered were those regulated by the Normative Deliberation 491/2018 of the Conselho Nacional de Meio Ambiente (National Environment Council) (CONAMA) (BRASIL, 2018) that directly affect the air quality, with impact on health and on the environment. These pollutants were total suspended particles (TSP) and their fractions, particulate matter with an average aerodynamic diameter of less than 10 µm (PM_{10}) and less than 2.5 µm ($PM_{2.5}$), sulfur dioxide (SO_2), carbon monoxide (CO) and nitrogen oxide (NO_X). Although volatile organic compounds (VOC) were not included in these legislations, they were also considered due to their important role in ozone formation.

Among the pollutants evaluated, considering an overall rate (sum of all sources) in the base year of this study (2015), NO_X was the most emitted, with an emission rate of 305 t year^{-1} (Figure 1). The emission of this pollutant is closely associated with combustion processes due to the thermal combination at high temperatures of nitrogen (N_2) and oxygen (O_2) present in atmospheric air (Zeldovich mechanism). In the case of stationary sources in Belo Horizonte, NO_X emissions occurred mainly in industrial boilers (companies 6, 8 and 13 to 17, Table 2), in biogas burning plants (company 27, Table 2) and in steelworks (company 28, Table 2).

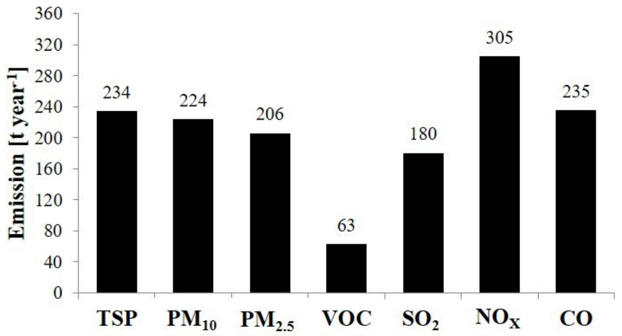

Figure 1. Emission rates of air pollutants by stationary sources in Belo Horizonte in 2015.

CO was the second most emitted pollutant in stationary sources in Belo Horizonte in 2015, with an annual emission of 235 tons (Figure 1). As for NO_X, this emission is also related to combustion processes due to incomplete fuel oxidation. The highest emission rates were mainly observed for companies that had wood fired boilers (companies 5 to 9, Table 2), BPF 1A oil boiler (company 13, Table 2), and the biogas and steel industry (companies 27 and 28, respectively; Table 2).

In the case of particles, both TSP and its fractions, PM_{10} and $PM_{2.5}$, emission rates were higher than 200 t year^{-1} (Figure 1). In this case, besides the particulate matter emission in the combustion processes, physical processes of grinding, transportation and materials finishing also contributed with their respective rates. Thus, in Table 2 it can be observed that the steel industry (company 28) was responsible for 81, 82 and 85 % of TSP, PM_{10} and $PM_{2.5}$, respectively, emitted by stationary sources inventoried in Belo Horizonte. The main reasons are related to the large number of sources (36 sources) and developed processes, such as transportation, loading and unloading of particulate raw materials, combustion in various types of furnaces, as well as the finishing of materials, such as blasting and painting. Nevertheless, significant contributions also came from companies 5 and 8 (wood fired boilers) and 13 and 16 (oil boilers) (Table 2).

It is important to emphasize that, out of the 234 t year^{-1} emitted of TSP, the biggest part corresponds to its fractions PM_{10} (96 %) and $PM_{2.5}$ (88 %). This close proximity between TSP and its fractions may be related to combustion systems, which form mostly fine particles. In addition, especially in industrial boilers, control systems, such as cyclones, are designed primarily for the removal of coarse particles, which results in higher emission of fine particles.

Since $PM_{2.5}$ is composed of particles with small diameters that are able to penetrate deeply into the pulmonary alveoli and the cardiovascular system, thus putting human health at risk, the high emission rates of

Table 2. Atmospheric emissions by typologies of stationary sources in Belo Horizonte in 2015.

Company		Emission [t year^{-1}]						
Nº.	Typology / Activity	TSP	PM_{10}	$PM_{2.5}$	VOC	SO_2	NO_X	CO
1	Production of malt and beer	0.02	0.02	0.02	0.01	0.02	0.24	0.20
2	Production of pharmaceutical products	0.04	0.04	0.04	0.01	0.02	0.23	0.22
3	Manufacturing of vests, helmets and ballistic plates	0.07	0.07	0.07	1.10	0.05	0.02	0.95
4	Production of malt and beer	0.01	0.01	0.01	0.01	0.01	0.10	0.05
5	Industrial laundry	6.87	6.18	5.22	20.79	13.33	0.47	7.74
6	Bleaching and dyeing in yarns, fabrics and textile articles	2.60	2.34	1.97	0.30	0.19	3.78	10.55
7	Slaughterhouse: slaughtering of cattle and pigs, manufacturing of meat products and preparation of slaughter by-products	1.15	1.05	0.62	0.09	0.05	0.10	23.65
8	Production of prefabricated concrete and industrialization of building materials	16.82	15.14	12.78	2.44	1.57	30.71	91.01
9	Manufacture of sealing adhesives and rubber products	0.98	0.88	0.74	0.11	0.07	1.34	2.38
10	Industrial laundry	0.16	0.16	0.15	0.01	0.79	0.45	0.04
11	Manufacture of rubber products	0.01	0.01	0.01	0.00	0.01	0.11	0.84
12	Hospital boiler	0.17	0.16	0.04	0.04	2.94	1.66	0.52
13	Hospital boiler	7.63	6.56	4.27	1.94	40.24	42.87	7.59
14	Hospital boiler	1.26	1.08	0.70	0.16	49.28	6.91	0.63
15	Hospital boiler	0.73	0.63	0.41	0.09	28.81	4.04	0.37
16	Hospital boiler	2.71	2.57	0.60	0.39	24.97	17.40	0.43
17	Hospital boiler	1.43	1.23	0.80	0.18	4.53	7.85	0.71
18	Production of soft drinks	0.03	0.03	0.02	0.04	0.03	1.65	0.15
19	Organic electronics laboratory	0.00	0.00	0.00	0.04	0.00	0.00	0.00
20	Manufacturing of building articles (sinks, tanks and washbasins in synthetic marble)	0.84	0.84	0.84	0.21	0.00	0.00	0.00
21	Manufacturing of machinery and equipment for mining	0.12	0.12	0.12	0.00	0.00	0.00	0.00
22	Manufacturing of machinery, equipment and apparatus for loads transport and elevation	1.49	1.49	1.49	2.47	0.00	0.00	0.00
23	Crematorium	0.19	0.17	0.17	0.03	0.26	0.67	0.17
24	Production of printed circuit boards	0.03	0.03	0.03	0.00	0.00	0.00	0.00
25	Production of voltaic films	0.00	0.00	0.00	0.01	0.00	0.00	0.00
26	Production of concrete	0.03	0.03	0.03	0.00	0.00	0.00	0.00
27	Production of energy from the burning of landfill biogas	0.00	0.00	0.00	0.00	7.34	49.51	11.65
28	Steel industry: steelmaking and processing of iron and steel products with ores reduction, including pig iron	189.03	183.22	174.51	32.43	5.59	134.58	75.19

this pollutant observed in the present study are a point of attention. According to Andreão et al. (2018), in 2013 and 2014, the concentration of $PM_{2.5}$ in the Belo Horizonte atmosphere was higher than the standards established by the World Health Organization (WHO) (10 µg cm^{-3}). The sources studied here may be potential contributors to this exceeding of the standards.

For SO_2, emissions occur due to the presence of sulfur in the fuels, which, during the combustion processes, is oxidized and converted into gas. In this study, SO_2 emissions were 180 t year^{-1} (Figure 1), with burning of fuel oil in industrial boilers, especially in companies 13 to 16 (Table 2), as the main contributor.

Finally, the least emitted pollutant was VOC, also formed during the combustion processes (incomplete oxidation), in addition to evaporative emissions in painting booths. Its total emission rate was 63 t year^{-1} (Figure 1), with the largest contributions coming from the steel industry (company 28) and from an industrial boiler with high consumption of firewood (company 5) (Table 2).

In the present study, only stationary sources for which licensing processes are required by the environmental agency were considered. Despite this, Kumar et al. (2016), evaluating the challenges of air quality management in the Metropolitan Area of São Paulo (MASP), reported the influence of unregulated sources on air quality, such as bakery chimneys, restaurants, pizzerias and steakhouses. In the case of pizzerias, Lima (2015) showed that, in the city of São Paulo there are about 8,000 pizzerias, of which approximately 80% use firewood in their kilns. Considering an average utilization rate of 48 tons of firewood per year per pizzeria, Lima (2015) estimated an emission rate of approximately 321 kg day^{-1} of $PM_{2.5}$. These issues show the need of improving the inventory with the incorporation of these other typologies of stationary sources, as well as to alert public authorities to the surveillance of other potential emission sources, which in previous scenarios did not exist or were considered to be low environmental impact agents.

Along with the observed contribution of the typologies of stationary sources for atmospheric emissions in Belo Horizonte in this study, in many urban areas, other sources, such as vehicular ones, have been reported to be the most representative. Considering the same baseline year of the present study, Santos (2018) estimated the atmospheric emissions of TSP, VOC, SO_2, NO_X and CO pollutants as 1,220, 4,616, 581, 13,992 and 16,574 t year^{-1}, respectively, by the vehicular fleet in Belo Horizonte. The emission rates were, respectively, 5.2, 73.4, 3.2, 45.8 and 70.5 times higher than the emissions from the stationary sources inventoried in the present study.

One way to identify which sources have contributed most to the deterioration of local air quality is to monitor the environmental concentrations of certain trace pollutants, such as particulate matter (Albuquerque et al., 2012; Andrade et al., 2012; Miranda et al., 2012). For Belo Horizonte and its metropolitan area, studies that have monitored and characterized the elemental composition of PM_{10} (Moura, 2016) and $PM_{2.5}$ (Andrade et al., 2012) have mainly attributed the environmental concentrations measured to other source typologies, such as vehicular and mining.

The study developed by Andrade et al. (2012), based on the analysis of $PM_{2.5}$ elemental composition, with subsequent application of receptor models (principal component analysis, multivariate statistics), identified four main factors that can explain the origin of fine particles in the Belo Horizonte atmosphere. The first one, representing 44 % of the collected mass, was related to particulate emissions from soil dust resuspension, mainly due to the presence of Si, K, Ca, Ti, Fe and Br. This factor was associated with the mining activities developed around the city and also to the materials transported to and from the mines. Factor 2, responsible for 13 % of all $PM_{2.5}$, was attributed to the burning of diesel, mainly due to the activity of heavy vehicles. The third factor, which represented 12 % of the collected mass, was associated with the formation of the secondary aerosol and also the combustion of fuels in industrial processes (including the inventoried sources). The last factor analysed, representing only 4 % of the collected mass, was linked to the emissions released by the exhaust pipes of light vehicles (Andrade et al., 2012).

Moura (2016), following a similar methodology as Andrade et al. (2012), but focusing on the composition of PM_{10} in several points of the Metropolitan Area of Belo Horizonte (MABH), also noted the importance of emissions due to mining activities and resuspension of soil dust, and due to vehicular activities.

These results reiterate the necessity of an inventory that encompasses the main type of sources, also considering the synergy between them, making possible a more accurate diagnosis of air pollution in urban areas. Furthermore, dispersion studies and air quality modeling may help to understand the influence of the surrounding areas on pollution in a particular study region, making possible the quantitative evaluation of the impact of mining activities from neighboring municipalities on Belo Horizonte's air quality, as previously reported.

Spatial and temporal distribution of atmospheric emissions from chimneys in Belo Horizonte

Belo Horizonte is a city with nine main regions: Venda Nova, North, Pampulha, Northeast, Northwest, East, South-Central, West and Barreiro. In relation to the spatial distribution of the identified stationary sources, it was possible to verify that, in regional terms, the Barreiro region was the one that hosted most of the sources identified (42 sources, 62.7 %) (Figure 2). Another important aspect of the spatial distribution is that no stationary sources were observed in Venda Nova or in the North regions. For the other regions of Belo Horizonte, the numbers of sources were very close, 8 of them being located in the West region (10.7 %), 6 in the Northwest (8.0 %), 4 in the South-Central, East and Pampulha (5.3 %) and 2 in the Northeast region (2.7 %).

The temporal emission profiles can be observed in Figure 3. According to the data collected, 44 (58.7 %) of the 75 identified sources have continuous operation (24 h day^{-1}) while the others (31; 41.3 %) have different

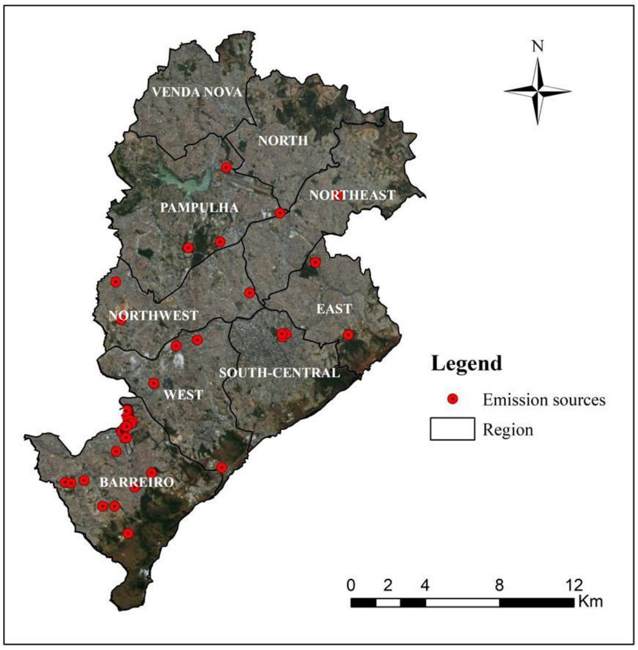

Figure 2. Stationary licensed emission source locations by region in Belo Horizonte in 2015.

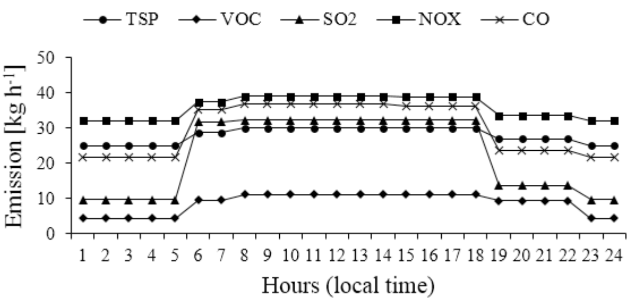

Figure 3. Hourly profiles of atmospheric emissions from stationary sources in Belo Horizonte in 2015.

operating standards, mostly ranging from 6 to 16 h day^{-1}. As result, for the different pollutants evaluated, three main emission profiles can be observed: a diurnal one from 6 to 18 h (local time), with the observed emission rates being the highest; one at the end of the day from 18 to 22 h (local time); and a nocturnal profile from 23 to 5 h (local time), in which observed emission rates were the lowest.

From these results, it is possible to verify small differences between the end of the day and the nighttime period profiles. Despite this, representative differences can be observed between diurnal profiles and the others, especially for SO_2 and CO. Increases in diurnal profiles for these pollutants are due to some activities such as hospital boilers and industrial laundries.

Assessment of uncertainties associated with the use of emission factors

From the comparison between the emission rates obtained from monitored data and estimates based on emission factors, in situations where the application of these two methodologies was possible, a set of 12 results was obtained for the TSP, 4 for NO_X and 6 for CO. For SO_2 and VOC, it was not possible to carry out this analysis, since most of the data was obtained from estimates. It should also be noted that the data obtained for TSP, NO_X and CO were solely related to the combustion processes in boilers, for which only AP-42 emission factors (US EPA, 1995) were used, in order to obtain a more consistent analysis related to the typology of sources. In this sense, due to the presence of isolated cases, the other typologies were not considered in this part of the study.

According to the results obtained, for TSP and NO_X pollutants, an overestimation in relation to the monitored data was verified, with a mean value of 37.2 and 39.7 %, respectively. The opposite profile was observed for CO, in which an average underestimation of 32.6 % was found.

The differences between the data obtained from the monitoring data and those estimated from the emission factors may be due to a number of different causes. The first one is related to uncertainties inherent to the emission factors, as already reported in AP-42 (US EPA, 1995). Other issues that may lead to the overestimation or underestimation of emissions is the lack of specific information about the control systems used, such as the existence or not of control equipment (for those companies for which control information was not reported, non-existence was considered) and the specific removal efficiencies for particulates and gaseous pollutants.

Through advanced statistical analyses, such as uncertainty analyses by the Monte Carlo method, some studies have demonstrated the divergence between data estimated from emission factors and actual data from continuous monitoring. Frey and Zheng (2002) evaluated NO_X emissions in coal-fired power plants and found total inventory uncertainty ranging from -16 to 19 %. These differences were attributed mainly to one of the several technological groups related to the production of thermal energy, suggesting a more accurate process of data collection to establish equivalence between the emission factors and the technology used in the emission source.

Pouliot et al. (2012) also compared estimates from the emission factors of AP-42 with continuous monitoring data of NO_X emissions in an electric power generation plant. According to the data of these researchers, the US EPA emission factors were reasonably representative for some sources, however, the values presented in the AP-42 should be updated, because more than half of the sources were not well represented. For the AP-42 emission factors for this source typology, uncertainties ranging from 25 to 92 % were observed, with the highest uncertainty values being related to the use of lower quality emission factors.

Frey and Li (2003), evaluating the emissions of several pollutants from stationary engines operating with natural gas, observed mean uncertainties in emission factors of ± 10 %, but also ranging from -90 to + 180 %. According to these authors, the wide range of uncertainties observed in some emission factors emphasizes the importance of recognizing and explaining the limitations of emission estimates.

The results obtained in the present study for the uncertainties generated due to the use of emission factors, despite coming from a small database and presented more generally, without an advanced statistical treatment, show the importance of carrying out emission inventories in a detailed, secure and accurate manner. Methods that consider real data such as continuous monitoring or parametric testing (for example, isokinetic monitoring) should always be prioritized. Estimation using emission factors should be applied only in the cases in which this information is unavailable. Awareness and clarity about the uncertainties generated can help in the decision making regarding pollution prevention and control policies, as well as give a better understanding of the results obtained in air quality models, since some studies attribute the poor modeling performance to the emission inventory inaccuracies (Borge et al., 2008; Albuquerque, 2010; Borge et al., 2014; Pedruzzi, 2016). According to Frey and Zheng (2002), if random and biased errors in emission inventories are not quantified, they can lead to erroneous conclusions about emission scenarios, source identification and the relationship between emissions and air quality.

REMARKS AND CONCLUSION

Based on the applied methodologies, 75 stationary sources of atmospheric pollutants were identified in Belo Horizonte, belonging to 28 companies. It was observed that NO_X, among the pollutants evaluated, was the most emitted, followed by CO, TSP, PM_{10}, $PM_{2.5}$, SO_2 and VOC, with emission rates of 305, 235, 234, 224, 206, 180 and 63 t $year^{-1}$, respectively.

Regarding the spatial distribution of the sources, the Barreiro region was the one that presented the highest concentration of sources, mainly because it is a more industrialized region in the municipality. The temporal distribution showed that, for all pollutants, the daytime period is the one that most contributes to the emission rates, ranging from 6 to 18 h (local time).

Finally, the uncertainty assessment showed that, in the evaluated cases, the TSP and NO_X pollutants were, on average, overestimated by 37.2 and 39.7%, respectively, when compared to the monitored data. The opposite profile was observed for CO, in which an average underestimation of 32.6% was identified. Awareness and clarity about the uncertainties generated can help in the decision-making regarding pollution prevention and control policies, as well as give a better understanding of the results obtained in air quality models, since some studies attribute the poor performance of air quality modeling to emission inventory inaccuracies.

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