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Papers

Atmospheric pollution: a case study of the Municipality of São Luís do Maranhão

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Abstract:
The Brazilian capitals have been presenting environmental problems of diverse orders, reverberating negatively in the life quality of its inhabitants. São Luís, the State of Maranhão's capital, with a population of larger than 1 million citizens consists of a good example of a Brazilian capital that can coexist with environmental atmospheric problems. The research when analyzing the atmospheric pollution in the city further sought to correlate with its geographic aspects (physical and human) by comprehending that it's only possible to discern the complexity of the problem when it's not limited only to the pollution sources and the emitted volumes. The collected data were obtained from seven automatic stations of air quality belonging to Company Vale S/A and oriented by an evolutive and integrated analysis. The achieved results by the study indicated that the EMAP station, localized in the county's port zone, was the sole one that presented values that exceeded the established limits by the Law with the subsequent values in percentages for Unbreathable Particles in the following years: in 2013 (68%); 2014 (87%); 2015 (110%) and 2016 (2%). It was also possible to distinguish between the months from July to December, in the dry season, significant rises in the atmospheric pollution indexes in the order of 24,5% for Unbreathable Particles and 35% for Total Particles in Suspension. It is concluded beyond polluting sources, that in São Luís case, the rainfall and wind are climatic atributes significant in the determination the levels of pollution in the study area.

INTRODUCTION

Air pollution, which is characterized by the emission of toxic gases and particulate matter into the atmosphere, whether from natural (dust produced by the wind, and methane gas from the biological degradation of organic material, volcanic eruptions, etc.) or anthropic sources, that comes in great part from large settlements and industrial sites, driven primarily by the strong presence of automobiles and of the emission of toxic gases in the industrial process, they are the ones responsible for putting at risk the quality of life of many of the living beings on the planet.

Air pollution in cities affects human health, mainly the the respiratory system, due to particles deposition (LOPES, 2004). In addition to provoking diseases of the respiratory tract, cardiovascular, dermatological, gastrointestinal diseases, ophthalmic problems and types of

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cancer that originate from the presence of atmospheric pollution in the environment are also identified (PEITER; TOBAR, 1998). Gouveia et al. (2006) analyzed the association between Particulate Matter (PM) atmospheric pollution and hospital admissions in São Paulo, found that an increase of 10μg m^{-3} of Inhalable Particles (IP) that is associated with an increase of 4,6% in admissions for asthma in children, 4,3% for chronic obstructive pulmonary disease and 1.5% for ischemic heart disease in the elderly.

Peiter and Tobar (1998) state that, in industrial cities, the emission of toxic and particulate gases by industries added to the pollution caused by the circulation of vehicles, often generate very critical situations for the health of the population. Air pollution is undoubtedly a very serious risk factor for human health. It is also noteworthy a serious fact that occurred in 1952, where about 4 thousand people died in the London region due to SO_2 poisoning from coal burning. A sudden cooling in the atmosphere caused by thermal inversion trapped the pollutants over the population

Conselho Nacional do Meio Ambiente (CONAMA) Resolution No. 03/90, which regulates Brazilian atmospheric conditions, conceptualizes air pollution as follows in its Article 1 - Single Paragraph:

> Air pollutant means any form of matter or energy with intensity and quantity, concentration, time or characteristics at odds with the established levels, and which makes or may make the air: unsuitable, harmful or offensive to health; inconvenient to public welfare; harmful to materials, fauna and flora; harmful to safety, to the use and enjoyment of property and the normal activities of the community (BRASIL, 1990, p.342).

For the World Health Organization (WHO), air pollution is conceptualized as "contamination of internal or external environments by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere". The emission of polluting gases changes the chemical composition of the atmosphere, which leads to changes in the environmental balance, with direct impacts on the health of the population.

Also states the Ministry of Environment - (MMA, 2009) that the health effects of the population by particulate matter indicate occurrences of: respiratory cancer, arteriosclerosis, lung inflammation, worsening of asthma symptoms, increased hospitalizations that can lead to death.

Air pollution can occur in several ways and be generated by several vectors. Da Silva (2016) found in research that the occurrence of burns, unregulated vehicles, inadequate urban construction patterns and streets without asphalt coverage can contribute much more significantly to the generation of air pollution than contaminants from industries.

another significant and determinant condition for understanding the problem of air pollution in cities are the geographic factors present and acting in the urban environment that are fundamental to the understanding of how they promote the intensification and resilience of pollution specificities. Many authors, such as Miller (2007); Braga et al. (2005); Davis and Cornwell (2008), point out that in urban spaces the level of air quality, to some extent, is conditioned by socio-environmental characteristics. Zheng et al (2017) studying the relationship of air pollution with land use patterns found that the occurrence is higher than the pollution values in spaces of intense land use compared to more vegetative spaces, as well as greater pollution variation in the winter period. These scholars highlight that the atmospheric characteristics such as wind, in its direction and intensity, temperature, rainfall, air humidity, as well as geomorphology and economic activities conditions the spatiality and intensity of pollution.

The physical geography of a location can determine the quality of the air whose daily atmospheric emissions are aggravated by the characteristics of the geomorphology and the climate, making it even more difficult conditions for the dispersion of the pollutants, we can mention the city of Santiago de Chile that, according to Garreaud and Rutllant (2006), states that in the city, in the winter period, it becomes much more susceptible to episodes of intense occurrences of thermal inversion. Another researcher Tian et al (2018) in studying the effects of pollution on the population of Hangzhou, China identified that pollution levels vary according to the seasons and their impacts are more severe in winter and smaller in summer.

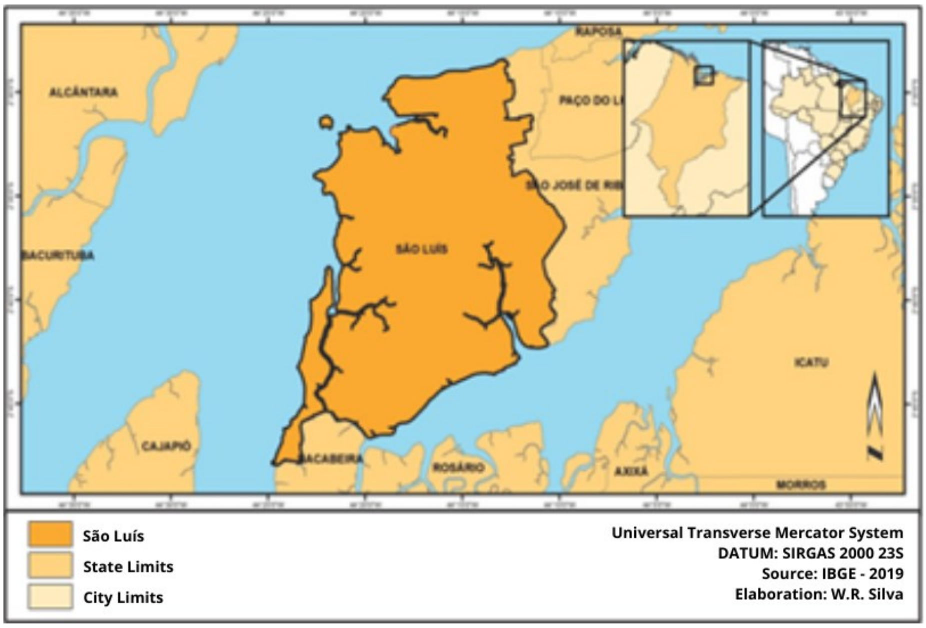
Thus, the objectives of the research was to verify the levels of air pollution in the city of São Luís where they allowed to evaluate both the urban environment, rural and industrial in correlation with its geographical aspects, especially the wind and rain. Researches that seek to monitor air quality by pollutants, in which they seek to quantify and spatialize them, aims, above all, to ensure the health of the population and of all living beings, in addition to promoting a sustainable and environmentally safe socioeconomic development with possibilities of prevention, control and reduction of emissions of pollutants.

In this sense, the research seeks to restore the importance of having an integrated approach to the problem of air pollution, not being limited to just the sources, but also including the analysis of the interference from the factors of geography, as well, the study fills a research gap on the topic of air pollution, involving the cities of the low latitude, in a morphoclimatic transition zone between the Amazonian with hot and humid climate, and the north-eastern semi-arid climate with very particular geographical features.

Location and geographical characterization of the study area

The municipality of São Luís is located in northeastern Brazil and north of the state of Maranhão, is located in the coastal region of the State, on an island within the Maranhense Gulf (Figure 1). Its topography is flattened and is characterized by a flat relief throughout the city of São Luís, reflecting that its altitude whose highest point reaches 70 meters (SILVA, 2012), also suffers direct influence of maritimity and because it is located geographically in low latitude - specifically at 2° 30’ S, provides a climatic configuration that, associated with the conditions of regional action of hot air masses and tropical atmospheric mechanisms, produces the existence of low variability thermal averages both in daily variations, as for the variations throughout the year, but with high temperature.

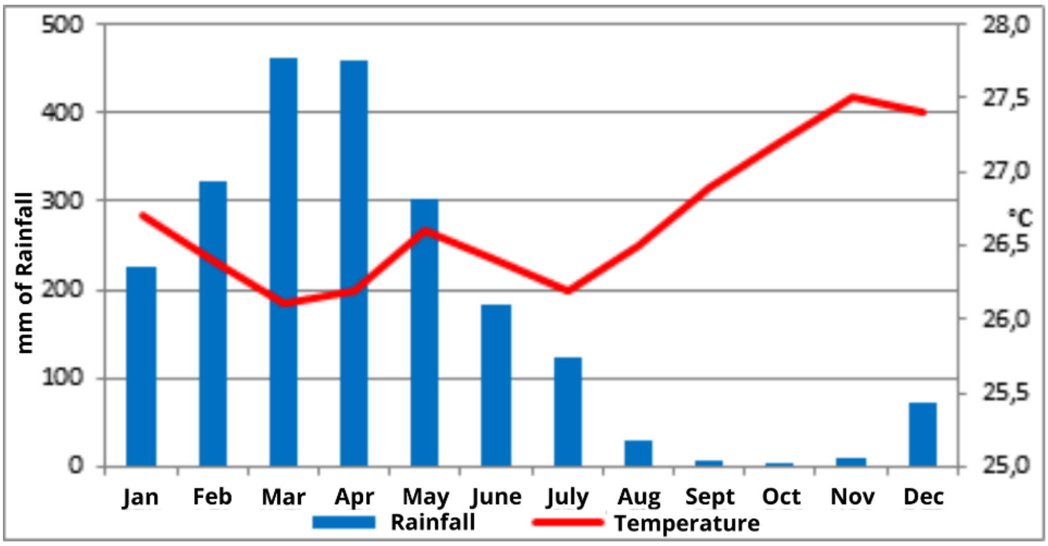
Figure 1: Location Map of the municipality of São Luís



Source: IBGE (2019).

The perpendicularity of the sun's rays acting on the surface of the city, is paramount to the low variability in heat, and in the absence of the seasonal cycles of the seasons of spring, summer, fall, and winter setting, as stated by Pinheiro (2018), and a classification of the existence of only two seasons, a rainy season (January to June) and dry season (July to December). By observing INMET's Climatological Normal of rainfall and temperature for São Luís it is possible to identify these characteristics (Figure 2).

Figure 2: Graph of the Climatological Normal (1981-2010) of rainfall and temperature for São Luís - MA



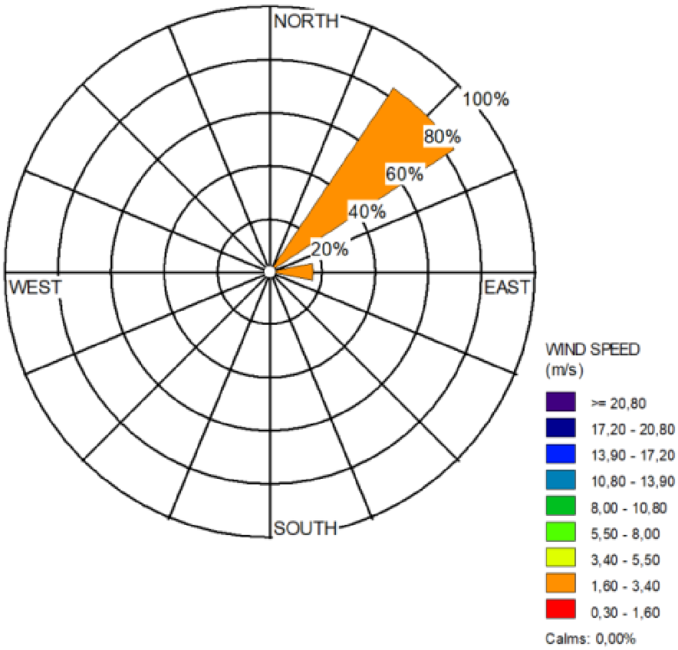
Data source: INMET. Org.: Authors, 2019.

Also according to Pinheiro (2018) the main atmospheric systems present and operating in the city of São Luís are, in particular, the Intertropical Convergence Zone (ITCZ) responsible for the annual determination of the rainy and dry period, and the influence of Trade Winds responsible for the actuation of the constant winds of regional origin and loaded with moisture. At secondary level of action, the Upper Tropospheric Cyclonic Vortices (UTCVs), generating periods of atmospheric stability with drought; the South Atlantic Subtropical High (SASH), the Easterly Waves Disturbances (EWD) and the Instability Lines (IL) with the generation of short periods of rainfall in the region and, on a local scale of influence, the sea breeze with daily winds and occasional rains by convective systems.

Another important variable of its climate configuration and that has a direct influence to understand the air pollution conditions of the city are related to the wind, Figure 3.

It stands out according to Figure 3 of the Climatological Normal of São Luís, that 82% of the winds are predominantly of northeast direction and 18% of east direction and their average intensity varies between 1.6 M/s to 3.40 m/s. According to Pinheiro and Galvani (2018) the highest wind intensities, in São Luís, are recorded in the months of September to December and the four months of the lowest intensity of the winds are the months of March to June. Its winds are characterized by being constant and very little occurrence of lull, however, considered of low intensity according to the Beaufort Scale, weak breezes.

Figure 3: Graph of the Compass Rose of the Climatological Normal (1981-2010) of the direction and intensity of the winds in São Luís.



Data source: INMET. Org.: Authors, 2020.

MATERIALS AND METHODS

Two parameters of particulate materials generating air pollution were chosen for the research: Total Suspended Particles (TSP) and Inhalable Particles (IP). The choice of these two particulates was due to the fact that these elements presented data in consistent quantities of the years studied, as well as they represent pollution values that identify both the pollution from the burning of fossil fuels (motor vehicles, vegetable biomass), and suspended material from the action of the wind.

According to the MMA (2009), particulate matter consists of:

> A complex mixture of solids with reduced diameter, whose components have different physical and chemical characteristics. In general, the particulate material is classified according to the diameter of the particles, due to the relationship between diameter and the possibility of penetration into the respiratory tract.

In Brazil, air quality standards were established by CONAMA Resolution No. 3 of June 28, 1990, which complements CONAMA Resolution No. 5 of June 15, 1989, in which established the National Air Quality Control Program - PRONAR. With this resolution were determined the national air quality standards for air pollutants: a) Total Suspended Particles - TSP and B) Inhalable Particles - IP, used in the research. Resolution 3/90 CONAMA, when established the monitoring standards for daily and annual mean values for TSP and IP pollutants, also determined that the daily indices should not exceed their values more than once a year, Table 1.

Table 1- Average concentration values of air quality standards for Total Suspended Particles (TSP) and Inhalable Particles (IP) determined by Resolution No. 3/90-CONAMA.

Pollutants	**Primary Pattern**	
	CONAMA (maximum concentration)	Time Reference
Total Suspended Particles – TSP	80 (µg / m³)	One year
	240 (µg / m³)	24 hours
Inhalable particles - IP	50 (<10µm³)	One year
	150 (<10µm³)	24 hours

Source: resolution no. 3/90 – CONAMA (BRASIL, 1990).

As determined by the Resolution standard for TSP pollution, the average annual concentration should not exceed 80 (eighty) micrograms per cubic meter of air, and for average concentrations of 24 (twenty-four) hours should not exceed 240 (two hundred and forty) micrograms per cubic meter of air. For IP polluters, the average annual geometric concentration shall not exceed 50 (fifty) micrograms per cubic meter of air and for average concentrations of 24 (twenty-four) hours shall not exceed 150 (one hundred and fifty) micrograms per cubic meter of air.

The city of São Luís has seven automatic air quality monitoring stations, belonging to the Vale S/A company, managed through the outsourced company ECOSOFT that installed and manages them. All automatic air monitoring stations are located geographically within the city of São Luís (Table 2) and the data acquired represent daily parameters collected every day, every hour, from the years 2013 to 2016 in all stations. We also highlight that some data collected from the series presented inconsistencies or failures indicating that in some days there were inaccurate, incomplete or absent records. We chose not to apply any statistical technique of correction of failures and where the incongruities occurred these days were ruled out.

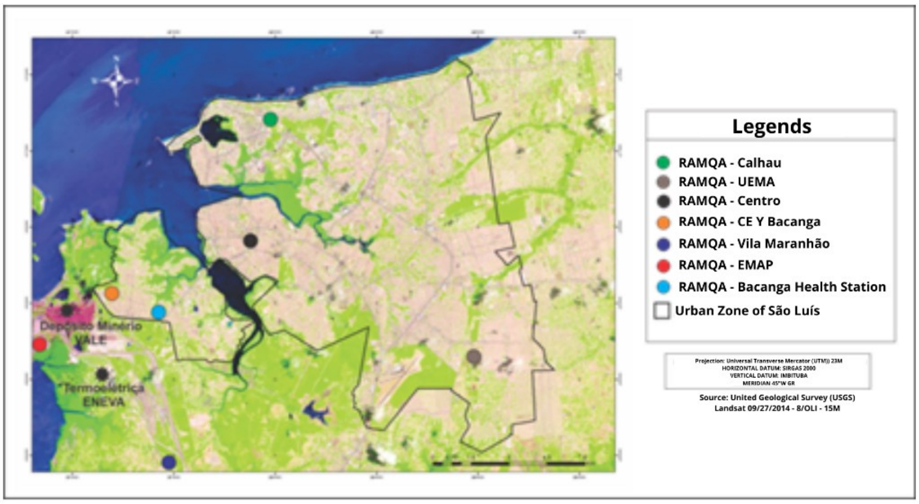
Table 2 - Location of the Geographic Coordinates of the Automatic Air Quality Monitoring Networks in São Luís.

AUTOMATIC AIR QUALITY MONITORING NETWORKS – RAMQA			
	STATIONS	Latitude S	Longitude O
1	RAMQA - Calhau Station	2° 29' 40,32"	44° 16' 43,78"
2	RAMQA - Centro Station	2° 32' 09,76"	44° 17' 32,25"
3	RAMQA - Uema Station	2° 34' 48,10"	44° 12' 33,50"
4	RAMQA - Bacanga Health Station	2° 33' 56,22"	44° 19' 13,98"
5	RAMQA - Vila Maranhão Station	2° 37' 29,69"	44° 18' 58,29"
6	RAMQA - EMAP Station	2° 34' 34,48"	44° 21' 58,17"
7	RAMQA - CE Y Bacanga Station	2° 33' 40,72"	44° 20 '09,04"

Source: Authors, 2019.

For better visualization of the location of the Automatic Air Quality Monitoring Stations in the city of São Luís, Figure 4 identifies their geospatial locations.

Figure 4 - Location of Automatic Air Quality Monitoring Networks - RAMQA in São Luís - MA.



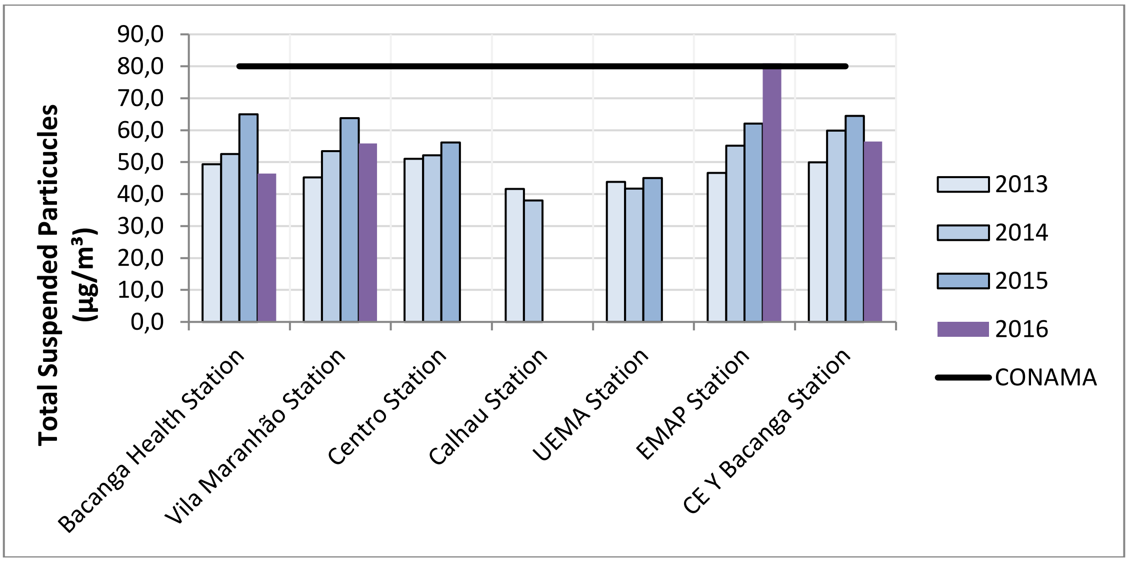
Source: United Geological Survey (USGS), Org.: Authors, 2019.

The observations to be highlighted are, first, that of the seven monitoring stations used in the research, five are located within the urban area of São Luís (Calhau Station – Uema Station – Centro Station – Bacanga Health Post Station – CE Y Bacanga Station), one in the port area (EMAP Station) and the last in the industrial district of the municipality (Vila Maranhão Station). The other highlight observed in the stations' location map is the locations of two enterprises likely to be major generators of air pollution: the place of deposition and storage of iron ore from Carajás-PA belonging to the Vale S/A company, and the other is the coal-fired thermoelectric of the ENEVA S/A company.

RESULTS AND DISCUSSION

Initially, for the annual average indices (Figures 5 and 6) were arranged all seasons and years used in the research. We observed that there were failures in the data collected by some stations for the generation of the annual average, so its representation was not possible.

Figure 5 - Graph of the annual average of Air Quality Monitoring Stations in São Luís for TSP pollution (µg/m³) compared to the limits established by CONAMA resolution 3/90 in the period from 2013 to 2016.

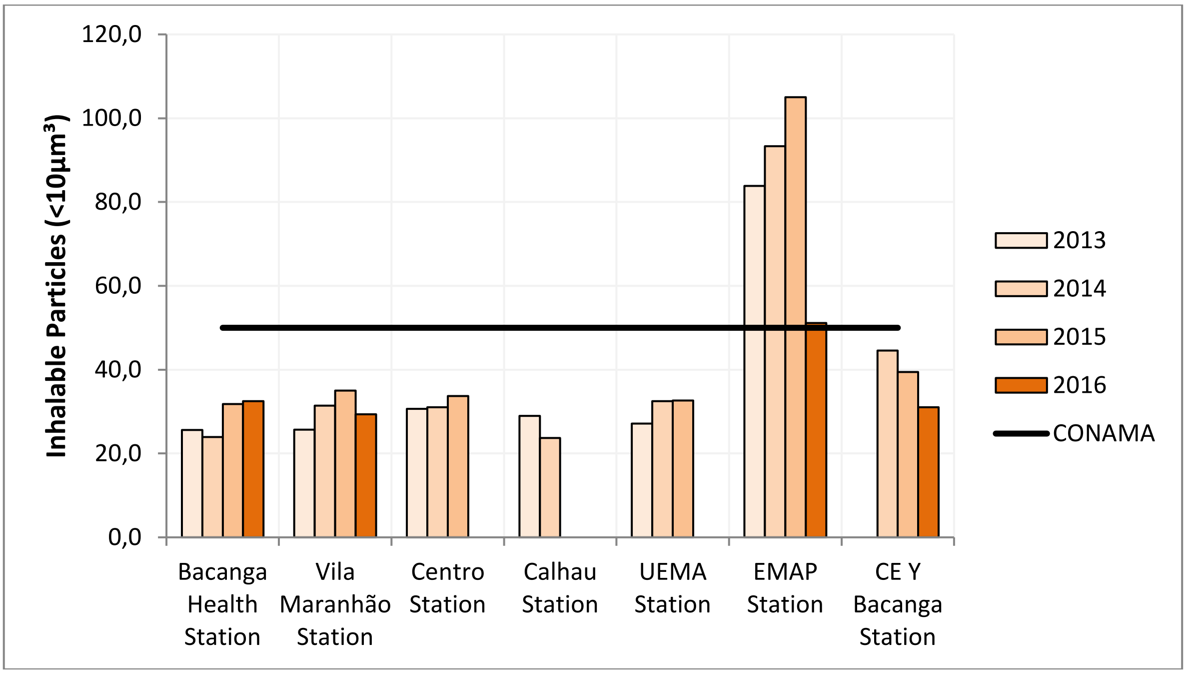


Source: VALE/Ecosoft - Org.: Authors, 2019.

With the graph in Figure 5 we identified that the EMAP station located in the port area of the city was the only one to exceed the parameters established by resolution 3/90 CONAMA for TSP pollutants (μg/m³) and this occurred in 2016 with annual average values recorded of 80.9 μg/m³, a value that exceeded by 0.9 μg/m³ the limits established by the resolution. In the port area, where is the Port of Itaqui through which are transported, among other products, iron ore from Carajás-PA, it is assessed that the movement of cargo from the port and, especially, iron ore, would be responsible for the generation of these air pollution indices.

Following, in Figure 6, we organize, by season and by year, the annual mean values for the parameters of pollution of inhalable particles in indices of <10μm³. We also point out, with regard to the graph, that it was not possible to graph a few years, in some stations, due to failures in data collection by the equipment.

Figure 6 - Graph of the annual average of Air Quality Monitoring Stations in São Luís for pollution by IP (μm³) compared to the limits established by CONAMA resolution 3/90 in the period from 2013 to 2016.



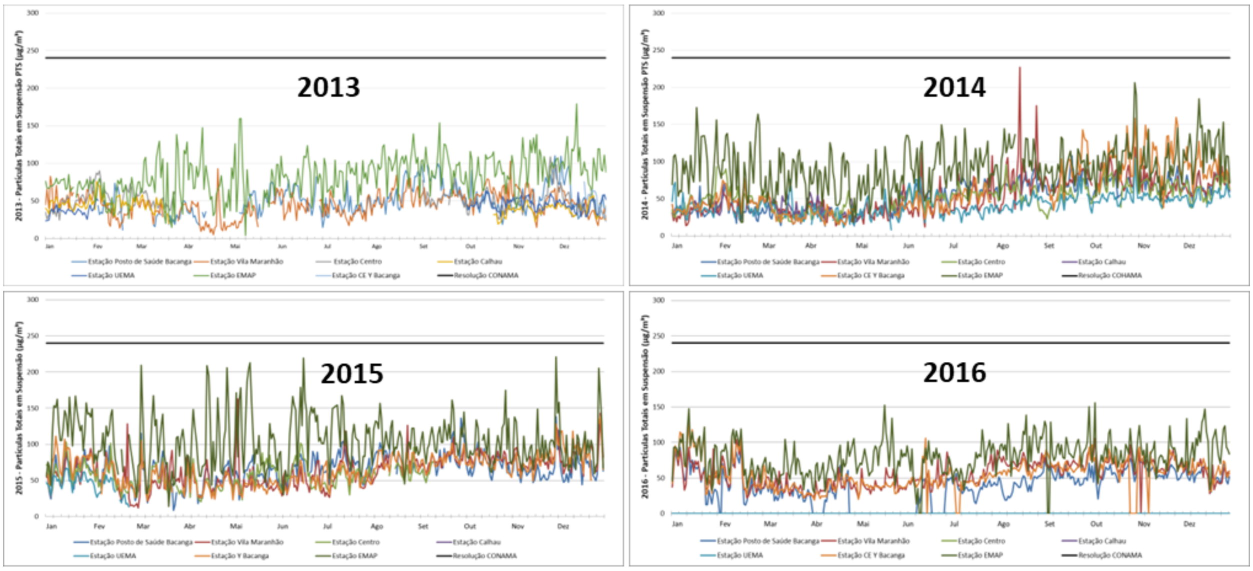
Source: VALE/Ecosoft - SEMA - Org.: Authors, 2019.

The negative highlight presented in the pollution values for pollution by IP (<10μm³), for all the years recorded, was the EMAP Station that exceeded the pollution limits established by Resolution 3/90-CONAMA. The EMAP station exceeded the limits of pollution of inhalable particles by 68% with values of 83.8 (<10μm³) in 2013, by 87% with values of 93.4 (<10μm³) in 2014, by 110% with values of 105 (<10μm³) in 2015 and by 2% with values of 51.1 (<10μm³) in 2016. After consulting the website of the Ministry of Economy, we identified that 2016 was when Brazil reached the lowest export volume of iron ore of the four years studied.

The identification of this situation marks a serious situation of air pollution by IP in every year, in an area managed and controlled, for the most part, by the company Vale S/A which, mainly, through the movement of iron ore, is generating serious air pollution indices. Thermoelectric is another company that, being within the area of influence of records of the EMAP station, should also have its activities better monitored. We also found that the other monitoring stations within the urban area of São Luís presented acceptable rates of air pollution by IP and TSP, determining that the volumes of automotive pollution are not yet able to exceed the limits established by the resolution.

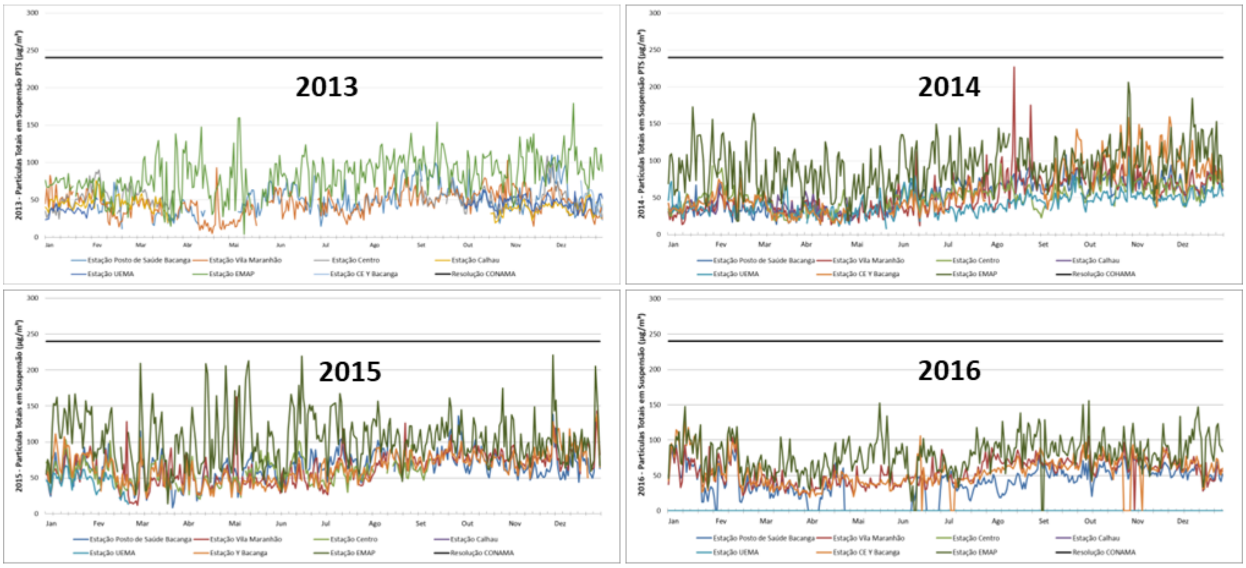
For the parameters of pollution concentration by TSP (μg/m³) and IP (<10μm³), compared with the limit values established by CONAMA resolution 3/90 in the four years studied in their daily values, we produced the graphs that are represented in Figures 7 and 8.

Figure 7 - Graphs of the daily averages of all Air Quality Monitoring Stations in São Luís for TSP pollution (µg/m³) compared to the limits established by CONAMA resolution 3/90 in the years 2013 to 2016.



Source: VALE/Ecosoft – Org.: Authors, 2019

Figure 8 - Graphs of the daily averages of all Air Quality Monitoring Stations in São Luís for IP pollution (<10µm³) compared to the limits established by CONAMA Resolution 3/90 in the years 2013 to 2016.



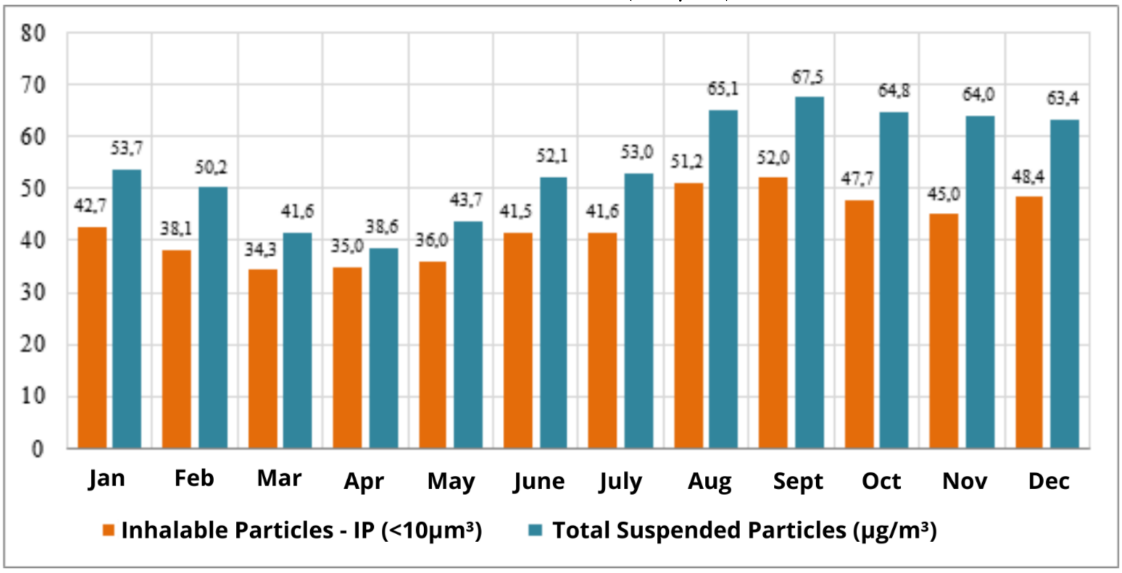
Source: VALE/Ecosoft - Org.: Authors, 2019.

The identified values of air pollution by IP and TSP for the daily parameters in São Luís remained, in the years studied, in all seasons, within the indices established by CONAMA resolution 3/90. However, the negative highlight is the EMAP station. After the analysis of the four years studied (2013 to 2016), it was the station that presented the highest air pollution indices, both for TSP and IP pollutants, among all stations installed in São Luís.

Although there is no parameter established by Resolution 3/90 - CONAMA for limit values of monthly average pollution by the particulate materials TSP and IP, we produced Figure 9 with the monthly average values of all seasons in order to identify the levels of pollution variations over the months and during the seasonal occurrence of the climate pattern that occurs in the region of a rainy season (January-June) and the dry season (July-December).

The way rainfall occurs influences air pollution levels in a given area. Researchers such as Guerra and Miranda (2010) have even stated that rains cause the atmosphere to be washed carrying its pollutants (*washout* and *rainout* effects). Thus, as there is a greater precipitated volume, the concentration of the pollutant decreases effectively. The researchers also state that wind speed also directly influences the concentration of pollutants because, the higher this speed, the greater the dispersion.

Figure 9 - Graph of the monthly average of the values recorded at the Air Monitoring Stations in São Luís (2013 to 2016) for the concentration parameters of Total Suspended Particles (µg/m³) and Inhalable Particles (<10µm³).



Source: VALE/Ecosoft - Org.: Authors, 2019.

The analysis of air pollution by TSP (µg/m³) and IP (<10µm³) indicated important variations between the months of the year. Noteworthy are the months of March and April that presented the lowest values of pollution by particulate materials (TSP - IP), while the month of September indicated to be the month with the highest rates of pollution for particulate materials (TSP – IP).

We observed that it is in the months of March and April that the Climatological Normal (1981-2010) of INMET para São Luís indicates to be the months with the highest rainfall volumes in the municipality, followed by the month of September that presents the second lowest annual rainfall volume. It is possible, therefore, to say that, in São Luís, during the months of July and December, during the dry season, confirming in the scientific literature on the subject, there are increased levels of air pollution by particulate matter (TSP, IP) in the order of 25.6% for the IP, and in 35% of TSP, and in the months of January to June, the rainy season, there is a decrease in the rates of pollution by particulate matter (TSP - IP).

CONCLUSION

Analyses of air pollution in the study area indicated that the conditions of air pollution by Total Suspended Particles (TSP) and Inhalable Particles (IP) are in acceptable conditions. The negative inflection recorded in the pollution parameters are for Inhalable Particulates, in all the years studied, was the RAMQA - EMAP Station located in the Port Area of the city that exceeded the pollution limits established by Resolution 3/90 - CONAMA. The EMAP station exceeded the IP pollution limits by 68% with values of 83,8 (<10µm³) in 2013, by 87% with values of 93,4 (<10µm³) in 2014, by 110% with values of 105 (<10µm³) in 2015 and by 2% with values of 51,1 (<10µm³) in 2016.

We also highlight that, between the months of July and December, in the dry season, there was an increase in air pollution indices by particulate materials (TSP - IP) and in the months of January to June, rainy period, there was a decrease in pollution indices by particulate materials TSP and IP.

By associating the characteristic conditions of wind with the air pollution, it was possible to identify, also, that, having the wind characteristics of predominant northeast direction, the urban area of the municipality is favored by being located in opposite direction to the wind where the largest generations of air pollution occur, identified in the port and industrial area of the municipality.

Thus, we conclude that the understanding of urban pollution in any city depends not only on the polluting sources and the volumes emitted in the atmosphere, but also on other geographical factors such as its climatic dynamics, geomorphological, building pattern, port and industrial dynamics, that is, aspects that can influence the concentration or dispersion of pollutants. These factors must therefore be analyzed from a geographical perspective, that is, in an integrated and dynamic way.

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REFERENCE LIST

BRASIL. CONAMA. **Resolução nº 03 de 1990**. Estabelece os padrões de qualidade do ar, métodos de amostragem e análise dos poluentes atmosféricos. Diário Oficial da República Federativa do Brasil. Poder Executivo. Ministério do Meio Ambiente. Brasília. 22 ago 1990. Seção I. p. 15.937-15.939.

BRAGA, B. et al. **Introdução à engenharia ambiental**, 2. ed. - São Paulo: Pearson Prentice Hall, p. 305, 2005.

DA SILVA, C. A. Estudos e técnicas de pesquisa de clima urbano como foco no subsistema físico-quimico, novos instrumentos, novas possibilidades. *In*: **Clima e Gestão do Território**. Paco Editorial, Jundiaí, p. 51 a 68, 2016. https://doi.org/10.11606/rdg.v0ispe.121848

DAVIS, M. L. CORNWELL, D. A. **Introduction to environmental engineering**: McGraw-Hill Companies, xvi, p.1008, 2008.

GARREAUD, D. R. RUTLLANT, J. **Factores meteorologicos de la contaminación atmosferica en Santiago**. *In:* **Episodios criticos de contaminación atmosferica en Santiago**. Ed. Coleccion de Química Ambiental, editorial universitária, pp 33-53, 2006.

GOUVEIA et al. Hospitalizações por causas respiratórias e cardiovasculares associadas à contaminação atmosférica no Município de São Paulo, Brasil**. Cadernos de Saúde Pública**, v. 22, n.12, 2669-2677, 2006. https://doi.org/10.1590/S0102-311X2006001200016

GUERRA, F. P.; MIRANDA, R. M. de. **Influência da meteorologia na concentração do poluente atmosférico pm2,5 na RMRJ e na RMSP.** Anais do II Congresso Brasileiro de Gestão Ambiental. IBEAS, Londrina – PR, 2011.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. Disponível em: <http://www.ibge.gov.br/home/estatistica/populacao/censo2010/default.shtm> Acesso em 2016, 2017, 2018 e 2019.

INSTITUTO NACIONAL DE METEOROLOGIA – INMET. Disponível em: <http://www.inmet.gov.br/portal/>

LOPES. J. S. L. Participação pública e controle da poluição: a ambientalização dos conflitossociais**. Revista de ciências sociais**, p.20-30, v.35, n. 1, 2004.

MINISTÉRIO DO MEIO AMBIENTE – MMA. Plano Nacional de Qualidade do Ar – PNQA. Acessado em 13/02/2019. Disponível em: <http://www.mma.gov.br/cidades-sustentaveis/qualidade-do-ar/plano-nacional-de-qualidade-do-ar>.

MILLER, G. T. **Ciência ambiental**. São Paulo: Thomson Learning, p. 123, 2007.

OKE, T. R. **Air pollution in the boundary layer.** *In*: Boundary layer climates. London, Mathuen& Co, Chap. 9, 1978.

PEITER, P.; TOBAR, C. Poluição do ar e condições de vida: uma análise geográfica de riscos à saúde em Volta Redonda. Rio de Janeiro, Brasil. **Caderno de Saúde Pública**. Rio de Janeiro. p. 473-485. 1998. https://doi.org/10.1590/S0102-311X1998000300003

PINHEIRO, J. M. **Clima Urbano da Cidade de São Luís do Maranhão.** 2018. 242f. Tese de doutoramento (Programa de Pós-Graduação em Geografia Física) Faculdade de Filosofia, Letras e Ciências Humanas. Universidade de São Paulo, São Paulo, 2018.

PINHEIRO, J.M.; GALVANI, E. Caracterização da direção e velocidade do vento na cidade de São Luís – MA. In: Galvani, E.; GOBO, J.P.A.; LIMA, N. G.B. **Climatologia Aplicada II**. Curitiba, Ed. CRV, 2018, p. 95-113.

SANTOS, V. A. A qualidade do ar de Dourados (MS): uma contribuição aos estudos de clima urbano com foco no subsistema físico-quimico**.** *In*: **Clima e Gestão do Território**. Paco Editorial, Jundiaí, p. 343 a 371, 2016.

SILVA, Q. D. **Mapeamento Geomorfológico da Ilha do Maranhão**. Tese (Doutorado em Geografia) – Universidade Estadual Paulista, Presidente Prudente, 2012.

UNITED STATES GEOLOGICAL SURVEY – USGS. Disponível em: https://earthexplorer.usgs.gov/ Acesso em mar/2019.

TIAN, L.; HOU, W.; CHEN, J.; CHEN, C.; PAN, X. Spatiotemporal Changes in $PM_{2.5}$ and Their Relationships with Land-Use and People in Hangzhou. Int. J. Environ**. Res. Public Health***,* 15*,* 2192, 2018. https://doi.org/10.3390/ijerph15102192

ZHENG, S.; ZHOU, X.; SINGH, R.P.; WU, Y.; YE, Y.; WU, C. The Spatiotemporal Distribution of Air Pollutants and Their Relationship with Land-Use Patterns in Hangzhou City, China. **Atmosphere***,* p8-110, 2017. https://doi.org/10.3390/atmos8060110