Respirable particles, the influence of the tropical climate and the importance of monitoring air quality in the city of Manaus-AM

https://doi.org/10.56238/sevened2024.004-021

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ABSTRACT

With the creation of the Manaus Free Trade Zone in 1967, the growth of the city of Ma-naus accelerated rapidly, increasing the consumption of materials and energy. The num-ber of vehicles also increased, and traffic became chaotic, contributing to high emissions of greenhouse gases and particulate matter. The city does not have a public policy for moni-toring atmospheric air quality, but some pioneering initiatives have been implemented by researchers at the Federal University of Amazonas (ENERAR Project/NIEMA/UFAM, 2005-2012) and more recently by the Amazonas State University (EducAIR Project). This paper analyzes inhalable particle data from the Air Quality Monitoring Station ac-quired under the ENERAR project developed by NIEMA/UFAM and considers the in-fluence of the equatorial climate on emissions, analyzing the number of particles sus-pended in the air in relation to rainfall levels at the time of data collection. It also in-cludes current air quality data published by the Electronic Environmental Surveillance System (SELVA) created by the Amazonas State University. The results suggest that the frequent tropical rains, which are a feature of the local climate, help to disperse the pollu-tants, but also underline the fact that in the dry season, when rainfall is very low and wind speed is practically non-existent, the pollutants remain in the air for much longer periods.

Keywords: Particulate material, Air quality, Monitoring, Climate change.

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INTRODUCTION

Located close to the equator (latitude 03°07'00"S, longitude 59°57'00"W), at an altitude of 67 meters above sea level and covering an area of 11,401km2, Manaus has a population of 2,063,547 inhabitants (IBGE, 2022). The city's growth increased dramatically after the creation of the Manaus Free Trade Zone (ZFM) in 1967. The largest city in the north of Brazil, it was listed as the ninth largest city in the country in 2000, became the eighth largest in 2004 and is now the seventh largest, according to the latest data released by the Brazilian Institute of Geography and Statistics (Torres and Martins, 2005). As a result of this growth, there has been a corresponding increase in the consumption of goods and services and in the size of the vehicle fleet, ultimately leading to a growing demand for matter and energy (Cartaxo, et.al., 2018).

Evaluating these conditions, one can understand why the accelerated process of urbanization in the capital of Amazonas was probably one of the most damaging transformations to the city, causing potentially disastrous results in the energy balance, climate, socio-spatial distribution, and economy of the region. The growth process of the city of Manaus was guided by confidence in the "hypothetical" inexhaustibility of nature. By treating nature as an inexhaustible source of resources, independent of human relations, capital dragged society into the uncontrolled exploitation of natural wealth and unbridled consumerism which, in the end, collided with the limitation of its own resources. (Valois and Cartaxo, 2022, p. 202)

When it comes to air pollution, atmospheric particulate matter (PM) directly affects the climate by scattering and absorbing solar radiation and indirectly by acting as a condensation nucleus in cloud formation processes. As air pollutants, PM10 and PM2.5 particles have received the most attention due to the problems they cause for human health. Considered according to their size (average aerodynamic diameter of the particles), coarse inhalable particles (PM10) are those with an average aerodynamic diameter in the range of 2.5 to 10 µm and fine or respirable particles (PM2.5) are those smaller than 2.5 µm. (Freitas and Solci, 2009)

And even if emission levels were maintained, air quality would vary according to the greater or lesser dilution of pollutants, which is determined by meteorological, topographical, and urban conditions. There is scientific evidence that the Amazon could be very close to breaking point. Deforestation rates accelerate a process of "savannization" of the rainforest that could become irreversible if these rates exceed 20% to 25% of the entire forested area of the Amazon basin. Currently, we have already lost 18% and a possible "savannization" of the Amazon is likely to cause new CO2 emissions into the atmosphere and significantly alter the rainfall regime, affecting food production in South America and the country's water and energy security. (WRI Brazil, 2022, cited by Valois and Cartaxo, 2022)

In a pioneering initiative, researchers from the Federal University of Amazonas installed an

Air Quality Monitoring Station (EMQA) in the eastern region of the city, with the aim of analyzing and measuring the level of atmospheric pollutants, especially in the areas near the thermoelectric plants, where emissions from burning fossil fuels are concentrated. Mobile emissions represented by motor vehicles circulating in the urban perimeter were also investigated, as the issue of transport and air quality is paradoxical. On the one hand, the increase in the number of vehicles meets the growing demand for mobility, but on the other hand, the effects on society in terms of environmental pollution are important. Consequently, transportation represents a significant contribution to the rise in air pollution, especially in the most populous cities, emerging as the largest source of urban air pollution in the developing world. These measurements are obviously necessary to determine whether the concentration levels of pollutants are within the limits set by the World Health Organization (WHO) and/or the National Environment Council (CONAMA). (Cartaxo et.al., 2018)

This work used the data available from the Air Quality Monitoring Station[5] to develop a preliminary estimate of air pollution in terms of inhalable particles (PM10) and to consider the contribution of fixed and mobile emission sources, as well as the influence of tropical rains, which are frequent in the Amazon region. The data was updated in relation to the new CONAMA Resolution 491/2018, noting a persistent lag when compared to the recommendations issued by the World Health Organization (WHO).

Recently, the Electronic Environmental Surveillance System developed by the University of the State of Amazonas has filled in some gaps in information about air quality in the city of Manaus, data that is published here showing the climate severity experienced by the people of Amazonas in the year 2023.

PARTICULATE MATTER

The term "particulate matter" is generally used to refer to a mixture of small solid or liquid particles of different diameters (aerodynamic diameter) suspended in the atmosphere. They have different chemical compositions and are capable of absorbing toxic substances such as SO_2, whose harmful effects are intensified in the presence of these particles. They come from different sources, both natural and anthropogenic, and when released directly into the atmosphere, they are referred to as primary particles; when they are formed in the atmosphere from chemical reactions between the primary particles and species present in the air, they are referred to as secondary particles.

The impact of particulate matter on human health and ecosystems depends on its chemical composition, size, and suspension time in the atmosphere. The larger the particle, the shorter its residence time in the atmosphere, but fine particles can be transported long distances by air currents,

[5] Acquired by the ENERAR/NIEMA/UFAM project with funding from CNPq (2011)

with a chemical and physical impact on the atmosphere, not only locally but on a regional and global scale, due to their longer residence time (Barbosa, 2007).

Until 1989, air pollution legislation in Brazil sought to regulate only particles with a diameter greater than 10 micrometers (µm). However, it was later shown that particles with diameters of less than 10µm, known as PM10, pose a greater risk to human health, as they penetrate further into the respiratory tract, hence the term "inhalable particles". The presence of these particles in the atmosphere also increases the speed of atmospheric chemical reactions, as the particles act as catalysts in the transformation of primary pollutants into secondary pollutants.

Smaller particles, with potentially even greater health risks, such as particles smaller than 2.5µm ($PM_{2.5}$), due to their tiny size, penetrate the respiratory system deeply, reaching the pulmonary alveoli. They are mainly produced by combustion: fires, industrial activities, motor vehicles, fuel burning and even domestic activities such as cooking. In the case of fires in the Amazon rainforest, winds can carry $PM_{2.5}$ particles hundreds of kilometers, with consequences for human health such as cancer, respiratory and cardiovascular diseases.

> In May 2018, the World Health Organization released alarming estimates: Every year, around 7 million people die on the planet because of exposure to airborne microparticulate pollutants. Recent studies carried out in 2019 by researchers at the Max Planck Institute indicate an even higher figure: 8.8 million deaths a year worldwide. In Brazil, it is estimated that 50,000 deaths a year result from air pollution (Maia, 2019, p. 12).

AIR QUALITY STANDARDS AND THE EFFECTS OF AIR POLLUTION

According to the World Health Organization (WHO), air quality standards vary depending on the approach taken to balance health risks, technical and economic feasibility, as well as political factors related to national capacity to manage air quality. In short, it's a question of choosing priorities and, in this sense, the WHO recommends that governments formulate air quality policies and adopt values as national standards considering their local circumstances.

In Brazil, air quality standards are established by CONAMA Resolution No. 491/2018, which repealed and replaced CONAMA Resolution No. 03/90. (Figure 1)

Figure 1 - Air quality index

Classificação	Concentração (µg/m³)					
	MP_{10} 24h	$MP_{2,5}$ 24h	O_3 8h	CO 8h	NO_2 1h	SO_2 24h
BOA	0 – 50	0 – 25	0 - 100	0 - 9	0 - 200	0 – 20
MODERADA	>50 – 100	>25 – 50	>100 - 130	>9 – 11	>200 – 240	>20 – 40
RUIM	>100 – 150	>50 – 75	>130 – 160	>11 – 13	>240 – 320	>40 – 365
MUITO RUIM	>150 – 250	>75 – 125	>160 – 200	>13 – 15	>320 – 1130	>365 – 800
PÉSSIMA	>250 - 600	>125 - 300	>200 - 800	>15 - 50	>1130 - 3750	>800 - 2620

Source - IEMA, 2023

Recent studies have shown that even at concentrations considered "safe" by current legislation, the effects on the health of individuals can be serious, demonstrating that the recommended air quality standards are still inadequate, especially for vulnerable populations (Steffens and Steffens, 2013).

The new legislation, therefore, despite the advances, is still far from meeting the WHO recommendations, which can be seen in Table 1, which shows the WHO standards and the current CONAMA standards in the first stage of its implementation:

Table 1: WHO standards and CONAMA No. 491/2018 standards

Poluentes	Tempo de amostragem	OMS 2005 (µg/m³)	Resolução CONAMA nº 491/2018
Partículas inaláveis (PM10)	24 horas	50	120
	Média anual	20	40
Partículas respiráveis (PM2,5)	24 horas	25	60
	Média anual	10	20
Ozônio	8 horas	100	140

Source: Adapted from Breder et. al (2020)

For Felini and De Simoni (2021), air pollution is a silent epidemic that kills 51,000 Brazilians every year and for which the vaccine would be public policies if well implemented. Despite this destructive potential, only 1.7% of Brazilian cities monitor air quality, meaning that most Brazilians, and here we can include the people of Amazonas, have no information about the quality of the air they breathe and, consequently, face an unknown enemy.

And even considering these 1.7% of municipalities where air monitoring is carried out, it can be seen from the data in Table 1 that Brazil does not monitor the air in an acceptable way, because the standards established in Brazilian legislation are more permissible than those recommended by the WHO and there are no penalties for non-compliance. (Felini and De Simoni, 2021)

The study, carried out by 14 experts and coordinated by WRI Brasil, comprehensively synthesized knowledge about air quality in the country and denounced the negligence of Brazilian environmental policies. "The State of Air Quality in Brazil", as the research was called, reveals, above all, how the impacts of air pollution reach other sectors besides the environment and health, as they also affect the economy, agriculture, climate change and others. In the developing world, this is a reality that exposes inequality, as it affects the most vulnerable populations more intensely. Apparently, everyone is subjected to the same atmospheric air, but for some (the sick, children, the elderly and the poor) the effect of pollution is greater (Felin and De Simoni, 2021; Valois and Cartaxo, 2022).

According to the Pan American Health Organization (OPAS, 2019) air pollution and household air pollution (from cooking) "cause more than 50% of acute lower respiratory tract infections in children under 5 in low- and middle-income countries". (Figure 2)

Figure 2: Mortality rate per 100,000 children attributable to the joint effects of air and household pollution in 2016 - by WHO region and income level

	Nível de Renda	Crianças <5 anos	Crianças de 5-14 anos
África	PBMRs*	184,1	12,9
	PRAs**	4,3	1,4
Américas	PBMRs	14,2	0,7
	PRAs	0,3	0,0
Sudeste Asiático	PBMRs	75,0	2,5
Europa	PBMRs	8,8	0,6
	PRAs	0,3	0,0
Mediterrâneo Oriental	PBMRs	98,6	3,6
	PRAs	5,3	0,4
Pacífico Ocidental	PBMRs	20,5	1,0
	PRAs	0,3	0,0
Todas	PBMRs	88,7	4,5
	PRAs	0,6	0,1

*PBMRs: low- and middle-income countries; **PRAs: high-income countries.
Source: OPAS, 2019, p.16, cited by Raposo, et.al., 2021

In the Amazon region, the impacts go beyond urban centers, as the frequent wildfires and forest fires generate pollutants whose levels of particulate matter reach 500 micrograms per cubic meter of PM10, around 25 times more pollution than the historical average for the region (20 micrograms per cubic meter). "With increased exposure to pollution, there has been an increase in the number of preventable deaths from non-communicable diseases in Brazil, especially in urban regions and in states with a high number of fires". (Raposo, et. al., 2021)

These particles move along with the air currents in the Amazon, carrying humidity to the Midwest, South and Southeast (the flying rivers). They also carry pollution to other regions of the country, affecting the climate and air quality.

THE INFLUENCE OF WEATHER CONDITIONS

It is known that the dispersion rate of particulate matter is a function of both topography and meteorological conditions. (Lyra et.al., 2011) When relative humidity is high enough, inorganic aerosols dissolve, while in conditions of low humidity, they form salts in the solid state and sometimes in the hydrated form. These conditions (topographical and meteorological) are indicators that combine unfavorable climatic and geographical conditions with relatively still air, constituting one of the greatest threats of air pollution to public health and national economies (Seinfeld, 2004).

When the gases released by chimneys and vehicle discharges enter the atmosphere, external conditions such as wind speed, wind direction, amount of precipitation, precipitation rate, air instability, temperature, atmospheric pressure and many others begin to affect them, favoring not only the accumulation of pollutants in the atmosphere, but also the formation of secondary compounds. All these meteorological factors, which vary in time and space, combined with topographical factors, directly affect the dispersion and transportation of pollutants. In addition, the earth's atmosphere is in constant movement, mainly because of sunlight passing through, which generates a non-uniform thermal balance. Meteorological parameters therefore vary considerably with location, height, and time (STERN et al. 1984).

Monitoring data and studying as many variables and their effects as possible is important for understanding potential environmental impacts on a local, regional, and global scale (Guerra and Miranda, 2011; Kay, et al, 2007).

Therefore, when examining the problems of air pollution in Manaus, meteorological conditions such as precipitation, temperature, humidity, and sunshine is clearly important. The city of Manaus is hot all year round, and the high temperatures and strong sunshine present are therefore likely to favor the photochemical reactions that lead to the formation of secondary particles. The topography, buildings, type and use of the land and the scarcity or abundance of plant species are also characteristics that can determine the course of pollutants released into the atmosphere, as they modify the microclimate and contribute to the formation of "heat islands" (Guerra and Miranda, 2011). Precipitation also interferes with the speed with which particles are removed from the atmosphere, as it promotes the removal of pollutants, since a significant part of the pollutants is incorporated into the rainwater (Barbosa, 2007; Kay, et al., 2007).

Just as meteorological variables can determine the degree to which pollutants are dispersed, the opposite can also occur, i.e., meteorological conditions can be affected by the presence of pollutants in the atmosphere over prolonged periods. For example, the number of particles in the urban atmosphere is directly proportional to the increase in fossil fuel consumption. This, in turn, can reduce insolation due to the increased concentration of condensation nuclei, can intensify precipitation and, consequently, can induce the formation of photochemical smog. In addition, and more generally, since polluting particles cause and accelerate chemical reactions, the presence of particles in the air aggravates the impacts of other greenhouse gases.

Some of the conditions for the formation of photochemical smog are clearly present in Manaus, especially in the hottest and driest months of August and September. Manaus reaches temperatures of 40°C in these months, and the high level of sunlight provides the energy needed for photochemical reactions. The limited movement of air masses also limits the dispersion of pollutants (INMET, 2011).

In addition to the critical conditions of high temperatures and light, and the limited movement of the air mass, Manaus also has intense vehicle traffic. Traffic and traffic jams on the busiest roads are constant every day throughout the year and the weather conditions facilitate the evaporation of hydrocarbons and photochemical reactions. During the rainy months of the year, although much higher levels of precipitation reduce the risk of smog, the likelihood of "acid rain" forming increases.

THE WEAKNESSES OF ENVIRONMENTAL LEGISLATION

Given the situation described above, it is not possible to think about improving air quality without defining a solid legal framework that can be aligned with the technologies available on the world market and adapted to the national reality. The fact is that Brazil has a series of environmental laws and regulations that set standards for air pollution control, but most of these regulations are infralegal and therefore do not have the power to generate rights or impose obligations. This has led to major weaknesses in air quality management policy.

The parameters regulated by environmental legislation (CONAMA No. 491/18) are as follows: Total Suspended Particles (TSP); Inhalable Particles (PM_{10}); Respirable Particles ($PM_{2.5}$); Smoke; Sulphur Dioxide (SO_2); Carbon Monoxide (CO); Ozone (O_3); Nitrogen Dioxide (NO_2) and Lead. Compared to CONAMA Resolution No. 03/90, there has been an advance in relation to the permitted limits, in addition to the fact that Respirable Particles were not regulated in the previous legislation.

The new air quality standards are divided into two categories:

I - Intermediate air quality standards - PI: standards established as temporary values to be met in stages; and

II - Final air quality standard - PF: guide values defined by the World Health Organization - WHO in 2005.

These parameters must be adopted in 4 stages: PI-1, PI-2, PI-3 and PF. Figure 3 compares the previous standards defined in CONAMA Resolution 03/90 with those of CONAMA Resolution 491/18 in force, with regard to particulate matter, PM_{10} and $PM_{2.5}$:

Figure 3: Air quality standards (PM_{10} and $PM_{2.5}$)

RES. 03/1990				RES. 491/2018					
POLUENTE	PERÍODO	µg/m3	ppm	POLUENTE	PERÍODO	PI-1	PI-2	PI-3	PF
						µg/m3	µg/m3	µg/m3	µg/m3
MP10	24 h	150	_	MP10	24 h	120	100	75	50
	Anual[1]	50	_		Anual[1]	40	35	30	20
MP 2.5	24 h	_	_	MP 2.5	24 h	60	50	37	25
	Anual[1]	_	_		Anual[1]	20	17	15	10

Source: Ferreira (SISEMA, 2019)

The first stage of the new legislation came into force with the publication of CONAMA Resolution 491/18 and comprises Intermediate Air Quality Standards PI-1. The Intermediate and Final Air Quality Standards (PI-2, PI-3 and PF) will each be adopted subsequently, taking into account the Atmospheric Emissions Control Plans and Air Quality Assessment Reports drawn up by the state and district environmental agencies.

It can be seen from figure 3 above that CONAMA Resolution 491/2018 aims to achieve the parameters recommended by the WHO in the final standard (FP) but does not set a precise deadline for the entry into force of the subsequent intermediate stages or the final stage. Under these conditions, instead of helping to achieve more restrictive limits, the legislation encourages inertia in any attempt to reach these limits. "After all, the reason for the existence of intermediate standards is that they effectively function as temporary objectives, leading in a staggered manner to the achievement of final standards." (Raposo et. al., 2021)

According to CONAMA Resolution No. 491/18, state and district environmental agencies must draw up an Atmospheric Emissions Control Plan within 3 years (from the publication of the Resolution) (Art. 2, item VI) defined in their own regulations, and every 3 years present a report on monitoring the plan, indicating any need for reassessment, ensuring that it is publicized. The plan must be submitted to the Ministry of the Environment in the first quarter of the fifth year following the publication of CONAMA Resolution 491/18 and must include a scope, identification of sources of atmospheric emissions, guidelines and actions with respective objectives, targets, and implementation deadlines, aimed at controlling air pollution in the state or district territory, observing the strategies established in the National Air Quality Control Program - PRONAR.

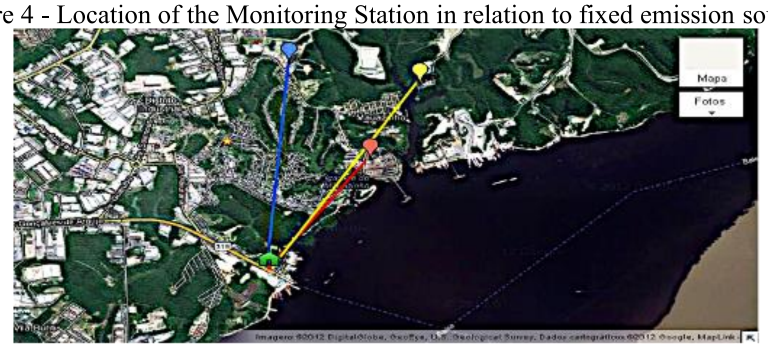
Despite the above determinations, the evolution of intermediate standards may stagnate in the first stage, since according to paragraph 4 of the Resolution, "if migration to the later standard is not possible, the standard already adopted shall prevail". (CONAMA 491/2018)

MATERIAL AND METHODS

This article compares the results, published in 2012 in Manaus by the ENERAR project, with the new legislation in force in Brazil on air quality standards (Resolution 491 of November 19, 2018) and with WHO recommendations. Given that Brazilian limits are more liberal, it is clearly prudent to relate the results to WHO standards, since, according to the WHO's own assessment of diseases due to air pollution, avoiding pollution means avoiding millions of premature deaths attributed annually to the effects of air pollution (WHO, 2005).

A monitoring station was installed in the eastern part of the city, at a site located 1.72 km from the Mauá thermal power plant, 2.72 km from the Breitener thermal power plant (UTE Breitener Tambaqui) and 2.84 km from the Manaus Refinery (REMAM), which between them are considered the city's main fixed sources of pollution (Figure 4).

Figure 4 - Location of the Monitoring Station in relation to fixed emission sources.



Source - Valois, 2012

Emissions from sources other than thermoelectric plants and cars were clearly incorporated into the samples, although together they were not considered to have a major impact on the selected area, especially since there are no significant potential sources, such as waste incineration, laundries, bakeries, and motels (known as non-industrial pollution sources (Cavalcanti, 2010).

The station used was a fully automated station that simultaneously collects and analyzes pollutants using spectroscopic methods. The use of this method is justified because it is reliable and sensitive for monitoring trace components, a requirement imposed by the growing concern for environmental quality, without, however, dispensing with knowledge about the components of the air and their chemical and physical behavior in the atmosphere.

To study the concentrations of particulate matter (Total Suspended Particles and PM10) and analyze air quality standards during the research period, a Continuous Environmental Particle Monitor (FH 62 C14 Series) manufactured by Thermo Fisher Scientific was used. This monitor uses continuous and simultaneous particle collection associated with beta ray attenuation, the radiation source being Carbon-14 due to its long half-life. As the name suggests, it works on a continuous cycle, generating pollutant concentration data every 30 minutes.

The results were stored, and the data was then used to calculate hourly averages of pollutant concentrations. Some measures were adopted to avoid errors that could compromise the interpretation of the results. These were based on the same measures used by the São Paulo State

Environmental Company (CETESB), as follows:

- For the hourly average, 75% of the valid hourly measurements were used.
- For the daily average, 66% (2/3) of the valid daily measurements were used.
- For the monthly average, 66% of valid monthly measurements were used.

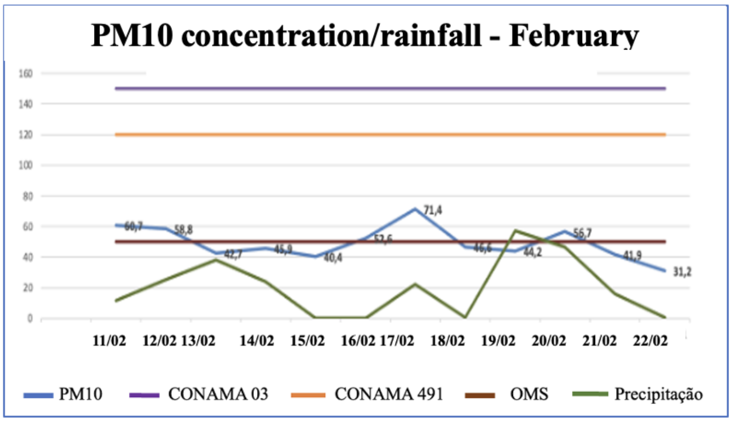
The data was collected from February to September 2011 and compared with meteorological data for the same period provided by the National Meteorological Institute (INMET). The wettest months were examined to consider the influence of tropical rains and, at the same time, facilitate comparison with the months of the dry season, which may be associated with a greater risk to public health.

RESULTS OF THE ENERAR PROJECT

The activities of the ENERAR project (NIEMA/UFAM) began on February 11, 2011. It can be seen (Figure 5) how permissible the CONAMA standards (nº 03/90 and nº 491/2018) are, discouraging air quality control and even encouraging polluting anthropogenic activities.

The values found for the daily concentrations of the pollutant PM10, released into the atmosphere during the month of February, did not exceed the standards then established by CONAMA nº 03/90 (150 $\mu g/m^3$), nor the new CONAMA nº 491/2018 standards in the initial stage (120 $\mu g/m^3$), but were above the standards recommended by the WHO on some days of the month. It is important to note, based on Figure 5, that the days with the heaviest rainfall corresponded to the lowest concentrations of the pollutant.

Figure 5 - PM10 emission levels and rainfall in February/2011

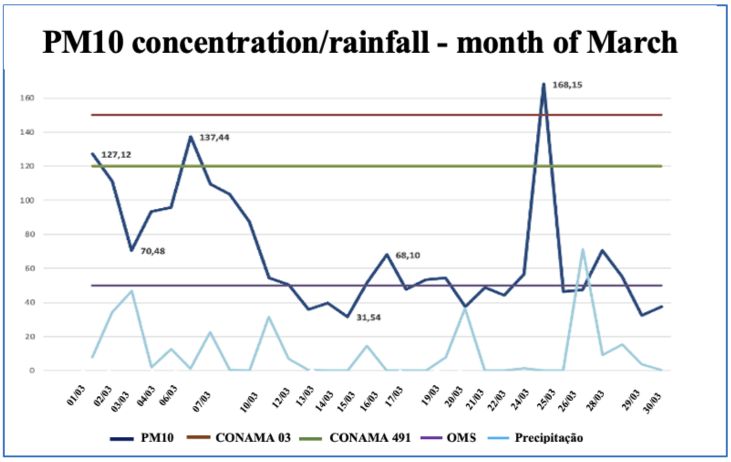


Source - Adapted from ENERAR Project Report, 2011

Rainfall is a very important parameter, as low concentrations of particles in the rainy season mean that they have been expelled from the atmosphere by rainwater. In this case, rain reduces the presence of the pollutant in the atmosphere by depositing it on the surface of the earth and transferring the pollution problem from one ecosystem to another.

Throughout the collection period, there were days of high rainfall and zero rainfall, even during the months of the "rainy season". The months with the highest concentrations of the pollutant in the air were February and March. We can observe the Figure 6 that shows March followed the same pattern as February: daily concentrations of the pollutant PM10 exceeded CONAMA standards (03/90 and 491/2018) on only 3 days. They were, however, above the WHO recommended standards on several days in March. In addition, as in February, on rainy days, the atmosphere cleared.

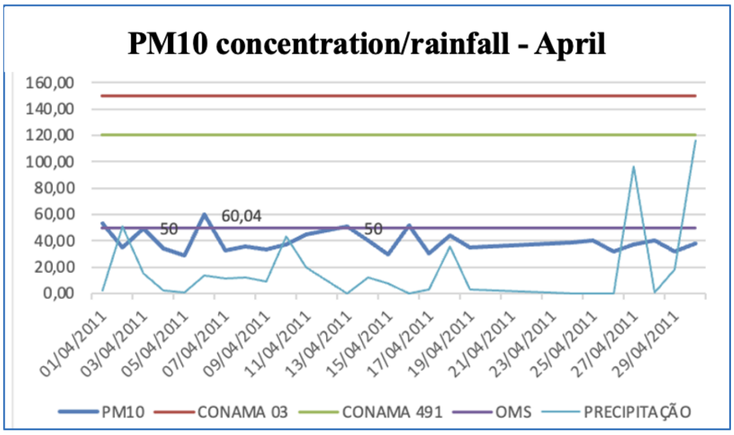
Figure 6 - PM10 emission levels and rainfall in March/2011



Source - Adapted from ENERAR Project Report, 2011

Figures 7 and 8 show the day-by-day behavior of PM10 emissions in April and May. April, which was particularly rainy, showed PM10 concentrations in the atmosphere below the standards regulated by the WHO.

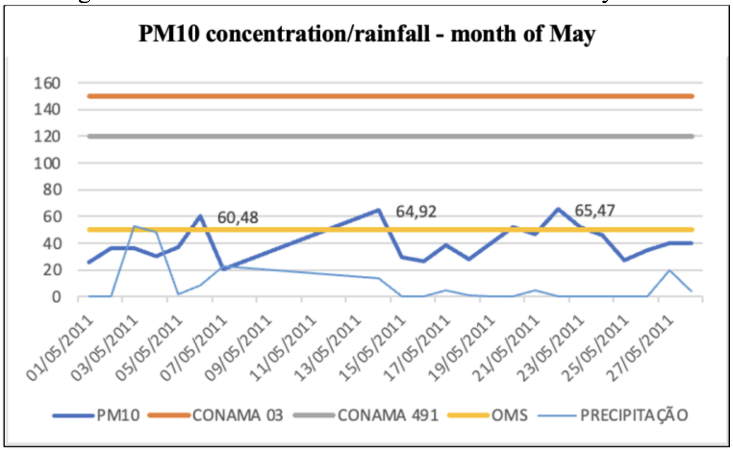
Figure 7 - PM10 emission levels and precipitation in April/2011



Source - Adapted from ENERAR Project Report, 2011

The same behavior was observed in May (Figure 8). The standards recommended by the World Health Organization were exceeded in just three days.

Figure 8 - PM10 emission levels and rainfall in May/2011

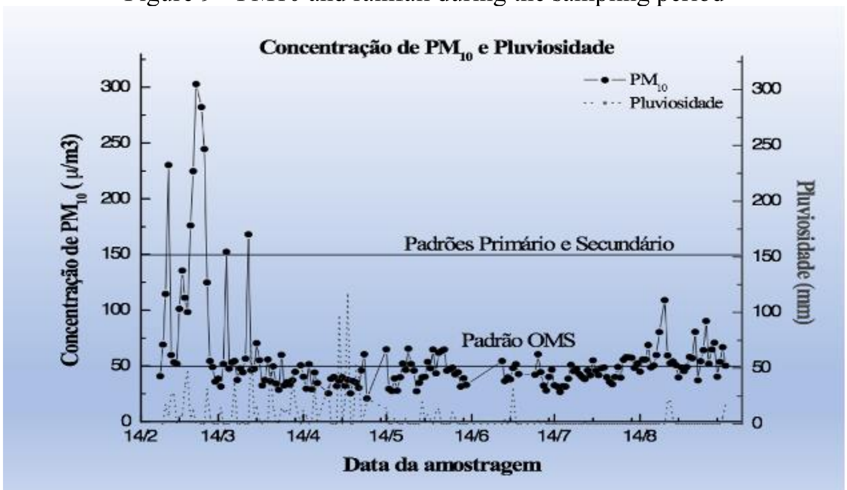


Source - Adapted from ENERAR Project Report, 2011

Although there are only two seasons, one dry and the other rainy, rainfall is not uniform either spatially or seasonally, and there is variability in the volume of rainfall from one year to the next, or even different intensities in the duration of rainfall in these seasons.

To analyze the contribution of tropical rainfall throughout the sampling period, figure 9 lists the variation in PM10 concentration, the standards regulated at the time by CONAMA (RE-03/90), and the standards recommended by the World Health Organization (WHO)

Figure 9 - PM10 and rainfall during the sampling period



Source: ENERAR, 2012

The months of February and March had the highest pollutant concentration peaks and rainfall was less intense. The wettest month was April and, proving our hypothesis, it was also the month with the lowest emissions of PM10 particulate matter into the atmosphere.

The number of times the limits of each standard (CONAMA 03 and WHO) were exceeded is shown in Table 3 and serves to illustrate the significant divergence of the respective air quality standards.

TABLE 3: Number of days when limits were exceeded.

Poluente	n	Número de ultrapassagem dos limites	
		CONAMA	OMS
PM10	**181**	**8**	**30**

Source: Adapted from ENERAR Project, 2011

The ENERAR project ended its activities in 2012 and since then the city of Manaus no longer has any parameters for assessing atmospheric air quality. The city has continued to grow, and its population has increased. In 2010 the population was 1,802,014 inhabitants and today, in 2023, according to the Census (2022) the number has reached 2,063,547 inhabitants.

AMAZON 12 YEARS LATER

In addition to emissions from vehicles and thermoelectric power stations, the pattern of land use in the Amazon region is also responsible for climate change. Deforestation and fires emit aerosol particles and alter the rainfall regime, prolonging the dry season, a phenomenon that is repeated year after year in Brazil, especially in the Amazon biome. In particular, 2023 was a very difficult year for the people of the Amazon, with deforestation and fires reinforced by the El Niño phenomenon and interfering with rainfall dynamics. As a result, air quality in the largest city in the state of Amazonas, Manaus, reached alarming levels.

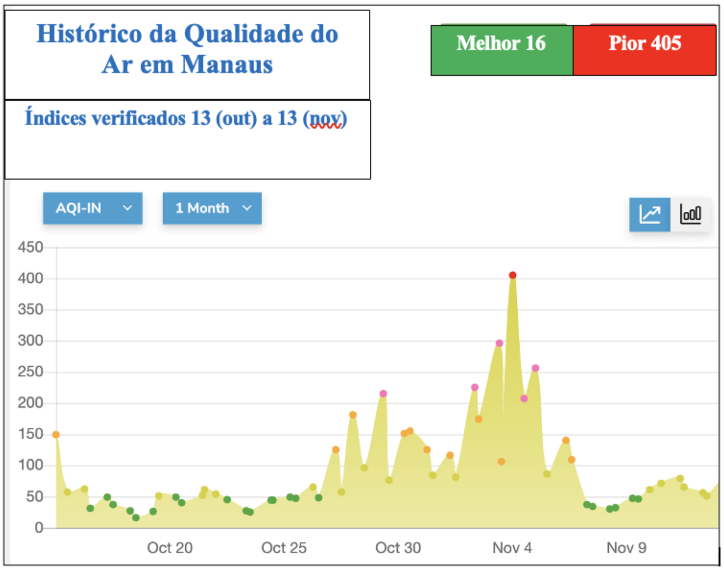
As mentioned above, Manaus still has no air quality monitoring station equipped with automatic analyzers capable of reliably providing the concentration levels of all the pollutants regulated by CONAMA Resolution 491. The advantage of monitoring stations is that they allow a more interactive study of pollutant levels with meteorological conditions and anthropogenic activities (deforestation and fires) and in this sense, the ENERAR and QUAREMA projects, funded by CNPq, were the last experiments carried out with this profile in the city of Manaus.

Attempts to fill these gaps and send information on the state of the city's atmospheric air have been made by the State University of Amazonas (UEA) which, through the Educ-AIR project, has created an electronic environmental surveillance system (SELVA), based on low-cost air quality sensors, data from environmental satellites and estimates from numerical air quality models. The system sends real-time information on PM2.5 levels and the occurrence of fires (Ferreira, 2023).

According to the World Air Quality Index, a database that monitors air quality at a global level, considering only PM10 and PM2.5 particles, the capital of Amazonas is considered one of the worst places in the world to breathe today. "The current concentration of PM2.5 in Manaus is 2.7 times higher than the limit recommended by the WHO for 24-hour air quality." (AQI, October 4th, 2023)

Figure 10 provides information on air quality in the city of Manaus during the period from October 13 to November 13, 2023.

Figure 10: Air quality in Manaus/Am. PM2.5 levels



Source: Adapted from https://www.aqi.in/dashboard/brazil/amazonas/manaus

We can see that November 4 was the most critical day, as the air quality in the city reached the worst levels according to the website "AQI.in".

Only 10 Brazilian states and the Federal District monitor atmospheric air using automatic analyzers. According to Vormittag et. al. (2021), there are 371 active stations, 80% of which are in the southeast of the country and 41.2% of the national stations are private. Particulate matter PM10 is the most monitored pollutant in 62.8% of the stations and PM2.5 in only 25.9% of them. And only in 5 states are real-time monitoring data communicated to the population, making it impossible to know about air quality and hindering defensive actions in relation to exposure to pollutants.

Despite being created in 1989, the National Air Quality Network is still not complete and, where it exists, it is not sufficiently implemented, making it impossible for environmental agencies to properly manage air quality. "There is, therefore, damage to: i) the diagnosis of air pollution; ii) information about it to Brazilian society and iii) the proper protection of health - which constitute violations of fundamental rights to health and the environment." (Vormittag, 2021, p. 17)

DISCUSSION

The abundance of rain is a distinctive feature of the hot and humid equatorial climate. In the Amazon there are only two seasons: summer with rain and summer without rain. However, rainfall in the wet season is not uniform and varies in terms of quantity and intensity. Stillness and intense sunshine are also characteristic conditions of the Amazon dry season. These conditions are most extreme in the months of August and September but can occur on any day of any month of the year, with heavy rainfall followed by intense sunshine being common for distinct and prolonged periods (Valois, 2012).

The year 2011 was particularly wet, with the highest rainfall occurring in the months of February to May. April was the wettest month with 515.90 mm of rain, significantly above the climatological average of 396 mm (INMET, 2011). The fact that this month provided the lowest readings for PM10 (Figure 4) suggests that abundant rainfall tends to dilute the pollutants, transferring them to another ecosystem and leaving a purified atmosphere. However, even with the effects of abundant rainfall throughout the wettest period, the limits recommended by the WHO for inhalable particles were exceeded on 16.57% of days in the first 4 months and, if we consider the whole period, this percentage rises to 40.6%.

It was also possible to observe that the limits of the CONAMA legislation are much less strict than the WHO limits, producing results that can mask reality and lead to questionable, if not dangerous, conclusions. The results, when compared with the particulate limit suggested by the WHO of 50ug/m3, indicate the need for special attention on the part of the environmental authorities and suggest the need to improve air quality monitoring and control. Compared to Resolution 491/2018, the contrasts are greater if we consider the uncertainties related to the timeframes in which the intermediate air quality standards will come into force.

More than a decade after the monitoring carried out by the ENERAR project, the Amazon is facing the worst drought in its history. The results have been exacerbated by the El Niño phenomenon and by forest fires and burn-offs. The SELVA (Electronic Environmental Surveillance System) program, created by the Educ-AIR project at the State University of Amazonas, has helped to show that the current levels of particulate matter concentration in Manaus reached alarming limits during the drought period in 2023 (4.5 times higher than the limit recommended by the World Health Organization for air quality in 24 hours).

As well as reliable information, the population needs to be equipped with safe and efficient legislation to deal with drastic climate change. This is now a global concern, as air pollution is set to become one of the most alarming issues for humanity's survival.

Finally, it is clearly necessary for any national environmental legislation to be effectively enforced throughout the country and, in Brazil, this certainly includes the Amazon region: Manaus, although it may be surrounded by the largest tropical rainforest on the planet, is by no means free from the effects of pollution. The year 2023 is proving that.

CONCLUSIONS

The atmosphere of the city of Manaus has been a neglected subject, partly due to its privileged location in the middle of a tropical rainforest abundant in animal and plant species. Hence the concept of a limitless surrounding forest ecosystem, which for a long time contributed to the idea of endless natural resources. To corroborate this concept, the city of Manaus has not previously been included among the most polluted cities on the planet. The significant levels of daily rainfall seemed to work in such a way as to prevent the accumulation of air pollution over long periods. However, these rains, although abundant, do not fall evenly and, during the dry season, are much less frequent and intense.

Air quality was monitored throughout 2011 by researchers from the Federal University of Amazonas, linked to the Interdisciplinary Center for Energy, Environment and Water (NIEMA). At the time this data was collected, air quality limits in Brazil were established by CONAMA No. 03/90. In 2005, the World Health Organization published a study (Air Quality Guides) recommending stricter concentration limits for atmospheric pollutants. According to this study, the suggested limits would imply a "lower risk to health" and should therefore guide the development of national air quality standards. However, despite the urgency of an immediate review of the standard then in force in the country, it was only changed in 2018, when new standards were set.

The new reference standard for monitoring air quality, CONAMA Resolution 491/18, still has limits that are not in line with the parameters of the World Health Organization and is the subject of criticism from various experts. One major criticism, which we consider to be the most important, is the lack of a deadline. As we have seen, the air quality standards are to be achieved in 4 stages, with the first stage coming into force immediately after the publication of the Resolution. As for the intermediate and final air quality standards, the regulation states that they should be adopted subsequently "taking into account the Atmospheric Emissions Control Plans and the Air Quality Assessment Reports drawn up by the state and district environmental agencies. It has been established, however, that if migration to the subsequent standard is not possible, the standard already adopted prevails. Under these conditions, cities that do not monitor air quality are also not obliged to draw up control plans or evaluation reports.

This study analyzed the relationship between concentrations of inhalable particles in the atmosphere of the city of Manaus and levels of rainfall. The data obtained in 2011 showed the influence of rainfall on air quality as it promotes the dilution of pollutants. On the other hand, periodic droughts have the opposite effect.

The year 2023 proved how much the historic drought in the region, aided by fires and the El Niño phenomenon, affected the climate and the quality of life of the Amazonian population, registering high levels of pollutants per cubic meter in the atmosphere. However, it is not only rainfall that influences atmospheric conditions: the movement of air masses, high humidity and high temperatures can also act to disperse pollutants.

Wind speed and direction directly affect the concentration, dispersion and trajectory of pollutants at or from the source, and all these factors must be taken into account in any analysis. This is why we insist on the importance of monitoring air quality in correlation with meteorological parameters in the city of Manaus.

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