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# Monitoring atmospheric pollution in Central Amazon: Case study carried out in Santarém City – PA

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**Abstract**

Air pollution is one of the most concerning and broadly debated environmental issues in contemporary times. It is a combination of particles, gases and harmful substances that end up contaminating the atmosphere and severely affect both human health and the environment. Therefore, the aim of the current study is to assess air quality in Santarém City – Pará State, based on data about fine Particulate Matter ($PM_{2.5}$). Data were collected through high-precision SDS011 air-quality sensor used to detect particle concentrations in the air at the range 0.3 µm to 10 µm. Data collection took place at 5 different points located in urban and peri-urban regions of Santarém City, in November 2022. According to the results, *Ramal dos Coelhos* community recorded 1,000 (µg/m³) PM on November 26th and 27th – the highest value recorded among all 5 analyzed points. It was followed by *Vila de Alter do Chão* and *Maracanã* neighborhoods, which recorded approximately 650 (µg/m³) PM on November 1st, 2nd and 11th, respectively. The highest value observed in *Caranazal* neighborhood (approximately 350 µg/m³) was recorded on November 6th. Finally, São Pedro community recorded the highest value (250 µg/m³) on November 19th. Furthermore, the point presenting the highest incidence of the herein analyzed particulate matter was located in *Maracanã* neighborhood. It was possible concluding that particulate matter concentrations in November were higher than standard values determined by the World Health Organization, a fact that emphasized the incidence of air pollution in Amazonian hinterlands.
Keywords: atmosphere, air quality, particulate matter, November.

## Monitoramento da poluição atmosférica na Amazônia Central: Estudo de caso realizado na cidade de Santarém, PA.

A poluição do ar é uma das questões ambientais mais preocupantes e amplamente debatidas nos tempos contemporâneos. É uma combinação de partículas, gases e substâncias nocivas que acabam contaminando a atmosfera e afetando severamente tanto a saúde humana quanto o meio ambiente. Portanto, o objetivo do estudo atual é avaliar a qualidade do ar na cidade de Santarém, estado do Pará, com base em dados sobre Particulate Matter fino (PM2,5). Os dados foram coletados por meio de um sensor de qualidade do ar SDS011 de alta precisão usado para detectar concentrações de partículas no ar na faixa de 0,3 µm a 10 µm. A coleta de dados ocorreu em 5 pontos diferentes localizados em regiões urbanas e periurbanas da cidade de Santarém, em novembro de 2022.
De acordo com os resultados, a comunidade de Ramal dos Coelhos registrou 1.000 (µg/m³) de PM nos dias 26 e 27 de novembro - o valor mais alto registrado entre os 5 pontos analisados. Foi seguida pelos bairros Vila de Alter do Chão e Maracanã, que registraram aproximadamente 650 (µg/m³) de PM nos dias 1º, 2 e 11 de novembro, respectivamente. O valor mais alto observado no bairro de Caranazal (aproximadamente 350 µg/m³) foi registrado em 6 de novembro. Finalmente, a comunidade de São Pedro registrou o valor mais alto (250 µg/m³) em 19 de novembro. Além disso, o ponto que apresentou a maior incidência da matéria particulada analisada aqui estava localizado no bairro de Maracanã. Foi possível concluir que as concentrações de matéria particulada em novembro foram superiores aos valores padrão determinados pela Organização Mundial da Saúde, um fato que enfatizou a incidência da poluição do ar no interior da Amazônia.
Palavras-chave: atmosfera, qualidade do ar, matéria particulada, novembro.

## 1. Introduction

According to the World Health Organization (WHO, 2021), air pollution takes place when the natural composition of the atmosphere, whether indoors or outdoors, is altered by the introduction of chemical, physical or biological elements capable of changing its original features. Air quality has been the cause for concern in many regions worldwide, mainly in developing countries, where pollutant concentrations exceed quality standards criteria (PINTO et al., 2014). Air pollution and climate change stand out among the biggest environmental threats to human health. Thus, improving air quality can help climate change-mitigation efforts (WHO, 2021).

There has been increase in air quality degradation rates in the Amazonian region over the years due to industrial growth, as well as to increased transportation, wildfire events and violations of environmental protection barriers (GOMES, 2020). Inhalable particles ($PM_{2.5}$ and $PM_{10}$) are one of the main pollutants found in the Amazon (CARDOSO; FONSECA, 2016). These pollutants account for increasing atmospheric pollution rates, as well as for hindering both biodiversity and air quality (DIAS et al., 2016). Furthermore, this pollution type has been linked to health issues, such as respiratory and heart diseases, and allergies (LIMA et al., 2019).

According to Silva et al. (2021), several wildfire events with negative impact on air quality take place in the Amazonian region during the dry season, which runs from June to September. These events lead to air pollution due to smoke emissions that result in a scenario even more adverse than the pollution levels observed in large South American cities.

Air pollution in urban environment comprises gaseous and particulate components. Gaseous components comprise ozone ($O_3$), volatile organic compounds (VOCs), carbon monoxide (CO) and nitrogen oxides (NOx) (GLENCROSS et al., 2020). Particulate matter, in its turn, is the most investigated pollutant, and its origin can be of the primary or secondary type. It varies in number, size, shape, surface area and chemical composition, depending on its production place and emission source (LIMA et al., 2019). Particulate matter is produced by fossil–fuel using, plant material burning, ammonia production in the field and emissions generated by both buildings and asphalt (TORRES, 2020).

According to São Paulo State Company (CETESB, 2022), the term "Particulate Matter" encompasses different pollutants, such as Particulate Matter ($PM^1$), Total Suspended Particles (TSP), Inhalable Particles ($PM_{10}$), Fine Inhalable Particles ($PM_{2.5}$) and Smoke (FMC). These pollutants comprise a wide variety of solid and liquid substances, such as dust and smoke, which remain suspended in the atmosphere due to their small size. The smallest particle size found in atmospheric PM reaches approximately 0.002 µm, whereas the largest particles reach approximately 100 µm. If one takes into consideration particle size distribution ranging from 0 µm to 10 µm, some particles can be trapped in the upper part of the respiratory system, whereas others can penetrate deeper and reach the pulmonary alveoli.

Particulate matter $PM_{2.5}$ can be defined as particles showing aerodynamic size equal to, or smaller than, 2.5 µm. Given their small size, they can penetrate deeply into the respiratory system and reach the pulmonary alveoli. The latest air quality guidelines by WHO (2021) recommend mean annual $PM_{2.5}$ concentration limit of 5 µg/m³ and 24-hour concentration of 15 µg/m³, on average.

Therefore, it is essential having an air quality monitoring system to measure atmospheric pollutant concentrations, to provide information about current air conditions, to create data history and to empower those in charge of decision-making processes (VORMITTAG et al., 2021). Monitoring data is the way to provide information about whether a given location adheres to air quality standards seen as safe for human exposure. Accordingly, the World Health Organization (WHO, 2006) advised countries to create an air quality monitoring infrastructure and to use it in city planning to help preventing public health events.

According to Vormittag et al. (2021), Brazil has 371 active air quality monitoring stations out of the total number of 430 stations in the country. Their study has also evidenced that most of these stations are located in the Southeastern region, whereas the Northern and Northeastern regions are the least represented ones - only Acre and Pernambuco states count on these stations, respectively. Moreover, 153 of these active stations belong to private institutions and they are used by public bodies to monitor air quality, whereas 218 of them are state-owned stations.

> Large cities in developed countries are usually dotted with a network of reference monitoring stations capable of monitoring air quality in real time. However, high costs associated with both the installation and maintenance of reference monitoring stations result in a relatively sparse monitoring process that only provides accurate data for a few locations. Although it is done to satisfy legal requirements, it does not provide information on localized gradients of potential importance for health protection purposes. Furthermore, these air quality monitoring stations may not exist in smaller cities or in underdeveloped regions (CASTELL et al., 2017, p.294).

Monitoring processes focused on particulate matter concentrations require the installation of complex, high-cost high-technology measurement stations (SILVA et al., 2021). According to Castell *et al* (2017), the set of equipment accounting for such a task is relatively large, heavy and expensive. Their prices range from R$27,700.00 to R$166,200.00 per device. In addition, they are subjected to rigorous instrument maintenance and calibration routines.

Accordingly, it is possible stating that air quality monitoring in Brazil remains incipient, mainly in the Northern region, which still lacks monitoring stations, if one takes into consideration its extensive territorial area and important urban centers (SILVA; VIEIRA, 2017). Using low-cost sensors as indicative measurements could help reducing costs with air pollution monitoring, as well as enable greater spatial coverage, mainly in remote areas where using traditional equipment is a complex process (CASTELL et al., 2017).

Therefore, the aim of the current study was to assess air quality in Santarém City, Pará State, based on data about fine Particulate Matter ($PM_{2.5}$).

## 2. Materials and methods

### 2.1. Study site

Santarém City's (PA) (Figure 1) territorial area covers 17,898.389 km and, according to the Brazilian Institute of Geography and Statistics (IBGE, 2022), its estimated population comprises 331,937 inhabitants. This city, which is located in geographic coordinates -2.4397562189531024 (latitude) and -54.71731203509144 (longitude), belongs to the Lower Amazonas Mesoregion and is known as the "Pearl of Tapajós" (UCHOA, 2011). According to Köppen's classification, climate in Santarém City is featured as Am, which indicates humid equatorial climate. This climate type has two quite distinct seasons: a well-defined dry season and another season featured by high rainfall rates (Costa et al., 2013).

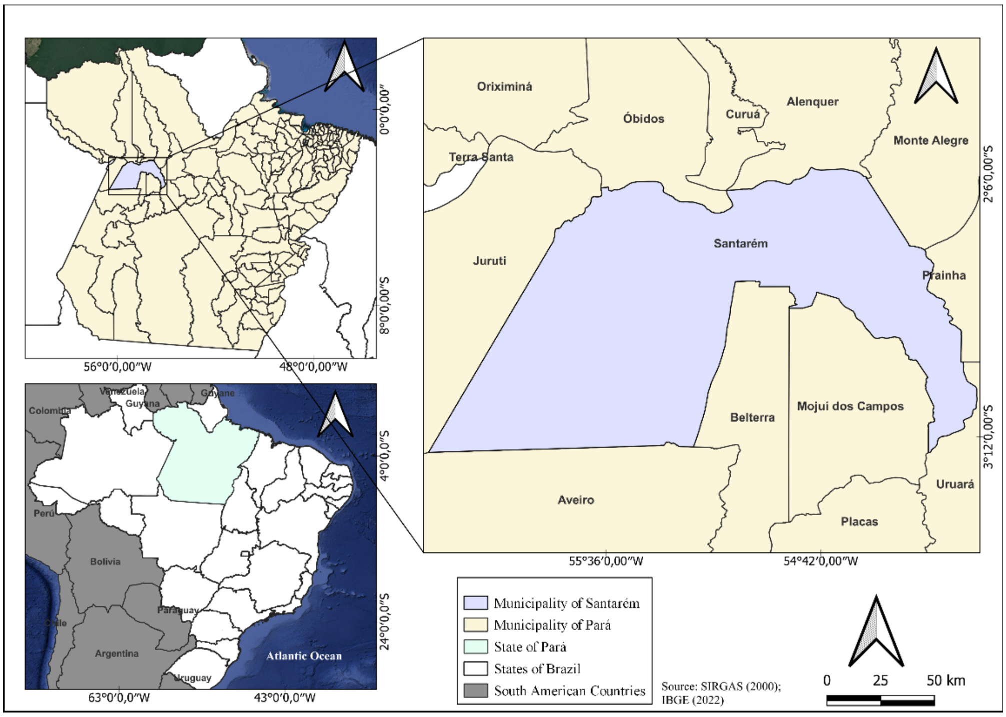

Figure 1- Location of Santarém City - PA.

Particulate matter data ($PM_{2.5}$) were collected through the 5-point SDS011 sensor (Figure 2). November was selected as data collection-related month because it is within the transition period. Consequently, it presents features of both aforementioned periods (dry and rainy) in the region.

Figure 2- Points selected for statistical analysis.

Points selected for sensors' installation were strategically distributed to cover areas farther from each other. Some of them were located in the urban area to cover both the Northern and Western zones of Santarém City, whereas others were selected in communities located in the peri-urban region, in adjacent districts.

These points were selected with the specific purpose of assessing pollution levels in both urban and peri-urban areas. *Caranazal* and *Maracanã* were the neighborhoods selected in the urban zone, whereas *Ramal dos Coelhos*, *São Pedro* and *Vila de Alter do Chão* were the communities selected in the peri-urban region.

2.2. Data collection

Data collection was carried out with SDS011 sensor, which is part of the air quality monitoring kit of the project called *Rede Piloto de Inovação no Monitoramento da Qualidade do Ar na Região do Oeste do Pará: "*Guardians of the Air*"* [Pilot Network for Air Quality Monitoring Innovation in Western Pará State's Region: "Guardians of the Air" (Figure 3).

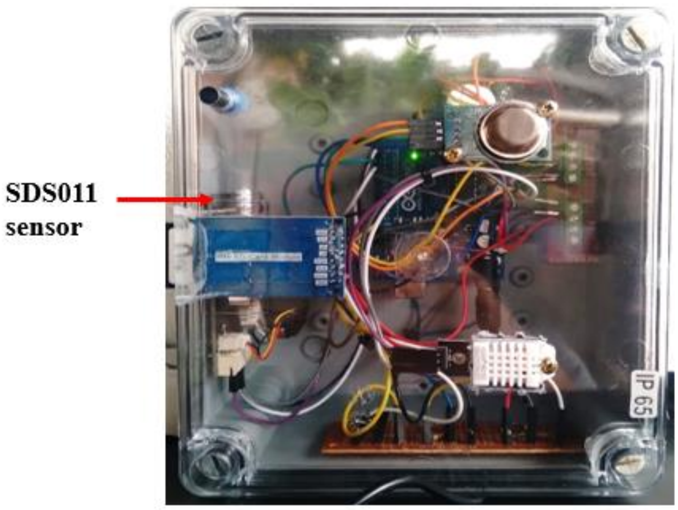

Figure 3: Air quality monitoring kit.

Data were acquired in text format, on a daily basis, at sampling frequency of 5 seconds. SD High Capacity (SDHC) memory card (figure 4) with storage capacity of 8 gigabytes and reading speed of 20 megabytes per second was used for data collection purposes.


Figure 4- Memory card used to collect data in the air monitoring kit.

## 2.3. SDS011 sensor

The SDS011 Sensor is used to detect Particulate Matters $PM_{2.5}$ and $PM_{10}$. Its technology is based on the laser diffraction theory, according to which, particle density distribution is determined through analysis applied to light intensity distribution patterns (GENIKOMSAKIS et al., 2018). The aim of this device is to collect data in a portable manner (Figure 5). It comprises a single-board controller that, in its turn, encompasses data logging tools, a GPS module, and a commercial optical PM sensor known as Laser $PM_{2.5}$. The aforementioned sensor, which has digital output and an internal fan, enables measuring particle density distribution at the range 0.3 µm to 10 µm (LIU et al, 2018).

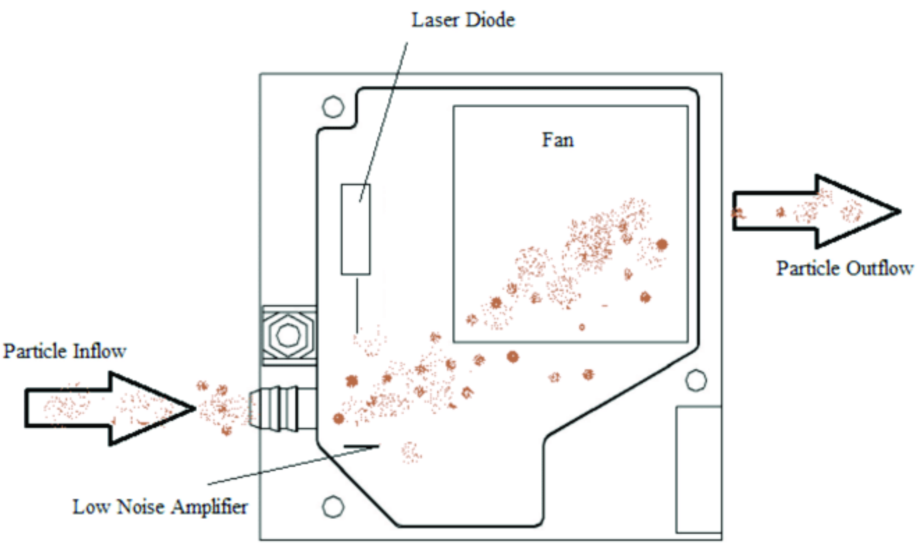


Figure 5- SDS011 sensor components. Source: Adapted from Genikomsakis et al., (2018).

SDS011 is a recent Air Quality Sensor developed by Nova Fitness, which is a spin-off from Jinan University, Shandong Province, China. It measures $PM_{2.5}$ and $PM_{10}$ at the range 0.0 µg/ $m^3$ to 999.9 µg/ $m^3$ and presents maximum relative error of ±15% at 25 °C, as well as 50% relative humidity, according to the manufacturer (Table 1):

Table 1- Features of the SDS011 sensor used to monitor $PM_{2.5}$.

| **Sensor Model** | SDS011 |
|---|---|
| **Manufacturer** | Nova Fitness |
| **Approximate price ($)** | 20 |
| **Dimensions (mm)** | 71x7x23 |
| **Approximate weight** | 50 |
| **Supply voltage (V)** | 5 |
| **Working current (mA)** | 220 |
| **Detectable size range (µm)** | 0.3 - 10 |
| **Size boxes** | Not available |
| **Estimated PM x Concentration** | $PM_{2,5}$ and $PM_{10}$ |
| **Concentration range (µg/m³)** | 0-999.9 |

Source: Adapted from (BADURA et al., 2018).

### 2.3.1. Related studies - validation

According to Badura et al. (2018), PM optical sensors have the additional advantage of low power consumption, since it operates with just 5 V voltage and working current often below 250 mA (as shown in Table 1). These sensors are compact and lightweight, and it makes them suitable for collecting frequent data, as well as turns them into excellent candidates to create widely distributed sensor networks.

According to Budde et al. (2018), the Nova Fitness' SDS011 sensor has been widely adopted in several regions around the world. Results observed by the aforementioned authors have shown that this low-cost sensor is capable of recording variations in fine dust particles with remarkable accuracy, overtime. More specifically, $PM_{2.5}$ measurements have shown promising potential, mainly to identify background particles. Furthermore, this sensor presented remarkable stability despite its affordable price.

Tagle et al. (2020) assessed the performance of a low-cost particulate matter particle sensor ($PM_{10}$ and $PM_{2.5}$) in an urban environment in Santiago City, Chile, whose prototype was built based on using SDS011 sensor (to measure $PM_{10}$ and $PM_{2.5}$), temperature and relative humidity sensor (BME280) and IoT board (ESP8266/Node MCU). These sensors were compared to continuous reference air quality monitors (BAM 1020 and TEOM 1400), as well as to a filter-based sampler (Partisol 2000i), at each measurement location. Results have indicated that the assessed prototype overall presented acceptable performance and could potentially be used to monitor mean daily $PM_{2.5}$ concentrations, after corrections based on relative humidity.

Badura et al. (2018), conducted a study focused on assessing low-cost sensors used for $PM_{2.5}$ environmental monitoring, which included four sensors types, such as PM SDS011 (Nova Fitness), ZH03A (Winsen), PMS7003 (Plantower) and OPC-N2 (Alphasense), as well as a TEOM 1400a analyzer. They observed that optical PM sensors often follow $PM_{2.5}$ variation trends in atmospheric air. However, they observed some temporary spikes in short-term raw data. The aforementioned authors have emphasized that both the SDS011 (Nova Fitness) and PMS7003 (Plantower) sensors recorded the highest accuracy and reproducibility rates among the assessed units - this factor can be a valuable resource when one uses a large number of sensors.

### 2.4. Sensors' installation description

All sensors were installed outside the homes of 5 fellows from "Guardians of the Air" project, in a place where air flow was not interrupted and the assessed sensors remained protected from rainfall events.


Figure 6: Sensors' installation site in all 5 selected points.

## 2.5. Data processing

Data were processed in Python programming language software version 3.11, in order to plot the graphs. Python is a programming language that shares common features with several other languages. This free software is widely adopted in practical applications (YUILL and HALPIN, 2006). It is essential emphasizing that using raw data in text format requires additional processing steps, such as pre-processing and records' cleaning. It is done to make them suitable for specific analyses to be carried out. These steps aim at ruling out likely inconsistencies found in raw data to ensure both results' reliability and validity.

## 2.6. Descriptive Statistics

Descriptive analysis was carried out in Python programming language software version 3.11 to enable plotting boxplots. Boxplots used to display summary data statistics, such as median, quartile, minimum and maximum, in visual format (Figure 6), are useful to identify trends, to detect outliers and to compare data distribution (NETO et al., 2017).

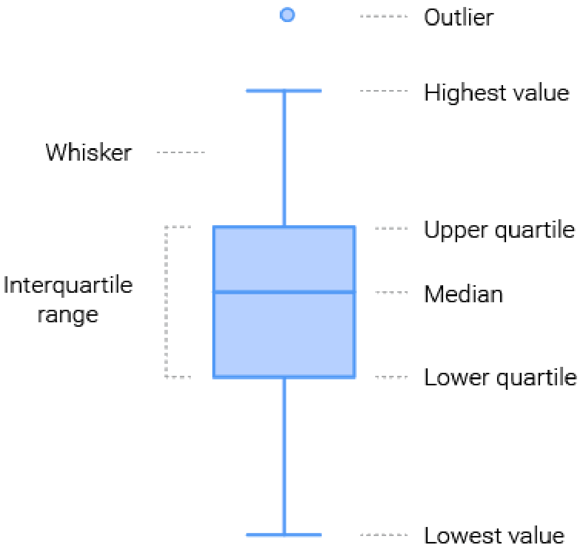

Figure 7- Boxplot structure. Source: learnbyexample.org

Boxplots are a useful tool adopted to analyze air pollutant data, since they help both visualizing and understanding the distribution of pollutant levels in a given area. They are an effective tool to help better understanding air quality in certain locations and identifying relevant patterns for studies.

## 3. Results and discussion

### 3.1. *Caranazal* Neighborhood

*Caranazal* neighborhood is one of the 56 neighborhoods in Santarém City. It accounts for approximately 1.44% of the total local population, which comprises approximately 9,310 inhabitants (OLIVEIRA, 2017). According to Uchôa (2011), this populous neighborhood hosts residents with average purchasing power. The presence of new commercial areas comprising mixed-use masonry buildings covered with clay roofs is a relevant feature of this region.

The analysis applied to monthly data on particulate matter $PM_{2.5}$ in *Caranazal* neighborhood allowed observing significant variation in this PM type, which recorded discrepant daily values. Notably, day 6 recorded the highest value, which was slightly higher than 350 (µg/m³) (Figure 8). A 70 µg/m³ filter was applied to help better visualizing the size of the boxes in the graph. Furthermore, based on Figure 9, days 19 and 29 recorded the highest and lowest PM variability, respectively.

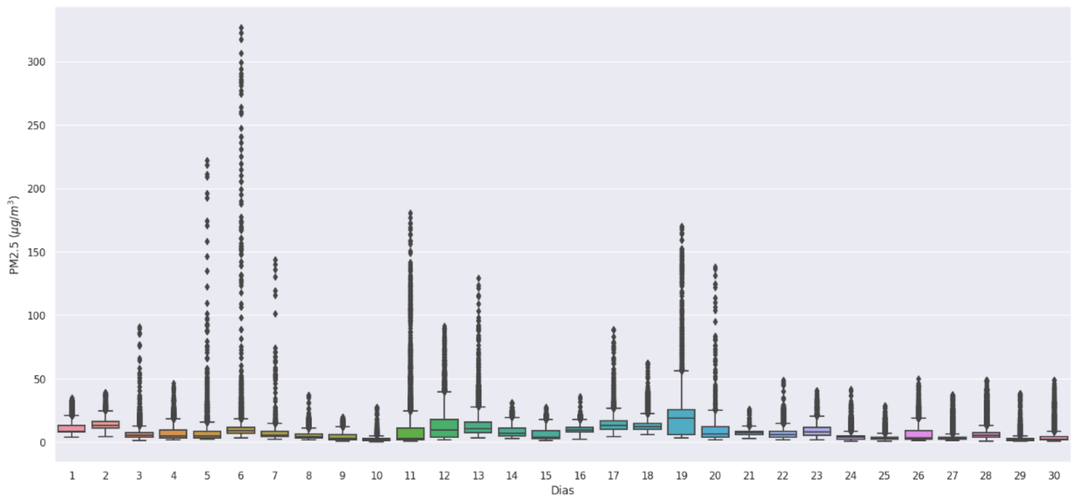


Figure 8- $PM_{2.5}$ behavior in Caranazal neighborhood, in November 2022.

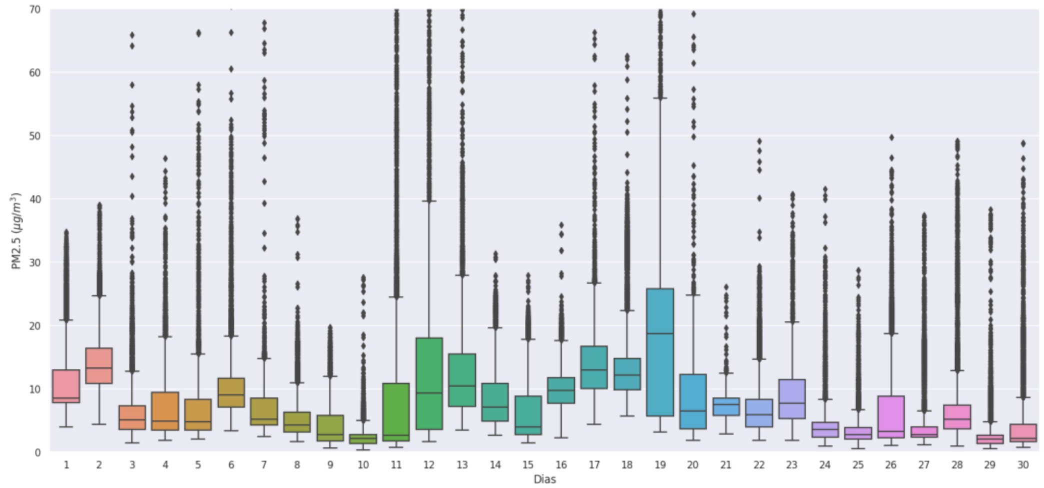


Figure 9- $PM_{2.5}$ behavior after 70 µg/m³ filter application in Caranazal neighborhood, in November 2022.

### 3.2. *Maracanã* Neighborhood

*Maracanã* neighborhood is located in a large area known as *Santarenzinho*, between the banks of Tapajós River, at latitude -2.4409585475177282 and longitude -54.7439559497543. The development of this neighborhood was boosted by the construction of Tapajós River shopping mall. According to the Brazilian Institute of Geography and Statistics (IBGE, 2010), this neighborhood is inhabited by approximately 3,695 thousand individuals, who account for approximately 1.20% of Santarém City's population.

Based on the analysis applied the herein monitored data, the highest particulate matter concentrations were recorded at the beginning of the assessed month – i.e., on November 2nd and 11th – when they reached approximately 650 µg/m³ (Figure 10). If one applies a 70 µg/m³ filter for better visualization purposes, it is possible seeing that days 16 and 25 recorded the highest and lowest PM variability rates, respectively, as shown in Figure 11.

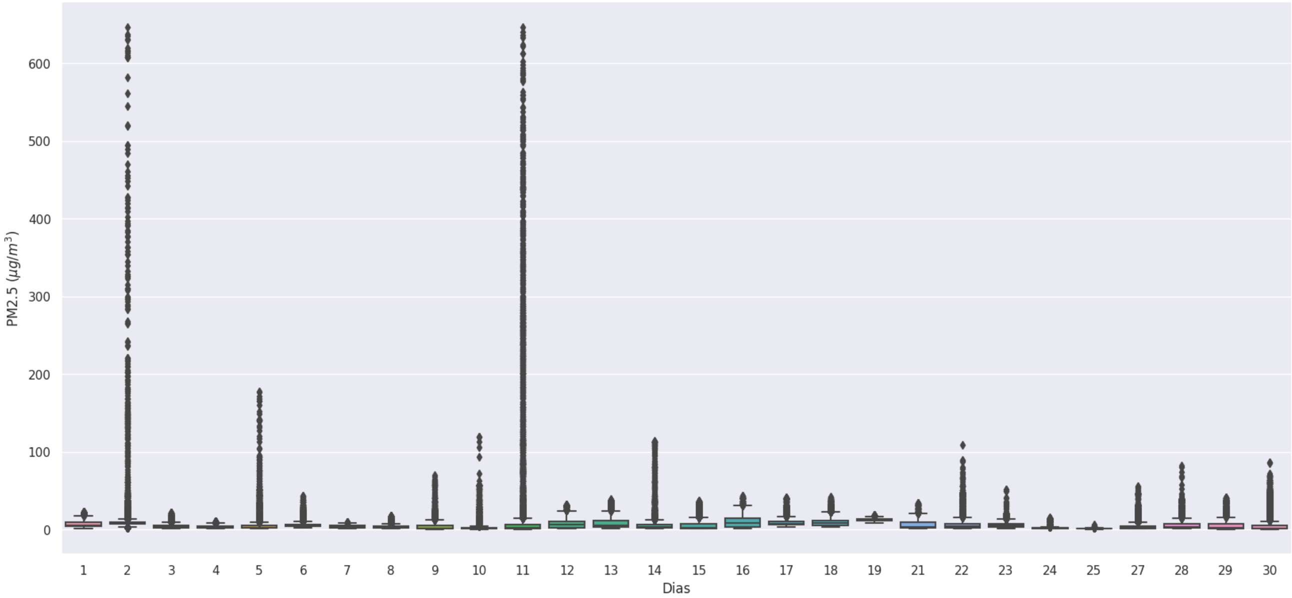


Figure 10- $PM_{2.5}$ behavior in Maracanã neighborhood, in November 2022.

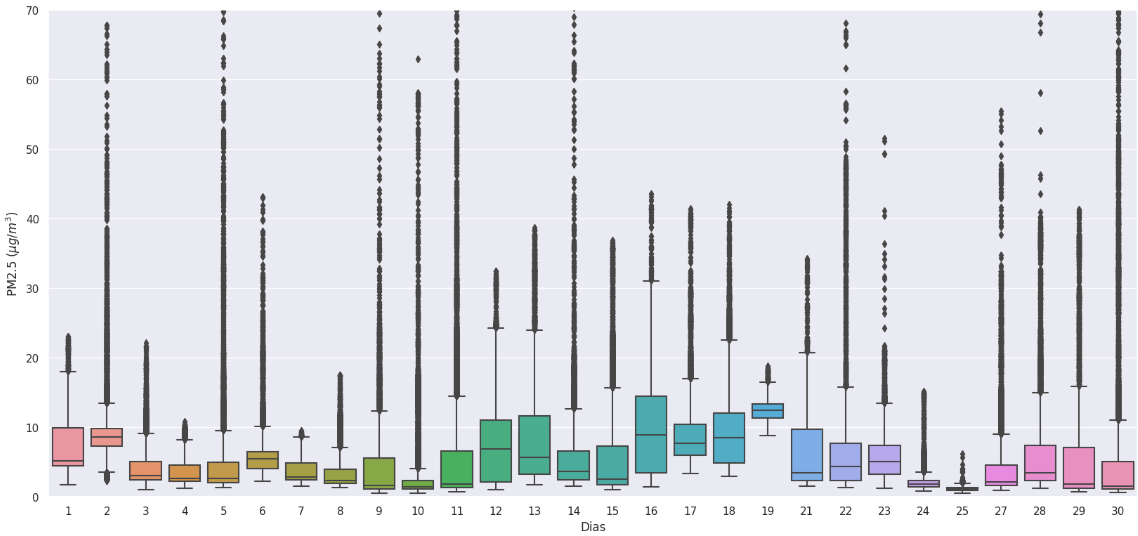


Figure 11- $PM_{2.5}$ behavior after 70 µg/m³ filter application in Maracanã neighborhood, in November 2022.

### 3.3. *Ramal dos Coelhos* Community

*Ramal dos Coelhos* community is located at the following geographic coordinates: latitude -2.462543881802721 and longitude -54.787798902981386. According to its residents, although this community is close to 100 years old, it was officially named *Ramal dos Coelhos* a few years ago, when it separated itself from *Cucurunã* community. It houses approximately 250 families, whose main income source derives from farming, fishing and açaí production.

$PM_{2.5}$ monitoring in *Ramal dos Coelhos* community (Figure 12) recorded fewer discrepant values than the previously mentioned points. However, PM concentration of 1,000 µg/m³ was recorded on November 26th and 27th – it was the highest concentration observed among the herein investigated five points. The hypothesis raised to justify this record lies on the incidence of burning events near the site where the monitoring equipment was installed in.

According to Silva (2013), using fire in natural areas and forests is a common practice in tropical and subtropical regions, mainly in areas presenting significantly dry season. This context is observed in several Brazilian regions, mainly in the Amazon.

Based on observations focused on collected-data variations, after applying a 70 µg/m³ filter to enable better visualization (Figure 13), it was possible seeing high PM variability at days 14, 19 and 20, despite the reduced discrepancy in values observed for *Ramal dos Coelhos* community in comparison to the other investigated points.

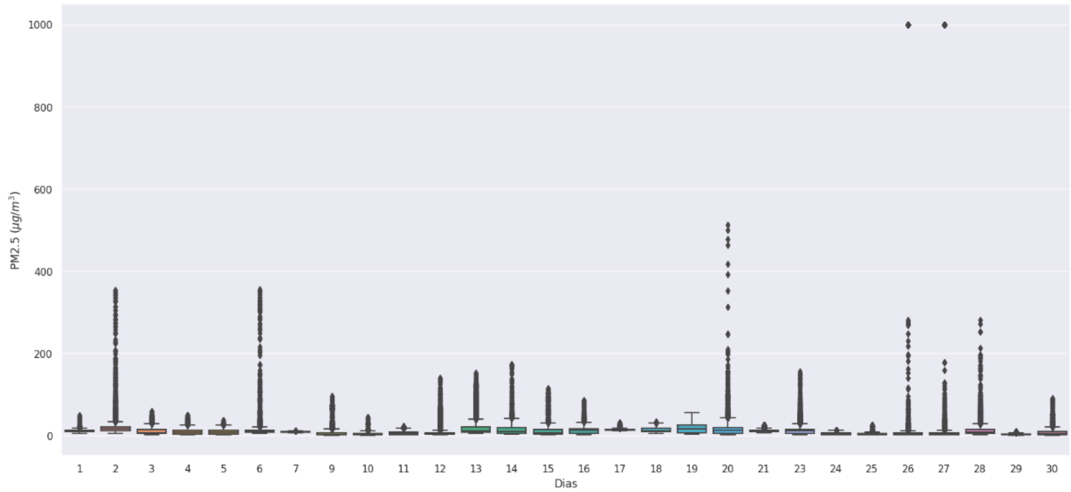


Figure 12- $PM_{2.5}$ behavior in Ramal dos Coelhos community, in November 2022.

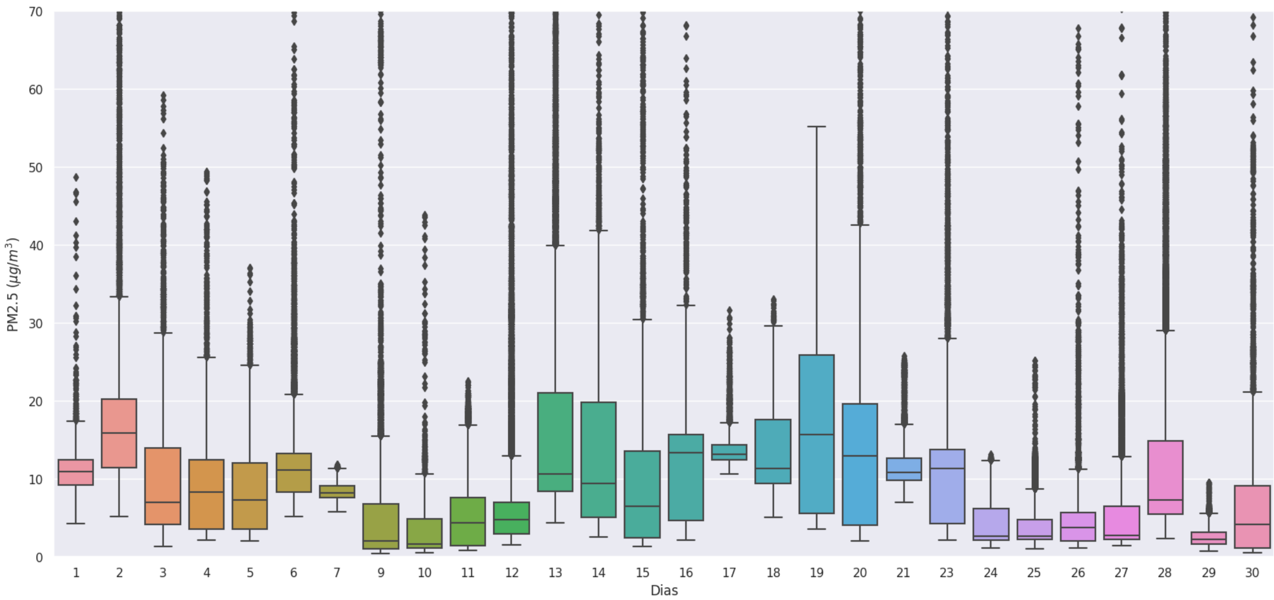


Figure 13- $PM_{2.5}$ behavior, after 70 µg/m³ filter application, in Ramal dos Coelhos community, in November 2022.

### 3.4. *São Pedro* Community

*São Pedro* community was founded on November 20th, 1977. It comprises approximately 90 families, whose main income source lies on agriculture. It is located near *Vila de Alter do Chão*, approximately 25 km away from Santarém City. It is accessed through PA-457 highway. This vegetation-rich community is near PA-457 highway, which provides access to *Vila de* Alter do Chão that, in its turn, presents higher vehicle flow on weekends due to its beach. The monitoring equipment installed in this community is located at the following geographic coordinates: latitude -2.5362080717167252 and longitude -54.8778698679120823.

Based on Figure 14, the highest $PM_{2.5}$ concentration was recorded on November 19th, and it exceeded 250 μg/m³. It is also worth emphasizing days 15, 22 and 27, when $PM_{2.5}$ concentrations were higher than 100 μg/m³. Based on Figure 15, and after applying a 70 μg/m³ filter, it appeared that days 02, 06 and the period between days 12 and 22 recorded the highest data variability.

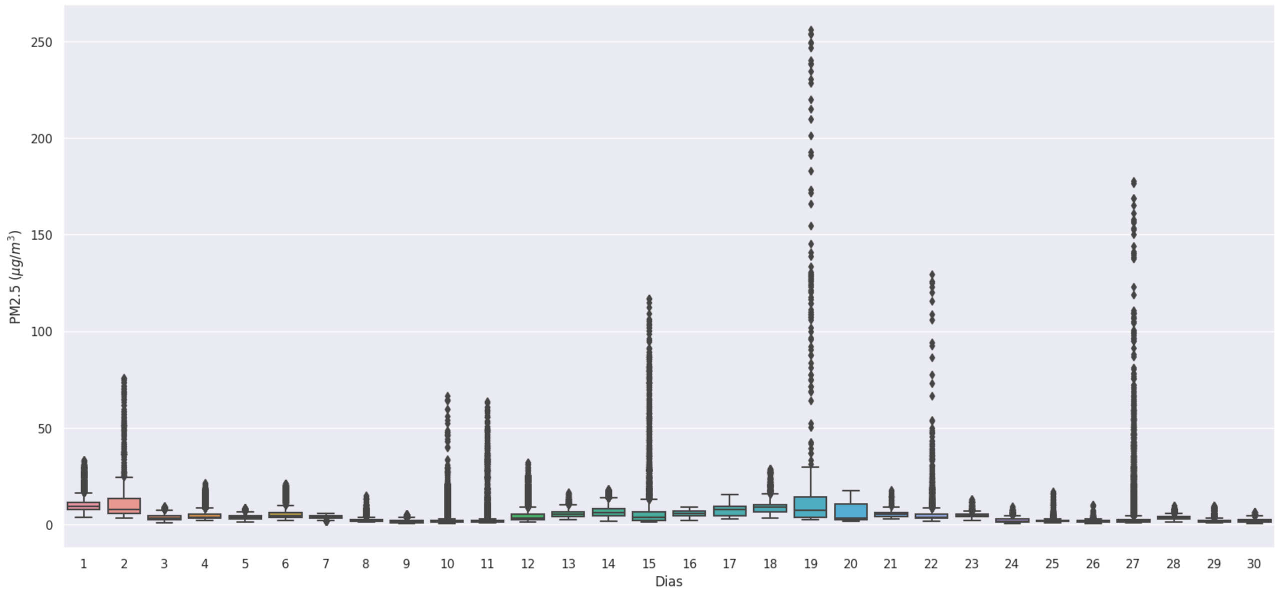


Figure 14- $PM_{2.5}$ behavior in São Pedro community, in November 2022.

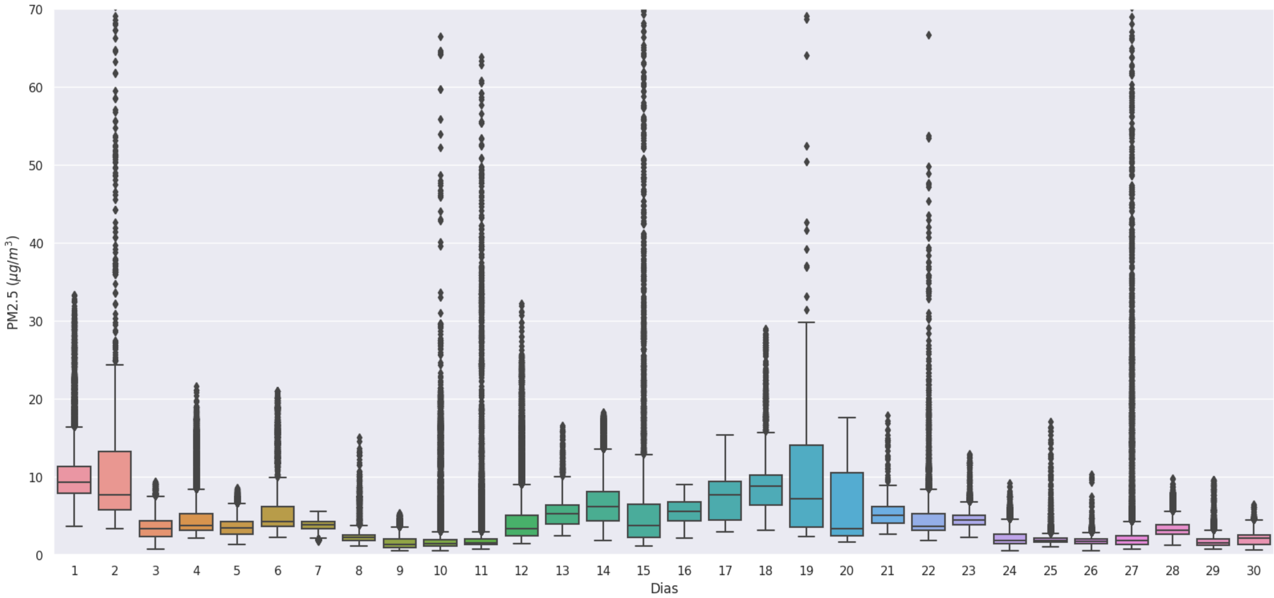


Figure 15- $PM_{2.5}$ behavior, after 70 μg/m³ filter application, in São Pedro community, in November 2022.

### 3.5. *Vila de Alter do Chão*

*Vila deAlter do Chão* is located on the banks of Tapajós River, 37 km away from Santarém City, and it is accessed through PA-457 highway. Its population comprises approximately 6 thousand inhabitants, whose main income source lies on tourism due to its popularity among Santarém visitors - it is known as the “Caribbean of the Amazon” (SILVA and GUIMARÃES, 2019)

$PM_{2.5}$ data collection in *Vila de Alter do Chão* was carried out for 22 days in November 2022, due to monitoring equipment malfunction caused by air passage pipe clogging resulting from the incidence of dust and insect nests in it. This issue has compromised collected data accuracy and led to lack of information about the last 8 days of the investigated month.

Based on collected data, day 01 stood out as the one recording the highest PM concentration - higher than 650 µg/m³ (Figure 16). In addition, higher data variability could be seen after applying the 70 µg/m³ filter, and it indicated significant fluctuations in particulate matter concentrations.

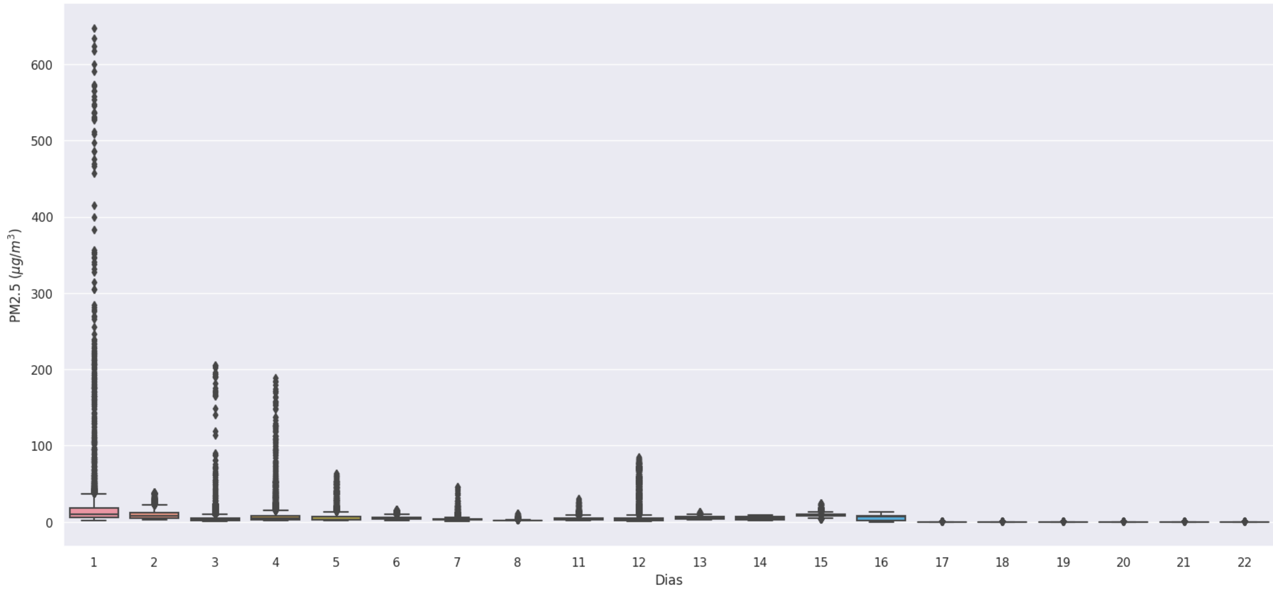


Figure 16- $PM_{2.5}$ behavior in Vila de Alter do Chão, in November 2022.

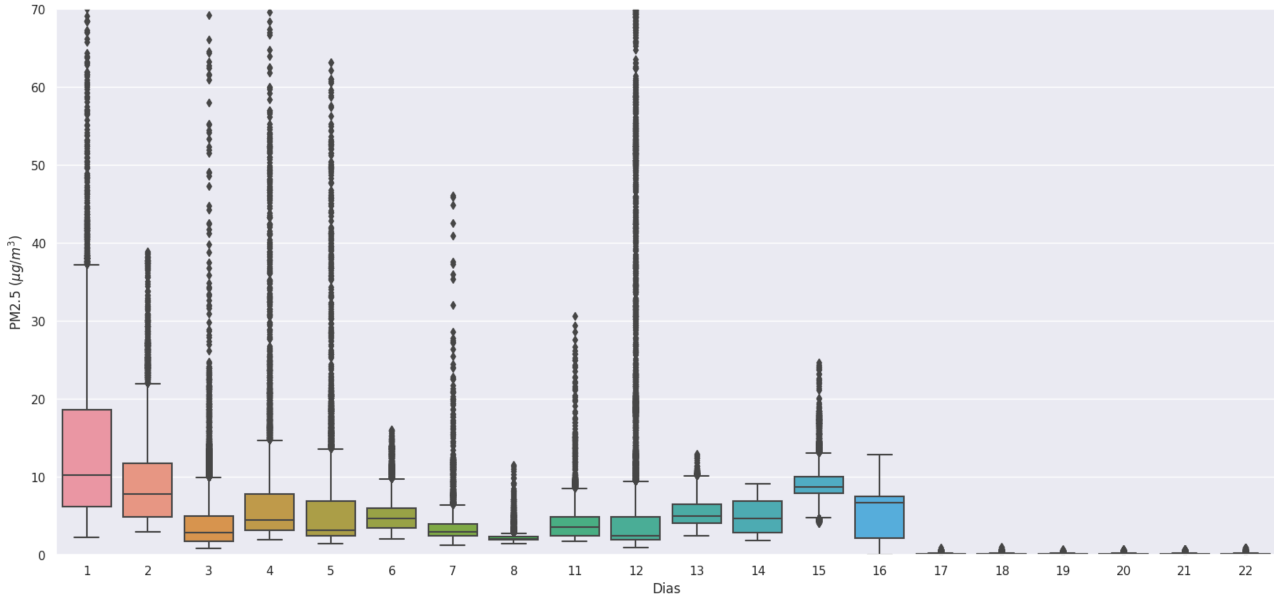


Figure 17- $PM_{2.5}$ behavior, after 70 µg/m³ filter application, in Vila de Alter do Chão, in November 2022.

Although the investigated neighborhoods and communities were mostly located in the peri-urban area of Santarém City, as well as are rich in surrounding vegetation, they presented high $PM_{2.5}$ pollution levels. According to Reddington *et al.* (2015), wildfire events resulting from deforestation and human activities, such as agriculture and land use, in the Brazilian Amazon region are the main causes of atmospheric pollutants’ concentration in it. Association between wildfires and incidence of pollutants is widely acknowledged as significant challenge for both biodiversity conservation and ecosystems' health. Particulate matter found in this region has the ability to move over long distances, since winds can transport pollution to distant areas, away from wildfire sources (Barcellos *et al*., 2019).

In addition, using low-cost sensors enabled real-time data collection, which provided a more accurate and updated air quality analysis in certain areas. There was significant difference in the concentration of the investigated pollutant among all 5 collection points. However, it is worth emphasizing that low-cost commercial sensors may have some accuracy and reliability limitations in comparison to high-accuracy monitoring instruments. If one takes into account that the SDS011 sensor has a quite affordable cost and presents satisfactory performance results, it is possible concluding that it has significant potential to be used for air quality analysis purposes (LIU et al., 2019).

Based on comparing $PM_{2.5}$ concentrations observed for all five locations (Figure 18), Maracanã was the neighborhood recording the highest incidence of this pollutant. However, its highest concentration was found in *Ramal dos Coelhos* community. This finding has pointed out that the monitored region had different air pollution sources. It is worth emphasizing that air quality standards set by WHO (2021) recommend mean annual $PM_{2.5}$ concentration limit of 5 µg/m³ and 24-hour concentration of 15 µg/m³, on average. Values up to 67 times higher than the one recommended by the World Health Organization were observed in the current study, and it highlighted that the Amazonian region already presents pollution levels comparable to those of large urban centers.

According to CETESB, (2022), the health-related effect of poor air quality indicates that the entire population may be at serious risk of developing respiratory and cardiovascular diseases, besides increasing the risk of premature deaths in people belonging to sensitive groups. According to Rocha (2022), children and elderly individuals are the groups mostly vulnerable to exposure to air pollution, as well as the ones subjected to its strongest impacts.

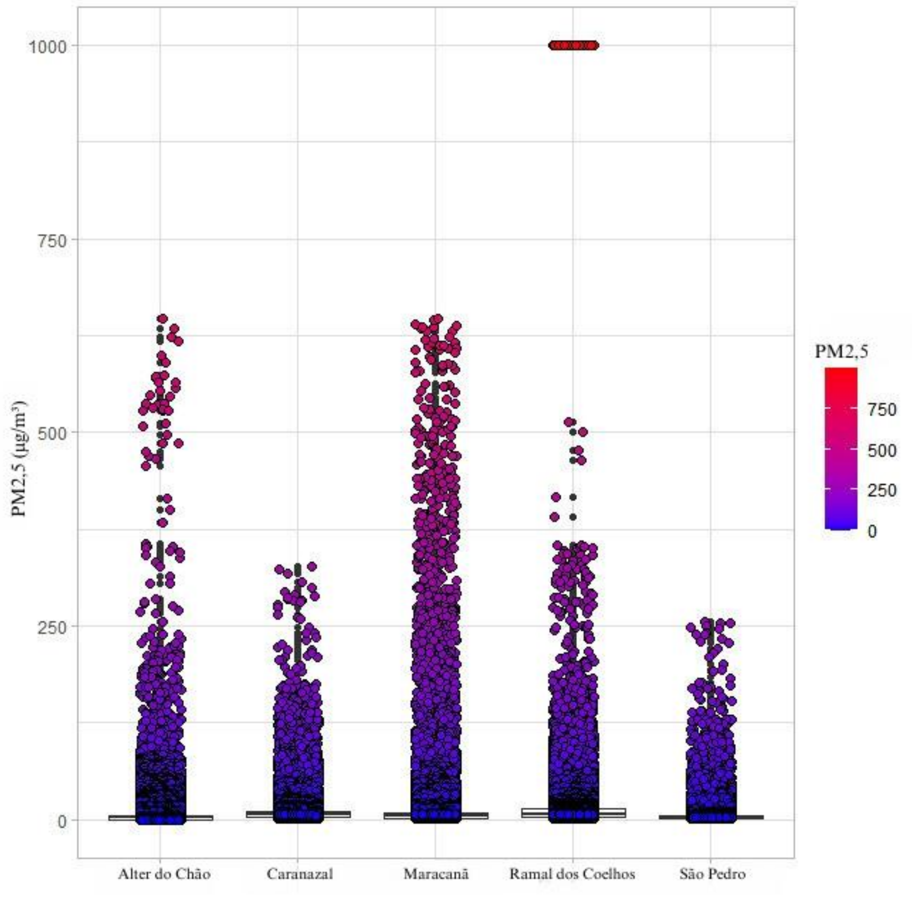


Figure 18- $PM_{2.5}$ concentration in the herein selected neighborhoods, in November 2022.

## 4. Conclusions

Findings in the current study have pointed out considerable differences in $PM_{2.5}$ levels among the investigated areas, and it highlighted the air pollution diversity in these locations, where $PM_{2.5}$ concentrations exceed the limits established by health and environmental agencies. This factor emphasizes the relevance of setting a monitoring network, since it enables analyzing air quality in different areas. The adoption of low-cost monitoring sensors enabled collecting continuous and comprehensive data about atmospheric pollutant concentrations in different locations. However, it is important emphasizing that although Santarém City is located in the Brazilian Amazon, there were days when it was possible seeing high pollution levels comparable to those observed in large urban centers. This information is essential to help better understanding pollution patterns, as well as their effects on both public health and the environment. Furthermore, it is necessary developing more rigorous policies and regulations focused on pollution sources to help promoting more effective environmental management in the investigated city, as well as in similar regions in the Amazon.

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