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Pollution in the Port Area and Respiratory Events in Santos, Sao Paulo, Brazil

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SUMMARY

Background: Port activities can cause negative socio-environmental impacts, with air quality degradation being one of them.
Objective: This study aimed to analyze a potential relationship between environmental air pollutants detected by the Environmental Company of the State of Sao Paulo (CETESB) air quality analysis station, located in Ponta da Praia, Santos and the occurrence of health events related to respiratory diseases.
Methods: At the CETESB "Santos – Ponta da Praia" station, from January 2021 to December 2022, monthly cumulative measurement of $PM_{2.5}$ and PM_{10}, SO_2, NO, NO_x and NO_2 inhalable particles were collected. Additionally, respiratory health events were verified through data from Unified Health System (SUS) database in the State of São Paulo from January 2021 to December 2022.
Results: The monthly averages SO_2 and NO_2 levels did not exceed the limits, but $PM_{2.5}$ levels exceed twice in July 2021 and 2022, and PM_{10} levels exceeded four times in May, June and July 2021 and July 2022. Although air quality measured by CETESB station was classified as good, a moderate correlation was identified between NO_2 emission and events of pneumonia, bronchitis, and chronic obstructive pulmonary disease events, especially among vulnerable population, up to 19 years old.
Conclusions: The results are significant for understanding the relationship between respiratory diseases and air pollution in the Port of Santos area.

Keywords: Port of Santos; Air quality; Inhalable gases and particles; Respiratory system diseases; Public health.

INTRODUCTION

The Port of Santos is the busiest in Latin America, the most significant in the Southern Hemisphere, serving as a gateway to South America. Given this, it is essential to note that port activities can lead to negative socio-environmental impacts, one of which is air quality deterioration [1,2,3], particularly from the atmospheric emissions of ships entering and leaving the Port of Santos [4,5].

Over the past few decades, increased international trade has resulted in higher tonnages of goods transported by ships, making maritime emissions a significant source of pollution. More than 80% of global trade is transported by sea in terms of tonnage, according to The International Council on Clean Transportation (ICCT) [6]. For more than 20 years, there have been indications that international maritime transport emits more environmentally impactful pollutants than estimated [7].

The effects of emissions from maritime traffic and cargo handling can affect and contaminate beaches, narrow channels, gulfs, sensitive ecosystems, and port workers, as well as the surrounding population, especially vulnerable groups such as elderly and children. A study conducted at the Port of Leixões, encompassing a resident population of 374,144 within the municipalities of Matosinhos, Leça da Palmeira, and Porto, revealed key findings regarding pollutant dispersion. Prevailing meteorological conditions, characterized by westerly-southwesterly winds (ocean to land) during the day and northeasterly winds (land to ocean) at night, suggest higher pollutant concentrations in the urban area near the port during daytime hours. Dispersion modeling algorithms confirmed that the dominant wind direction is responsible for transporting

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pollutants over the surrounding area, particularly PM10 and NO_x. Berthed ships constitute the primary source of NO_x emissions, contributing over 50% to the measured concentrations [8]. This finding is corroborated by another study of four Portuguese ports, which attributed 73% of total NOx concentrations to berthed ships [9].

However, in the port environment, it is crucial to consider atmospheric pollutants from other sources, such as trucks, railroads and cargo-handling equipment, all powered by fossil fuels [10,11].

High concentrations of pollutants such as SO_x (Sulfur Oxides), NO_x (Nitrogen Oxides), and particulate matter (PM) have gained global attention due to their potential to exacerbate respiratory diseases, heart problems, hypertension -relates conditions, and even cancer, leading to premature death of affected populations [8,12].

A study investigating the associations between prenatal exposure to $PM_{2.5}$ and neonatal respiratory distress identified a strong link between $PM_{2.5}$ exposure and the need for assisted ventilation, multiple clinical interventions, and systemic antibiotic use in newborns [13].

A study in Turkey found a correlation between between air pollutants and respiratory diseases, where asthma symptoms in children were linked to SO_2 (sulfur dioxide) and PM10 concentrations, which were also associated with chronic obstructive pulmonary disease (COPD) in the elderly population [14].

Air quality standards (PQAr) represent the concentration of a specific pollutant in the atmosphere over a given time period and one of the tools for air quality management. The PQAR are defined by National Environment Council of Brazil - CONAMA Resolution No. 491/2018 [15] and CONSEMA Resolution No. 4/2021 [16]. Air quality, as established by State Decree No. 59,113/2013, can be classified as NI (good), N2 (moderate), N3 (Poor), N4 (very poor) and N5 (awful) [17].

Santos, with a population of 433,991 inhabitants (Brazilian Institute of Geography and Statistics -IBGE/2021), is home to a large port located in close proximity to residential areas, including vulnerable populations of elderly people, children and a large number of tourists, especially weekend and holiday [18].

Considering that the "Santos – Ponta da Praia" station is the CETESB station in Santos closest to the Port of Santos and can indicate the air quality of the port region and its surroundings, the objective of this work is to analyze a possible relationship between the environmental atmospheric pollutants detected by the CETESB air quality analysis station and the occurrence of respiratory diseases.

MATERIAL AND METHODS

This is a cross-sectional study and followed the reporting recommendations from the STROBE (Strengthening the reporting of observational studies in epidemiology) roadmap for observational studies [19].

Data was collected from the air quality monitoring station of CETESB and the SUS (Unified Health System) Department of Informatics database for the State of São Paulo. A total of 3,688 patients were included in the study.

The pollutants detected by the CETESB air quality analysis station located in Ponta da Praia in Santos from January 2021 to December 2022 were analyzed. The air quality monitoring (QUALAR) was carried out by the CETESB station called "Santos – Ponta da Praia". This mobile station is located at the Rebouças Sports Complex, Praça Eng. José Rebouças s/n, Ponta da Praia [19,20]. The station is configured to monitor the following pollutants relevant to this study: inhalable particles (PM_{10} and $PM_{2.5}$), SO_2 and nitrogen oxides (NO, NO_x and NO_2) [20, 21].

To verify the occurrence of respiratory diseases in the city of Santos, an observational and analytical study was carried out using the SUS database in the State of São Paulo through the TabNet DATASUS system (DATASUS, 2022). The data for respiratory diseases were collected according to the International Classification of Diseases and Related Health Problems, 10th Revision (ICD-10). Morbidity data for respiratory diseases (Chapter X of ICD-10), including pneumonia, bronchitis, and COPD, were examined by age group (children, adults, and elderly).

Subsequent statistical analysis was carried out using TIBCO Statistica™ version 14.0.0.15. The Kolmogorov-Smirnov test was used to assess data normality, and Pearson correlation was applied to examine the linear relationship between continuous variables. Statistical significance was set at $p<0,05$. Correlation magnitudes were classified as weak, moderate, or strong according to Cohen's scale [22].

RESULTS

Table 1 presents the monthly values of $PM_{2.5}$, PM_{10}, SO_2, NO, NO_x and NO_2 monitored by the CETESB station "Santos – Ponta da Praia" from January 2021 to December 2022.

According to CETESB's air quality classification, most measurements were within the "good" category (N1). Only $MP_{2.5}$ and MP_{10} presented some measurements with moderate air quality (N2): July and August 2021 and May to September 2022 for $MP_{2.5}$, and May to September 2021 and 2022 for MP_{10}. As of September 2021, MP_{10} has been rated as poor (N3).

As mentioned, the measurements of NO_2, NO, NO_x and SO_2 in the analyzed period remained at N1.

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Table 1. Monthly average values (μg/m³) of pollutants monitored at the CETESB Station "Santos – Ponta da Praia" in the period from January 2021 to December 2022

	Jan 21	FeB 21	Mar 21	APr 21	May 21	Jun 21	Jul 21	AUg 21	SeP 21	OCt 21	Nov 21	DeC 21
MP_{10}	16	21	24	23	**37**	**34**	**37**	28	28	21	21	19
NO_2	19	25	23	24	31	27	36	29	26	20	20	22
NO	12	22	21	23	32	29	40	24	14	10	11	17
NO_x	20	31	29	31	43	38	52	35	25	19	19	26
$MP_{2,5}$	12	11	11	9	14	12	**18**	14	13	8	9	9
SO_2	1	2	2	2	3	2	3	2	1	1	2	2
	Jan 22	**FeB 22**	**Mar 22**	**APr 22**	**MaY 22**	**Jun 22**	**Jul 22**	**AUg 22**	**SeP 22**	**OCt 22**	**Nov 22**	**DeC 22**
MP_{10}	22	19	22	23	28	25	**36**	26	28	21	19	19
NO_2	25	26	27	26	34	34	41	38	35	27	24	23
NO	21	28	23	28	40	36	42	32	29	13	18	18
NO_x	31	37	33	37	51	47	56	46	43	25	28	27
$MP_{2,5}$	11	11	11	10	14	12	**17**	11	12	9	8	10
SO_2	3	3	2	2	3	2	3	3	2	2	3	2

Source: CETESB; Air quality information system – QUALAR.
Note: overtaking according to the current targets are indicated in bold

Figure 1. Pearson correlation (r) between monthly NO_2 values (μg/m³) monitored at the CETESB "Santos – Ponta da Praia" Station and hospital health events of (A) respiratory system diseases, (B) pneumonia and (C) bronchitis, emphysema, and other chronic pulmonary diseases according to the ICD-10 classification in the city of Santos\s.

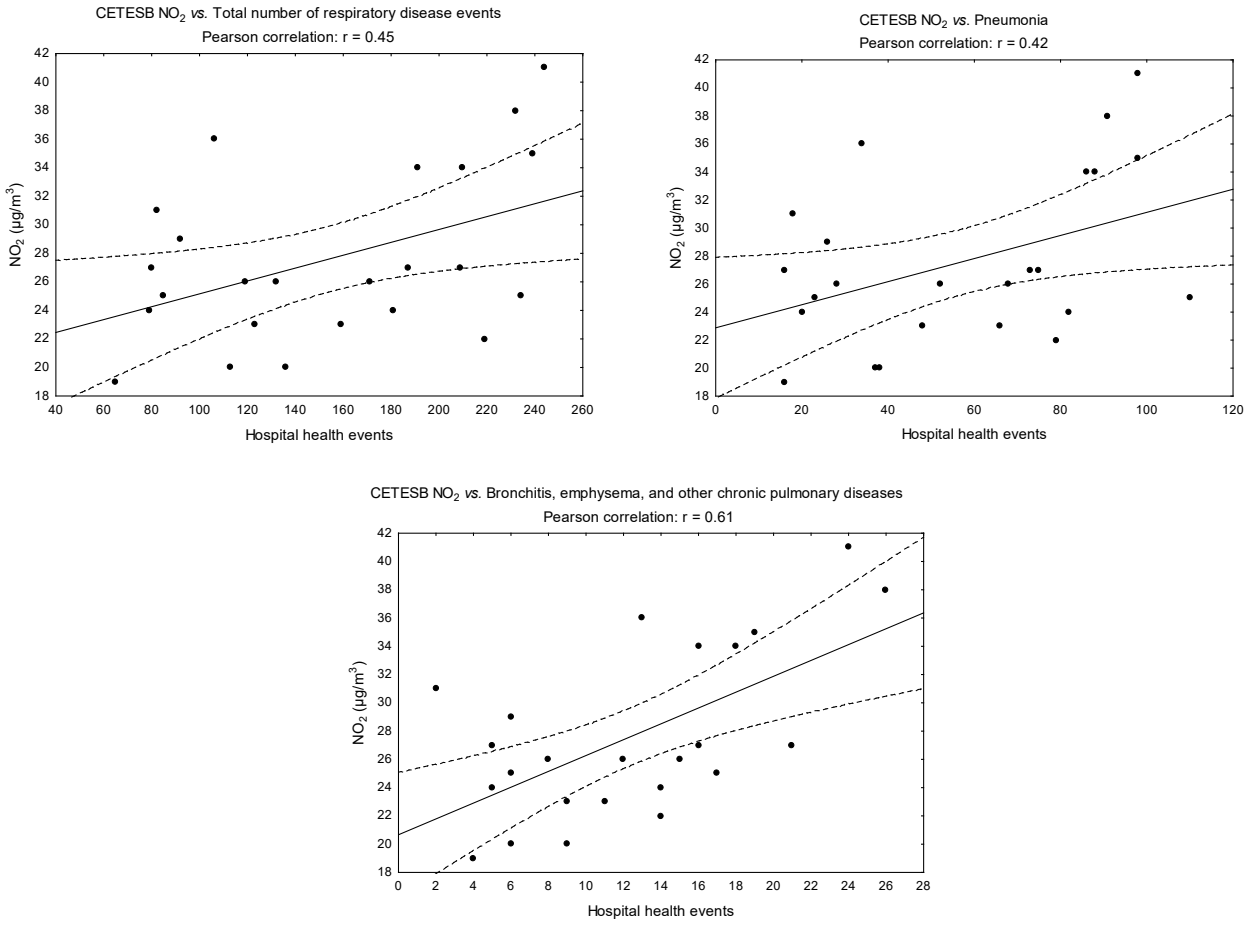

Table 2. Number of Respiratory System Disease Events (ICD-10 Chapter X) Registered in the SUS Database for the Municipality of Santos (SP), Brazil, from January 2021 to December 2022

ICD-10 List	2021 Jan	2021 Feb	2021 Mar	2021 Apr	2021 May	2021 Jun	2021 Jul	2021 Aug	2021 Sep	2021 Oct	2021 Nov	2021 Dec	TOTAL
Other diseases of the respiratory system	34	44	46	47	46	43	48	41	55	59	74	96	633
Pneumonia	16	23	48	20	18	16	34	26	28	38	37	79	383
Bronchitis, emphysema and other COPD	4	6	9	5	2	5	13	6	12	6	9	14	91
Acute bronchitis and acute bronchiolitis	3	10	15	3	6	6	8	12	5	1	6	17	92
Asthma	-	-	4	2	5	7	1	4	14	5	10	7	59
Other acute upper respiratory infections	-	-	1	-	1	-	-	-	1	1	-	1	5
Other diseases of the nose and paranasal sinuses	3	1	-	-	1	1	1	2	-	1	-	-	10
Other diseases of the upper respiratory tract	3	1	-	-	2	2	-	-	1	-	-	3	12
Bronchiectasis	-	-	-	2	1	-	-	-	-	1	-	-	4
Acute laryngitis and tracheitis	-	-	-	-	-	-	1	-	1	1	-	-	3
Chronic diseases of the tonsils and adenoids	2	-	-	-	-	-	-	1	-	-	-	1	4
Acute pharyngitis and acute tonsillitis	-	-	-	-	-	-	-	-	1	-	-	1	2
Pneumoconiosis	-	-	-	-	-	-	-	-	1	-	-	-	1
Respiratory system diseases (CID: J00-99)	65	85	123	79	82	80	106	92	119	113	136	**219**	1.299

ICD-10 List	2022 Jan	2022 Feb	2022 Mar	2022 Abr	2022 May	2022 Jun	2022 Jul	2022 Aug	2022 Sep	2022 Oct	2022 Nov	2022 Dec	TOTAL
Other diseases of the respiratory system	86	58	79	74	69	66	87	77	103	85	63	66	913
Pneumonia	110	52	73	68	86	88	98	91	98	75	82	66	987
Bronchitis, emphysema and other COPD	17	8	16	15	18	16	24	26	19	21	14	11	205
Acute bronchitis and acute bronchiolitis	14	12	12	11	27	9	20	10	3	7	12	10	147
Asthma	1	-	5	2	9	9	7	17	10	15	9	4	88
Other acute upper respiratory infections	1	1	-	-	-	1	5	5	4	2	-	2	21
Other diseases of the nose and paranasal sinuses	1	-	-	-	-	-	1	-	-	2	-	-	4
Other diseases of the upper respiratory tract	1	-	-	-	-	1	-	2	1	-	-	-	5
Bronchiectasis	1	-	-	-	-	-	-	-	-	1	-	-	2
Acute laryngitis and tracheitis	1	-	-	-	1	-	1	1	1	-	-	-	5
Chronic diseases of the tonsils and adenoids	-	1	1	1	-	1	1	-	-	1	1	-	7
Acute pharyngitis and acute tonsillitis	1	-	1	-	-	-	-	3	-	-	-	-	5
Pneumoconiosis	-	-	-	-	-	-	-	-	-	-	-	-	0
Respiratory system diseases (CID: J00-99)	**234**	132	187	171	**210**	191	**244**	**232**	**239**	**209**	181	159	2.389

Note: overtaking according to the current targets are indicated in bold

It is worth mentioning that the highest monthly average NO_2 values (n = 712) were observed between May and September 2021 and 2022.

Based on data from DATASUS, 3,688 respiratory health events were recorded in Santos from January 2021 to December 2022, excluding influenza and COVID-19. The data are presented in Table 2. The highest number of events occurred in December 2021 (>200/month, n = 219), January (n = 234), May (n = 210), July (n = 244), August (n = 232), September (n = 239) and October 2022 (n = 209). Most of these events affected children and adolescents (<1-19 years, n = 1156), followed by the elderly population (+60 years; n = 1549) compared to the adult population (20-59 years; n = 925).

The variables of health events classified in Chapter X of ICD-10 (1) pneumonia and bronchitis; (2) emphysema and other chronic lung diseases; and (3) total number of respiratory system diseases showed a significant association with NO_2 emissions ($p<0.05$; Figure 1A, Figure 1B and Figure 1C). The results reveal that the values of the air pollutant NO_2 and the number of bronchitis, emphysema and other chronic pulmonary diseases have a strong (r = 0.61) and statistically significant association ($p<0,05$).

Pearson's correlation analysis showed a moderate and statistically significant association ($p<0.05$) between NO_2 emission in the air and the total number of respiratory events from January 2021 to December 2022 in the population up to 19 years old (r = 0.45) (Figure 2). No significant differences were obtained between the NO_2 emission in the air and the total number of respiratory events in the adult and elderly populations (data not shown).

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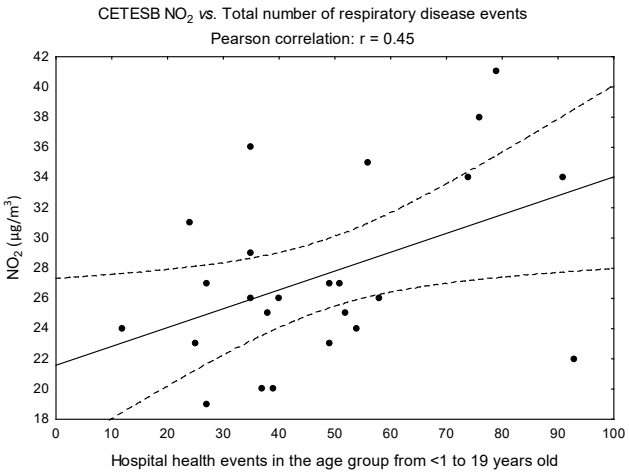
Figure 2. Pearson correlation (r) between monthly NO_2 values (µg/m³) monitored at the CETESB Station "Santos – Ponta da Praia" with hospital health events in the age group from <1 to 19 years old



DISCUSSION

Data from DATASUS (January 2021–December 2022) reveal a higher incidence of respiratory diseases (excluding influenza and COVID-19, based on ICD-10 classifications) in specific months: December 2021, and January, May, July, August, September, and October 2022. Children, adolescents, and the elderly experienced a disproportionately higher number of these events compared to adults, highlighting their increased vulnerability and the need for targeted health interventions. This aligns with research from Turkey linking air pollutants to respiratory problems, particularly asthma in children and COPD in the elderly, correlating with SO_2 and PM_{10} concentrations [14,23]. Similarly, a study in the ports of Copenhagen and Elsinore found that PM_{10} accumulation caused health issues, prompting recommendations for reducing NO_x and PM_{10} emissions from ships and monitoring pollutant levels near ports [24].

Our findings show that monthly average $PM_{2.5}$ and PM_{10} levels in Santos frequently exceeded national and state air quality standards (CONSEMA Resolution No. 4/2021, IT-3) during the study period, especially in July—coi ncidentally the month with the highest number of ship dockings in 2022. While overall air quality was generally good, $PM_{2.5}$ and PM_{10} levels reached moderate and even poor classifications (September 2022 for PM_{10}) during several months. It's crucial to consider both ship-based and land-based sources (trucks, railroads, cargo handling, storage) as contributors to PM_{10} emissions in port environments [10,11]. A study by Sarra and Mülfarth (2021) specifically linked PM_{10} emissions in the Ponta da Praia area to grain handling and transportation [5].

The CETESB "Santos – Ponta da Praia" station monitors pollutants relevant to vehicular and overall public health concerns, including $PM_{2.5}$, PM_{10} , SO_2, NO, NO_x, and NO_2 [25,26]. Our analysis revealed a moderate, statistically significant correlation between NO_2 emissions and respiratory events in the susceptible population under 19 years old, and between NO monitored by CETESB and acute bronchitis/bronchiolitis. This underscores the importance of addressing port-related pollution, given the potential exposure of both port workers and nearby residents. Studies from Ambarli port in Turkey [27] and by Sarra and Mülfarth [5] further emphasize the contribution of bulk solid handling to air pollution and increased respiratory health risks. Previous research in Santos [28] found no association between calculated NO_x and respiratory diseases but did observe a correlation between CETESB-monitored NO_x and conditions like acute bronchitis/bronchiolitis and chronic pulmonary diseases.

The Port of Santos's proximity to urban areas, including vulnerable populations (elderly, children) and a substantial tourist influx, amplifies its socio-environmental responsibilities [18]. Globally, ship emissions contribute significantly to premature deaths from cardiorespiratory issues and lung cancer [29]. A study in China's Pearl River Delta highlighted the negative health impacts of marine emissions, particularly near ports, and suggested that adhering to MARPOL standards could mitigate these effects [29]. Therefore, stringent regulation and supervision of the Port of Santos are essential to protect both port workers and the surrounding community [30].

CONCLUSION

While overall air quality in Santos was generally good, $PM_{2.5}$ and PM_{10} levels frequently exceeded air quality targets, particularly during periods of high ship activity. Although no statistically significant correlation was found between PM emissions and overall respiratory events, a moderate correlation was observed between NO_2 emissions and respiratory events in the vulnerable under-19 population. Furthermore, a moderate correlation was found between monitored NO and specific respiratory illnesses like acute bronchitis and bronchiolitis. These findings highlight the complex relationship between respiratory health and air pollution in the Port of Santos region, emphasizing the need for continued monitoring, targeted interventions for vulnerable populations, and strategies to mitigate emissions from both ship and land-based sources.

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