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EXPOSURE TO PARTICLES AND ENVIRONMENTAL POLLUTANTS, THEIR EFFECTS ON HEALTH - CASE STUDY IN THE PORT OF FIGUEIRA DA FOZ

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Abstract: There is a growing concern with the evaluation of the external environment air due to the strong industrial and urban expansion. It is always desirable that the air is fresh and pleasant, that is, it does not have a negative impact on health. In the case of a port area, they are subject to various pollutants that are harmful to health, even more so if it is an international port. The main objectives were to evaluate the exposure of workers/residents in the surrounding area to outdoor air pollutants, $PM_{2,5}$, PM_{10}, CO_2 and ultrafine particles. The measurements were carried out in the port of Figueira da Foz We checked whether there was any parameter outside the normal range and which of the points stood out. In this study, UFP levels were compared with other common air quality monitoring parameters. The results indicate that UFP values are high, with point 3 being the most notable. Degraded air quality poses a significant risk to human health, especially for children and the elderly. Although the primary sources of UFP are related, other preventive measures are needed to reduce these particles.

Keywords Occupational Exposure; Respirable particles; Health; Environmental Pollutants.

Introduction

Work-related illnesses, which include work accidents, occupational illnesses, “work-related illnesses” and “illnesses aggravated by work”. It is a broad concept that encompasses all work situations that (negatively) influence the health of those who work. (Uva, 2006). The quality of the external environment is a concern that has been with man for many centuries, since the industrial revolution when “smog” occurred, the term used to define the accumulation of air pollution. It is always desirable that the air is fresh and pleasant, that is, it does not have a negative impact on health(Abreu, 2010). Over the last decade, a series of research and studies have focused on understanding the emission, formation, dispersion, exposure and effects of Ultrafine Particles (UFP). Most of these studies take place in European cities (Bruyninckx, 2021), with only a few emerging Asian cities, where the majority of the world's urban population resides. The main reason for such lack of attention/sloppiness in Asian cities is their focus on complying with strict regulations for pollutants, whose concentrations often exceed regulated limits.

Decree-Law 102/2010, of September 23, defines inhalable particles (PM_{10}) as suspended particles capable of passing through a selective air intake, as defined in the reference method for sampling and measuring particles inhalable, standard EN 12341, with a cutting efficiency of 50% for a diameter of 10 μm and respirable particles ($PM_{2,5}$) such as suspended particles capable of passing through a selective air intake, as defined in the method of reference for the sampling and measurement of respirable particles, standard EN 14907, with a cutting efficiency of 50% for a diameter of 2.5 μm (Ambiente, Qualidade do Ar Ambiente- Particulas em Suspensão) (Jones, Thornton, Mark, & Harrison, 2000).

In order to guarantee the protection of people from exposure to this pollutant, the 2014 NP 1796 standard established the exposure limit value (EV) for inhalable particles at 10,000 g/m³ and for respirable particles at 3,000 g/m³. The main health problems mentioned in the European list of occupational diseases are: acute dermatitis due to contact with toxic products, contact urticaria, irritative contact dermatitis, conjunctivitis, allergic rhinopathy, asthma, extrinsic allergic alveolitis, adenocarcinoma of the nasal cavity and paranasal sinuses and nasal sinus cancer (Amaral, 2012).

Ultrafine particles (UFP) are defined according to ISO/TC 146/SC2 as particles with a diameter less than or equal to 100 nm (0.1 μm). These particles pose a significant risk to human health when inhaled in high concentrations over time. UFP dominate particle number concentrations and surface area and are therefore capable of transporting large concentrations of condensed toxic air pollutants. It is likely that the redox-active components in UFP from fossil fuel combustion reach the cardiovascular system, leading to heart rate variability and blood pressure.l (Delfino), also having an impact on the lungs, which can lead to lung cancer and/or lung inflammation. (Ohlwein, 2019).Carbon dioxide (CO2) is a colorless and odorless gas that, in high concentrations, can be harmful to workers' health. Although CO2 is a natural component of the air we breathe, prolonged exposure to high levels can cause a range of health problems. Such as respiratory problems, exposure to high levels of CO2 can lead to breathing difficulties, feelings of shortness of breath and increased respiratory rate. At the site under study, the area covered by the installations is immense, where the entry of goods is constant, whether by boats or heavy vehicles; both coming from different parts of the country or the world. There is therefore a risk of illness or accidents given the constant entry and exit. If preventive measures are not created and followed, the number of accidents will multiply, whatever their nature. Therefore, it was essential to monitor air quality at different points, as well as implement preventive measures, in order to safeguard the health of workers. As such, the main objectives of this research work were to evaluate the exposure of workers to air pollutants ($PM_{2,5}$, PM_{10}, CO_2 and UFP) in suitable and strategically chosen locations and meteorological variables (Hr and Tº).

Materials and Methods

Study design

This study was observational level II, descriptive-correlational and cross-sectional in nature, and the measurements were carried out in the municipality of Figueira da Foz, district of Coimbra.

Population and sample

The sampling design was defined as non-probabilistic and as a convenience technique. The target population was made up of workers who travel to the port and inhabitants of the surrounding area, located in Figueira da Foz, in Coimbra. After a briefing together with some people responsible for the administration of the Port of Figueira da Foz, 4 points were chosen within the facilities, with the aim of covering as much area as possible and where there is the greatest movement of cargo and machinery.

Instruments and Data Collection

This study was carried out during the months of October to July, the years 2023 and 2024, with the data collection period taking place in the months of April and May.

Firstly, several measurement points were defined, namely: point 1, next to the containers; point 2, next to the port administration offices; point 3, next to two warehouses where there was constant external circulation of machines and heavy vehicles and the last point, point 4, located at the westernmost point of the port.

After defining the measurement points, analytical data was collected. Data collection was based on the assessment of air quality, using the assessment of atmospheric pollutants (CO_2, $PM_{2,5}$ and $_{10}$ and ultrafine particles-UFP) and the meteorological variables temperature (T) and relative humidity (Hr). (Hui Wang, 2023), (Viitanen, Uuksulainen, Koivisto, Hämeri, & Kauppinen, 2017), (Pasquiou, *et al.*, 2021), (Marval & Tronville, 2022).

Measurements at each point were carried out during the months of April and May, over a period of 30 minutes (Nota Técnica NT-SCE - 02, 2009), per point divided into two 15-minute measurements. The measuring equipment was placed next to the dock line, always preserving the port's proper functioning with maximum safety. At this stage, potential sources of contamination were also considered.

To collect data, four portable real-time reading devices were used. Regarding the parameters, CO_2, T and Hr, the Velocicalc equipment, brand TSI, was used; to evaluate PM $_{2,5}$ and PM $_{10}$, the Aerotrak Portable Particle Counter equipment, TSI brand, model 9550 was used; For ultrafine particles, the P-Track Ultrafine Particle Counter equipment, TSI brand, model 8525, which has a reagent with a 99.9% isopropyl alcohol solution.
The World Health Organization Standard, directive 2015/1480 of August 28, 2015, which amends some aspects of 2004/107/EC and 2008/50/8/EC, was considered as a reference. Decree-Law No. 243/86, of August 20, the reference comfort environmental conditions for T must range between 18 and 22˚C, while Hr must range between 50 and 70% (Decreto-Lei nº243/86 de 20 de agosto, 1986).

Statistical analysis

Statistical analysis of the data was carried out using the IBM Statistical Package for the Social Science (SPSS), version 29. When interpreting the statistical tests, a confidence level of 95% was considered for a maximum random error of up to 5%. A normality test was carried out and it was found that the data followed a normal distribution. This fact allowed the use of a linear correlation test for data analysis. Pearson correlation, also known as linear correlation, was performed in statistical tests. It is a statistical measure that quantifies the linear relationship between two continuous variables. This correlation is represented by the Pearson correlation coefficient (r) (J, 2023), whose value varies between -1 and 1. It is possible to understand through the value, predict the behavior of the variables under study. If r=1, it indicates a perfect positive linear correlation (when one variable increases, the other also increases consistently); r = -1: Indicates a perfect negative linear correlation (when one variable increases, the other decreases consistently); r = 0: Indicates that there is no noticeable linear correlation (the variables do not have a linear relationship).
Having been carried out, two more types of statistical tests, Student's T test and 1-Factor ANOVA test and the Scheffe test.
level 2

Results and Discussion

In the table under analysis, we performed correlations with the aim of evaluating the behavior between the variables (T, CO2, Hr, PM 2.5, PM10 and UFP).

Table 1. *Pearson correlations between UFP and other pollutants.*

N=1886		T	CO2	Hr	PM2,5	PM10	UFP
T	r	1	-,392**	-,780**	-,070**	,585**	,227**
	Sig.		0,000	0,000	0,002	0,000	0,000
CO2	r		1	,537**	-0,041	,184**	-,231**
	Sig.			0,000	0,077	0,000	0,000
Hr	r			1	-0,001	-,476**	-,189**
	Sig.				0,980	0,000	0,000
PM $_{2,5}$	r				1	-,077**	-,098**
	Sig.					0,001	0,000
PM $_{10}$	r					1	-,055*
	Sig.						0,016
UFP	r						1
	Sig.						

This behavior is noticeable through the value of "r". We can thus verify and divide into two distinct groups, that the coefficients of CO2 and Hr with T are negative correlations. That is, when there is an increase in temperature, there is a decrease in carbon dioxide and relative humidity or vice versa. The most significant value originating from the Hr – T correlation with a coefficient of -0.780. It can easily be related to what happens in the environment, where the negative correlation between carbon dioxide and temperature is related to the behavior of gases in natural systems. When the temperature increases, the solubility of carbon dioxide in water decreases. This is because water molecules have a greater capacity to dissolve carbon dioxide at lower temperatures.

Furthermore, biological processes, such as photosynthesis, also influence the concentration of CO2 in the atmosphere. Plants and algae absorb CO2 during photosynthesis, reducing its concentration. Therefore, when the temperature rises, the tendency is for CO2 to be released from the water and ecosystems, resulting in a negative correlation between these variables.

The opposite happens regarding the correlation between Hr – CO2 where the coefficient is 0.537, which is synonymous with a positive correlation, that is, when there is an increase in Hr there is also an increase in CO2. Where in turn can be explained through several factors. Firstly, the respiration of living organisms, including plants and animals, leads to the release of carbon dioxide.

The more organisms are present in an environment, the higher the concentration of CO2. Furthermore, the decomposition of organic matter also releases CO2 and in the case of humid environments they are generally conducive to having more decomposing organic matter, which contributes to the positive correlation.

Finally, the solubility of CO2 in water also plays a role; colder, nutrient-rich waters may contain more dissolved CO2, thus increasing the correlation with relative humidity. (Medeiros Filho), (Môsso, 2018).

Next, the correlations between PM2.5, temperature, carbon dioxide and relative humidity were verified. We can see some similarity between the coefficients, all of which are negative, synonymous with negative correlations. That is, when one increases the other decreases, however in the case of the correlation coefficient between PM 2.5 and Hr of -0.001, we can say that it is an extremely weak negative correlation, due to it being close to zero.

The correlations between PM10 with temperature and carbon dioxide are positive correlations, with coefficients of 0.585 and 0.184, respectively. Due to the existence of a positive correlation between these variables, when one increases, the other also increases.

In the case of the correlation between PM10 and Hr, we have a negative correlation with a coefficient of - 0.476. Noting that the concentration of fine particles is directly linked to air quality and human health, causing various complications/diseases.

The negative correlation between the variables (in particular, temperature, relative humidity, carbon dioxide, PM 2.5 and PM10) is relevant to understanding the health risks associated with exposure to these particles.

These correlations are relevant for environmental monitoring and the establishment of regulatory standards.

Cities and regulators must consider these relationships when setting policies to improve air quality and public health. (Montgomery, 2012), (Tabachnick, 2013).

Consequently, a correlation was verified between three variables ($PM_{2.5}$, PM_{10}, UFP) and their coefficients. In both cases, there is a negative correlation between the variables analyzed. That is, when $PM_{2.5}$ or PM_{10} increases, UFP decreases or vice versa. This behavior was already expected due to previous tables and the short life cycle of PMs. For example, through an increase in relative humidity, there is a decrease in temperature, which can lead to a change in the PM under study, that is, with an increase in H_r, there is agglomeration or precipitation of PM, which can increase the size of the PM. $PM_{2.5}$ to PM_{10} or to another size. (Hair Jr, 2014).

In the table under study, we can analyze the correlations between temperature, carbon dioxide, relative humidity, UFP.

In the case of the coefficient between T-UFP, the correlation coefficient is positive, meaning that there is an association between the variables, with a value of 0.227.

As the temperature increases, UFP levels also tend to increase, and vice versa. The closer the coefficient is to 1, the stronger this positive relationship.

A negative correlation, as is the case with the remaining correlations (CO2-UFP and Hr-UFP), when one variable increases, the other tends to decrease. With the coefficient of this relationship being -0.231 and -0.189, respectively.
As for the correlation coefficient of 0.128 (between Location-UFP), it indicates a weak positive association between UFP concentrations and the different locations where the samples were collected, with 4 different locations being analyzed within the port facilities.
When the UFP value increases, the values of the "local" variable also tend to increase, but this relationship is not significant.
The strength of the correlation is low, suggesting that other factors may be influencing these variables independently of each other.
The coefficient of 0.002 indicates an extremely weak correlation between UFP concentrations and climatic conditions (Climate).
In other words, changes in UFP concentrations are not significantly associated with climate variations.
We cannot therefore infer causality based on correlation alone. I also safeguard the possibility of external factors that also influence sampling (intense traffic, proximity to the sea, seasons).
In the table under analysis, table 2, where we have two sub-variables: "Sun" and "Cloudy", originating from the "Climate" variable. It is important to note that the "Climate" variable is a variable that we were unable to control, hence the discrepancy in the sample values (N=18) and (N=1868), respectively. Still on this variable, "Climate", it was composed of more sub-variables that were not relevant to the study in question, as they had an N=0.

Table 2. *Particle Levels in relation to Climate.*

	Sun (N=18)	Cloudy (N=1868)	Diferença média	p-value
	M± Dp	M± Dp		
$PM_{2,5}$	1149244,61±431063,557	5260033,51±7545133,669	-4110788,894	0,021
PM10	739658,83±936354,942	1013636,5±1197151,325	-273977,668	0,333
UFP	10163,33±552,183	10518,52±22800,361	-355,189	0,947

Subtitle: M- Media; Dp- Standard Deviation; Test: T Student

Standard Deviation (Dp) is a statistical measure that expresses the degree of dispersion of a set of data. When the standard deviation is small, the values are closer to the mean. On the other hand, a larger standard deviation indicates greater variability in the data.(Triola., 2017). Therefore, in general, we expect the standard deviation to be close to the mean value of the results, but this may vary depending on the distribution of the data. Both in the context of PM2.5, PM10 and UFP, the average values are quite far from the standard deviation.
As for the mean difference, it refers to the difference between the means of two populations or groups. A positive mean difference indicates that the first group's mean is greater, while a negative mean difference suggests that the second group's mean is greater. Noting that, also in the three pollutants under analysis, the values are always negative, indicating that the average value of the "Cloudy" variable is higher in relation to "Sun".
The p-value (or p-value) is a number calculated from a statistical test that describes the probability of having obtained a specific set of observations if the null hypothesis were true. In other words, it indicates how likely it is that the data occurred under the null hypothesis. The lower the p-value, the more likely it is that the null hypothesis will be rejected. In this case, the p-value for $PM_{2.5}$ was 0.021, which indicates that there is statistical evidence to reject the null hypothesis, that is, there is no significant difference in the $PM_{2.5}$ means between the groups, suggesting a variance in the values between the conditions studied. As for PM_{10}, a p-value of 0.333 was obtained, indicating that there are no significant differences, the same happened with UFP, expressed through a

p-value of 0.947. This discrepancy in the results obtained may be due to large differences between the observed values (for example, extremely sunny days and others that are very cloudy). It is also important to highlight that the study was carried out in spring, in a location located on the riverbank, which greatly influences natural climate variability. It can be concluded that there was no significant difference between the parameters evaluated during the study.

Now carrying out a more detailed analysis regarding the locations, in table 3, it is possible to observe the Average, Maximum and Minimum values, and the Standard Deviations.

The locations chosen for the study were: point 1, next to the containers; point 2, next to the port administration offices; point 3, next to the warehouses; and point 4, located at the westernmost point of the study site.

Table 3. *Pollutant levels compared to the locations under study.*

		Média	Standard Deviation	Standard Error	Minimum	Max
PM 2,5	Containers(1) N=483	3359053,23	744249,272	33864,514	1195384	4209430
	Offices(2) N=464	1859334,95	877201,190	40723,043	633595	2896460
	Warehouses(3) N=474	13764472,98	11166351,856	512887,527	933175	26899999
	Westernmost point(4) N=465	1799816,50	263457,103	12217,531	860135	2109924
PM 10	Containers(1) N=483	2627825,01	1166524,914	53078,721	1192000	4056603
	Offices(2) N=464	796182,86	692540,327	32150,378	70999	1571346
	Warehouses(3) N=474	465696,41	98738,054	4535,189	176986	741926
	Westernmost point(4) N=465	101889,07	15499,887	718,790	29000	120063
UFP	Containers(1) N=483	10277,67	21220,581	965,570	487	128000
	Offices(2) N=464	2980,06	1566,491	72,723	193	10400
	Warehouses(3) N=474	13061,05	25723,29	1181,51	8,00	128000,00
	Westernmost point(4) N=465	15685,46	29270,56	1357,39	8,00	120000,00

Test: ANova 1 Fator

In a first analysis, PM2.5, it was possible to observe that the location with the highest Average and Maximum values were “Warehouses” (point 3). Place between bulk loads and solid loads, with constant movement of vehicles and machines. As for PM_{10}, we found, as before, that the place with the highest Average value is also the place with the highest Maximum value, this being “Containers” (point 1). Regarding the UFP, the place with the highest Average value is “Point + West” (point 4), as for the highest Maximum value, the same was observed in point 3, “Warehouses”. As for the p-values obtained, we can state that there is a significant difference between the different pollutants in relation to the different points, since p-value ≤ 0.05, therefore, it is possible to reject the null hypothesis. (Annex II). A Scheffe test was also carried out taking into account $PM_{2.5}$, where it was possible to observe that the average values of the “Containers” are significantly higher than those of the “Offices” and the “Westernmost point” location (p-value < 0.001 in both cases). Furthermore, “Containers” have significantly lower mean values than “Warehouses” (p-value < 0.001). “Offices” have significantly lower mean values than “Warehouses” (p-value < 0.001). However, “Offices” have significantly higher mean values than “Westernmost point” (p-value = 0.999). “Warehouses” have mean values significantly higher than “Westernmost point” (p-value < 0.001).

The same test was also carried out for PM_{10}, where it was found that the average values of “Containers” are significantly higher than those of “Offices”, “Westernmost point” and “Warehouses” (p-value < 0.001 in both cases). “Offices” presented mean values significantly higher than those of “Warehouses” and “Westernmost point” (p-value < 0.001). However, “Offices” have significantly lower mean values than “Westernmost point” (p-value < 0.001). “Warehouses” have significantly higher mean values than “Westernmost point” (p-value < 0.001). The results suggest that “Containers” have superior performance compared to other locations. (Annex III)

It was also carried out in relation to UFP, where the average values of “Containers” are significantly higher than those of “Offices” (p-value < 0.001). Furthermore, “Containers” have significantly lower mean values than “Warehouses” (p-value = 0.289) and the “Westernmost point” region (p-value = 0.003). “Offices” present mean values significantly lower than those of “Warehouses” (p-value < 0.001) and “Westernmost point” (p-value < 0.001). (Annex IV).

Some of the results were expected, since, during the measurements carried out, there was movement of machines, heavy vehicles and also the presence of boats in operation, “connected”. It was noticeable, at the site under study, that there were different types of loads, the most relevant in this case being bulk loads. This type of load, being products moved without individual packaging and, especially in granulated form, gives rise to the deposition of dust in various places, particularly on the floor.

Due to these external factors present at the site, together with atmospheric factors (winds), dust is raised, thus spreading throughout the surrounding area. This causes atmospheric contamination, aggravated on hotter days, dry days, as previously noted, an increase in T leads to a decrease in Hr.

The only preventive measure observed, in order to mitigate these effects, was a “broom cart” that cleaned and washed the pavement, whenever necessary. The same happens on rainy or very humid days where the floor is naturally washed. Rain acts as a cleaning agent, removing dust from the surface. This process is widely observed in nature and in urban environments. This washing after rain has both beneficial and challenging implications for the study of air quality. Rain washes away dust particles and pollutants present on the surface of the pavement, helping to clean the environment. After rain, air quality may temporarily improve, especially where there is a large accumulation of dust, as in the case under study. Rainwater can react with pollutants deposited on the ground, releasing them back into the air. This can occur with substances such as nitrogen oxides, giving rise to acid rain. (Mirlean, 2000). To assess the impact of natural ground washing on air quality, it is important to take measurements before, during and after rain. In short, the natural washing of the ground by rain is a complex process, with positive and negative effects on air quality.

Conclusions

Air quality is everyone's right, and because emission mitigation solutions exist and are effective, energetic action towards cleaner air, with everyone's participation, is essential (Lopes).

Through the results obtained in this study based on comparisons of UFP and other commonly monitored parameters, it can be concluded that it is necessary to take measures to improve air quality. The UFP values are high, with sampling point 3 being the most significant, and also the most expected due to the type of activity carried out. It was also possible to conclude that there is a relationship between different parameters that causes an increase or decrease, making it possible to understand this behavior, as well as the importance of various external factors. It is important to note that although the primary sources of UFP are related, they are not the only source of the problem. The degradation of air quality represents an important threat to human health, having been associated with the worsening of respiratory, cardiovascular and neurological diseases, especially in children and the elderly. Studies also indicate a correlation between exposure to some pollutants and the occurrence of different types of cancer. (Santana, 2012). In particular, due to its small size and ability to enter the bloodstream and lungs, it poses a high risk to human health. Therefore, the main objective is to develop activities within the scope of continuous improvement: improvement in safety to perform tasks and work activities, improvement in facilities and jobs and improvement through the promotion of health in the workplace. (Moreira, 2024; Pinto, 2012). Even if it is a challenge in relation to UFP, it should be reduced, since the most common preventive measures are not effective. During the study, some limitations were found, such as the lack of specific legislation regarding reference values regarding the concentrations of atmospheric pollutants in outdoor air, as well as for ultrafine particles. As well as the short sampling time, this topic is extremely important, and the continuous monitoring of the parameters studied is extremely important. It is also important to create specific legislation, thus parameterizing limit values and making this type of studies constant.

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