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The role of urban forest to support the air quality assessment: biological monitoring of Porto de Santos activities in Guarujá, Baixada Santista – SP, Brazil[1]

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Sessão Temática 04: Convergências entre Urbanização e Natureza

Abstract. Particulate Matter (PM) plays among the main air contaminants and Green Infrastructure has been recognized as an alternative to improve air quality. Trees can directly reduce the PM levels by trapping it on their surface. This study aimed to provide data on the role of urban forest to trap air contaminants and also identifying their main sources in urban areas. The biological monitoring method was used to measure heavy metal concentrations in samples of plants hung on tree branches in three urban forests, with diferent vehicular fleet and human activities. The City of Guarujá, an important coastal tourist city, and where is located the Porto de Santos, was chosen to be the sudy area. Urban fragments in the port regiont of the city showed higher Cd, indicated its source is heavy-duty fleet. Cu showed the highest values during the wet (holiday) season in all study areas, strongly marking the intensity of the light vehicular fleet. Forest fragments were efficient to reduce air pollutants, highlighting their importance as equipment for environmental planning. These results will serve as a tool for the strengthening of policies in a city with wide socio-environmental inequality and economic importance due to the ports and tourism activities.

Keywords: Atmospheric Pollution; Biological Monitoring, Heavy Metals; Urban Forests; Environmental Public Policies.

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O papel da floresta urbana em apoio à avaliação da qualidade do ar: monitoramento biológico das atividades do Porto de Santos em Guarujá, Baixada Santista – SP, Brasil.

Resumo. O Material Particulado (MP) figura entre os principais contaminantes do ar e a Infraestrutura Verde tem sido reconhecida como alternativa para melhorar a qualidade do ar. As árvores podem reduzir os níveis de MP, prendendo-os em sua superfície. Este estudo teve como objetivo fornecer dados sobre o papel da floresta urbana na retenção de contaminantes aéreos e identificar suas principais fontes em áreas urbanas. O monitoramento biológico foi utilizado para medir as concentrações de metais em amostras de plantas penduradas em galhos de árvores em florestas urbanas, com diferentes frotas veiculares e atividades humanas. Guarujá, importante cidade turística litorânea, e onde está localizado o Porto de Santos, foi escolhida para área de estudo. Os fragmentos urbanos da região portuária da cidade apresentaram maior concentração de Cd, indicando que sua origem é a frota pesada. O Cu apresentou os maiores valores durante a estação chuvosa (férias) em todas as áreas de estudo, marcando fortemente a intensidade da frota de veículos leves. Os fragmentos florestais foram eficientes na redução de poluentes, destacando sua importância para o planejamento ambiental. Esses resultados servirão de ferramenta ao fortalecimento de políticas cidades com ampla desigualdade socioambiental e importância econômica devido aos portos e atividades turísticas.*Palavras chave:*

Poluição Atmosférica; Monitoramento Biológico, Metais Pesados; Florestas Urbanas; Políticas Públicas Ambientais.

El papel del bosque urbano para apoyar la evaluación de la calidad del aire: monitoreo biológico de las actividades de Porto de Santos en Guarujá, Baixada Santista – SP, Brasil

Resumen. *El material particulado (MP) se encuentra entre los principales contaminantes del aire y la Infraestructura Verde ha sido reconocida como una alternativa para mejorar la calidad del aire. Los árboles pueden reducir directamente los niveles de PM atrapándolos en su superficie. Este estudio tuvo como objetivo proporcionar datos sobre el papel de los bosques urbanos para atrapar contaminantes del aire y también identificar sus principales fuentes en áreas urbanas. Se utilizó el método de monitoreo biológico para medir concentraciones de metales pesados en muestras de plantas colgadas de ramas de árboles en tres bosques urbanos, con diferente flota vehicular y actividad humana. La Ciudad de Guarujá, importante ciudad turística costera, y donde se encuentra el Porto de Santos, fue escogida para ser el área de estudio. Los fragmentos urbanos en la región portuaria de la ciudad presentaron mayor Cd, lo que indica que su origen es la flota de servicio pesado. Cu mostró los valores más altos durante la temporada húmeda (vacaciones) en todas las áreas de estudio, marcando fuertemente la intensidad de la flota vehicular ligera. Los fragmentos de bosque fueron eficientes para reducir los contaminantes del aire, destacando su importancia como equipamiento para la planificación ambiental. Estos resultados servirán como herramienta para el fortalecimiento de políticas en una ciudad con amplia desigualdad socioambiental e importancia económica por la actividad portuaria y turística.*

Palabras clave: Contaminación atmosférica; Monitoreo Biológico, Metales Pesados; Bosques Urbanos; Políticas Públicas Ambientales.

1. Introduction

The growth of cities is a current reality and has taken place more intensely in developing countries (GRIGGS et al., 2013; GÜNERALP et al., 2017; THEOPHILO et al., 2021, RAMON et al., 2022). Rapid urban expansion involves not only population growth but also changes in the economic, socio-political and infrastructure realms of communities.

Since the phenomenon of urbanization generally occurs in an unplanned manner, it is characterized by inefficient resource utilization; i.e. pressure on a city's ability to provide basic services such as energy, education, healthcare, transportation, sanitation and security (BHATTA, 2010).

Moreover, urbanization favors the use of motorized vehicles, which contributes to release a load of chemical substances in the air, soil and water and it also changes the landscape. For instance, large buildings and other infrastructures are preferred than open land and vegetation. As a result, green spaces are reduced in number and the soil becomes impermeable, dry, and prone to urban heat island effects (FRUMKIN, 2002; VIEIRA, et al., 2018; MARTINS et al., 2021).

In the case of coastal area, especially for the port cities, the chalenges regarding environmental polluition are even more complex, since they present a huge heavy-duty vehicle fleet that transports commodities and also emits high levels of air contaminants in streets adjacent to ports as a result of the emissions from, mainly, the trucks and ships bringing cargo in and out of the port area (THEOPHILO et al., 2021).

This scenario is typical in the coastal city of Guaruja, which belongs to Baixada Santista and is near to the megacity São Paulo-SP. In addition to its paradisiac beaches, which result in a demographic explosion by tourists, the city also presents an intense port activity throughout the year. As a result of this combination, Guaruja has been experienced several adverse effects related to the traffic, such as the enrichment of air contaminants, emitted by the vehicle fleet (THEOPHILO et al, 2021).

Among the toxic substances from vehicle sources are carbon monoxide (CO), sulfur (SOx) and nitrogen oxides (NOx) and particulate matter (PM). This latter is rich in heavy metals, such as cadmium (Cd), copper (Cu), zinc (Zn) and others. Since PM is easily inhaled, it can cause a variety of public health problems (RODRIGUEZ et al, 2010; FERREIRA et al., 2017; BULBOVAS et al., 2020).

Although the Environmental Company of the State of São Paulo (CESTEB) inspects air quality, following the guidelines of State Decree nº 59.113/2013, through the parameters and measurement techniques, the monitoring in Guarujá is recent. The control has started in 2016, and has included only a collection station, for PM measurement (CETESB 2018).

As an alternative to conventional air quality monitoring network, scientific studies have been highlighting that nature itself can contribute to the diagnosis and reduction of atmospheric pollution (RAMON et al., 2022; KELLY et al., 2022; MARTINS et al., 2021). The expansion of urban green areas and the protection of natural ecosystems can also efficiently improve ecosystem services, especially for the poorest population (RIBEIRO et al., 2021).

Nowak et al. (2018) used a computacional approach to evaluate the benefits of treescape to improve environmental quality in 86 Canadian cities For the authors, the green infrastructure was capable to remove atmospheric pollutants, attenuating more than 16,000 tons of air contaminants and preventing about 30 deaths, 22,000 incidences of respiratory diseases and saving nearly 230 million Canadians dollars in health care.

Ferreira et al. (2021) also indicated that urban forests play an important role to mitigate air pollution, since they provide multiple benefits, such as biogeochemical control and biodiversity maintenance. Therefore, the development of researches focus on the understanding the efficiency of the urban forest regarding to minimize adverse effects of environmental pollution are very usefful for the stakeholders to to propose and implement public policies for the requalification of urban space, as well as for a better quality of life.

Accordingly, this study aimed to evaluat the spatial and temporal concentration of Cd and Cu in Guarujá, based on information obtained by a biological monitoring of the atmospheric pollution and the role of fragments of Mata Atlântica to trap these heavy metals, which are from the vehicle fleet of the coastal city. The information gathered from the research may promote an agreement with the administration of the Port to support some green projects in the greyest and most socioeconomically vulnerable area of the city.

2. Research Design

2.1 Study Area

Guarujá – SP is part of the Metropolitan Region of Baixada Santista; with an estimated population of 1.7 million people. On the national scene, the city is certainly recognized for its tourist vocation, due to its natural beauties embedded in an island (with the shape of a dragon), with an area of 143 km² in extension, which houses 25 paradisiacal beaches. In addition, other cities at Baixada have high tourist potential; therefore, the region, during the summer seasons, which comprise the months of November to March, especially at the end of the year and Carnival, can have an increase of up to 50% over its total population. This number becomes more worrying for the port cities, since there is a substantial increase in the vehicle fleet which, added to the already usual one that accesses the Port, means that, in the case of the Municipality of Guarujá, some premises of the Master Plan are neglected (LIMA et al., 2022).

In terms of weather conditions, the City of Guaruja, the dry season normally is between April and September, while the rainy season happens between October and March. Accordingly, the driest months of the city (June and July) are also the coldest ones and have rainfall values below 100 mm per month, with average air temperature around 18 ^{o}C. The warmer and rainest months are December, January and February (30 ^{o}C and ~300 mm and respectively). This period coincides with a demographic explosion in the city, by tourists who seek the beautiful beaches of the region for the summer holiday season, which also brings an intense increase in cars and vans (ESTANCIA DE GUARUJA, 2022).

Although the atractive touristic beaches, 70% of the city's native population lives in precarious areas in the outskirts of the city. It is estimated that around 150,000 are directly affected by emissions from freight transport accessing the Port, whose left bank is entirely located at Vicente de Carvalho District, a neighborhood of Guaruja where there is a predominance of residences and commercial activities (LIMA et al., 2022).

2.2 Biological Monitoring Stations

Tillandisia usneoides L were acquired from a producer located in the Cordeiropolis - SP, a city where anthropic pollution is no significant. The same producer has provided bromeliads used in other biomonitoring studies (GIAMPAOLI et al., 2016, 2021; THEOPHILO et al., 2021).

The samples of bioindicator were exposed in three sites with distinct vehicle fleet profiles and different urban characteristics. One of them was next to the Vicente de Carvalho district - as beforementioned- where there is a predominance of the heavy vehicular fleet, that discharge commodities at the Port de Santos. The Piaçaguera Forest Fragment (PIA) is characterized as the poorest and greyest residential area of the city.

The seconde exposition site was in a Urban Forest Fragment (UF) located in the central region of the city, which offers a wide range of products and services, characterized by light vehicular fleet traffic, predominated by cars and vans. The

third place for sampling exposure was a protected area (PAR) of biodiversity named Serra do Guararu Conservation Unit in Brazil (control area), with little local traffic and a marked seasonal flow of people, predominated by high-income tourists (Figure 1).

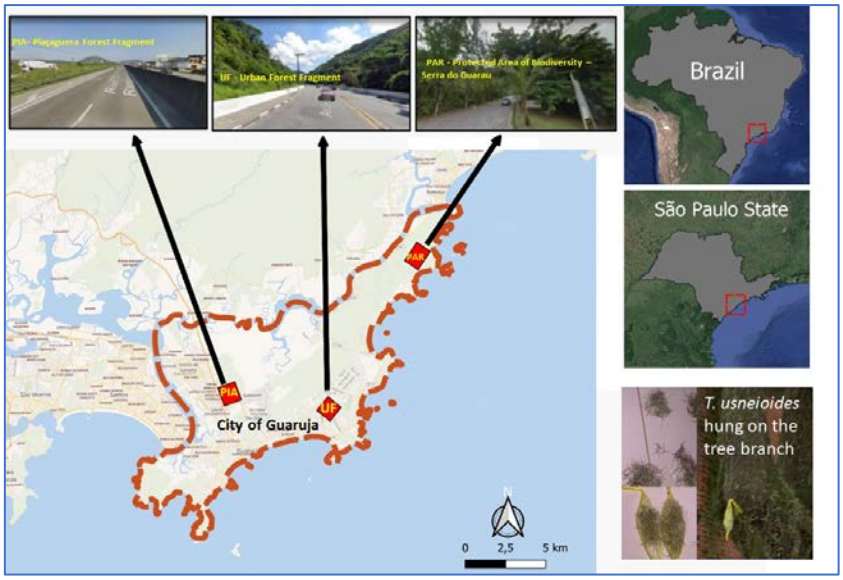

Figure 1. Study area and sampling sites (Source: Authors).

Around 15 grams of T. *usneioides* was hung on a tree branch within the sampling sites. Plants were arranged in six rows, with five replicas in each row. The rows were - here - labelled as L1 that indicated the samples were exposed on trees located at the boundary between the green area and the roadway; L2 was placed far 10 meters from L1 - and so on - up to L6. The exposure of plants in the PAR was the only one that did not have a border with streets or avenues.

Firstly, the plants were exposed between June and September 2019 (dry season); thereafter, between January and March 2020 (rainy season). Although the exposure of plants for 60 consecutive days is the most usual (Cardoso-Gustavson et al., 2016), we adopted 75 days, so that the retention time of atmospheric pollutants did not exceed the capacity of the plant to adsorb air contaminants (MARTÍNEZ-RESÉNDIZ et al. 2015; GIAMPAOLI et al., 2021).

2.3 Chemical Analysis

The collected samples were stored in cellulose fiber packaging (cardboard) and transported to the Chemistry laboratory at UNINOVE, until preparation for quantification of the pollutants. In the next step, the samples were dried (until constant weight) in an oven with air circulation at 40°C, to prevent the loss of volatile elements. After this procedure, the samples were lyophilized without prior washing and ground in a vibrating mill until obtaining a fine and homogeneous powder.

0.6 g aliquots of Peach leaves bioindicators and reference materials, (SRM 1547) were accurately weighed into 15 mL centrifuge tubes, then transferred to teflon tubes and a mixture of nitric acid solution was added and hydrogen peroxide (10 mL de HNO_3 e 2 mL de H_2O_2). The samples were submitted to digestion in a digester block, according to protocol 3050 (USEPA, 1986). The clear and

homogeneous solutions were analyzed using the Atomic Absorption Spectrometry (AAS) technique, on the Perkin-Elmer AAnalyst 800 equipment, belonging to the Neutron Activation Laboratory, Research Reactor Center, Institute for Energy Research and Nuclear (LAN/CRPq/IPEN). The detection and quantification limits of the analyzed elements are presented in Table 1.

In this work, the data obtained for the heavy metals Cd, Cu; the choice of these elements is due to the fact that they are recognized tracers of vehicular pollution (FIGUEIREDO and RIBEIRO, 2015; CARDOSO-GUSTAVSON et al., 2016; THEOPHILO et al., 2021).

Table 1. Limits of detection (LD) and quantification (LQ). (Source: Authors).

	LD	LQ
Heavy Metal	(µg/kg)	(µg/kg)
Cd	5.0	16.0
Cu	55.6	177.3

2.4 Statistical Treatment

For testing the effect of the characteristics of the samplig site (PIA, UF, PAR), the distance of the bioindicator exposuring from the road (L1-L6) and seasonality (dry and rainy periods) on the variability of the Cd and Cu concentrations, a multivariate analysis of variance (MANOVA) was carried out. Since the normality of the data set was not observerd, multivariate outliers (Mahalanobis distance) and non-parametric MANOVA (multivariate Kruskal-Wallis) were also applied.

3. Results and Discussion

The air pollutant contents varied depending on the season and place of exposuring. With regard the position of the plants in lines, T *usneoides* L. exposed in PIA presente higher values of Cd than in the other sampling sites. The highest Cu concetration was observed at PAR during the rainy season and the lowest was in PIA. Notwithstanding, the metal presented a strong effect of seasonality, with lower values recorded in the dry season (Figure 2).

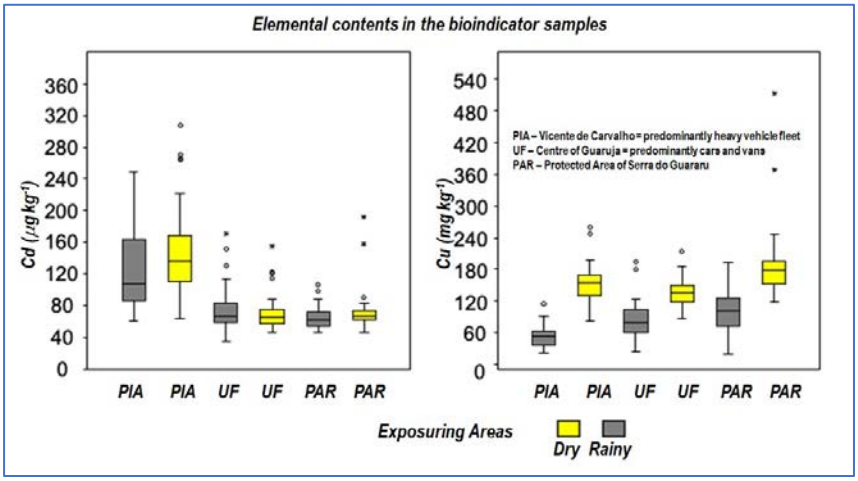

Figure 2. Cd and Cu measured in the bioindicator samples collected from different exposuring sites (Source: Authors).

The rainy season displayed slightly higher values than the dry season at each exposure site. According to Figure 3, Cd presented an attenuating effect of the vegetation along the exposure lines, especially at PIA and UF. The attenuation of Cu concentration related with the distance from the road (L1-L6) was not observed, which suggests that the distance from the main source of the element, the concentration of Cu did not change (Figure 3).

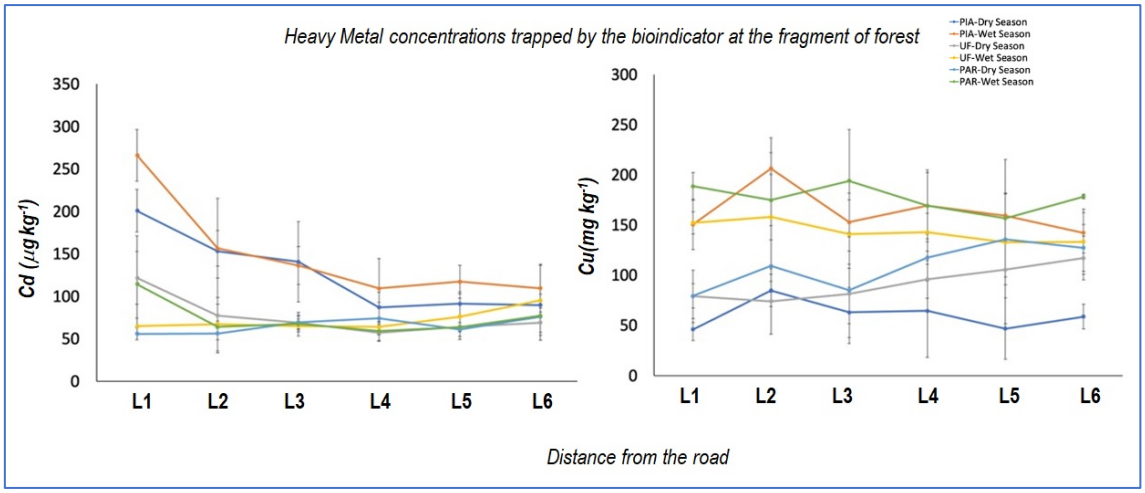

Figure 3. Cd and Cu observed in the samples regarding the distance from the road (Source: Authors).

With regard the Kruskal-Wallis multivariate analysis, the results indicated hat both location and season were important to differentiate the concentration of air contaminants in the T *usneoides* L. Copper presented a seasonal effect; however, the metal did not differ along the exposure lines at each site. The geolocalization of the fragment of the was important to favor the input of the metals in the bioindicator samples. The distance of plants from the main source of vehicle emissions (streets and avenues) revealed, in the multivariate analysis, that Cu was not significantly trapped (Table 2).

Table 2: Non-parametric MANOVA and significance value* to assess the effect of seasonality and the study area on the variation of the air pollutant concentrations (Source: Authors).

	Test	*Cd ($\mu g\ kg^{-1}$)*	*Cu ($mg\ kg^{-1}$)*
Seasonality	Kruskal-Wallis H	0.902	92.378
	Probability (*p*)	0.342	<0.0001*
Study Area	Kruskal-Wallis H	80.703	14.517
	Probability (*p*)	<0.0001*	<0.0001*
Distance from the road	Kruskal-Wallis H	12.296	2.338
	Probability (*p*)	0.031*	0.801

The heavy metal concentration observed along the different samplig sites, in both seasons, falls within the values found by other air quality biomonitoring studies with Tillandsia usneoides L. (NOGUEIRA, 2006; VIANNA et al., 2011; CARDOSO-GUSTAVSON et al., 2016).

The metal Cu is considered one of the best tracers for the gasoline fleet (VIANNA et al., 2011; CARDOSO-GUSTAVSON et al., 2016). However, the three study areas presented relevant numbers of light vehicle, that runs on gasoline; then, it was not observed significative differences in Cu contents, which could be strongly related to the sampling sites. Therefore, in the case of the Guaruja; this metal could not be considered the best tracer to atmospheric pollution. In contrast, Cu was the best tracer to the seasonal enrichment of air pollutants. This makes sense, considering that the city is a summer tourist place.

Concerning Cd, the results indicated a significant variation of its contents when compared among the sampling sites, with the median highest values at PIA (season: dry = 105.25 $\mu g\ kg^{-1}$ and rainy = 135.48 $\mu g\ kg^{-1}$). The avenue that borders the PIA also borders the residential area of Vicente de Carvalho district. Even worse, trucks enter, transit and park on the streets of this district waiting for the moment to unload commodities, emitting tons of atmospheric contaminants, annually. Moreover, since Cd is the best marker for diesel (COUFALÍK et al., 2019), the highest levels of the metal at PIA also agreed with Theophilo et al. (2021), but in the case of that study, the authors verified the levels varying from 44 up to 3,000 $\mu g\ kg^{-1}$. The critical sites corresponded to Idalino Pines Street, which is the only street access to the cargo Port terminal.

A previous study that also supports our findings is by Nogueira (2006), who analyzed the spatial distribution of Cd in the São Paulo Metropolitan Region. The regions that presented the highest metal contents (around 2400 $\mu g\ kg^{-1}$) comprised Santo Andre and Mauá. Both cities are surrounded by the Mário Covas and Anchieta Highways, which are a complex infrastructure with several huge roads to improve the traffic of trucks coming from the interior of the country towards the Port of Santos.

The median values of atmospheric pollutants at the UF were intermediate when compared to the two other sites of PIA. Although the medians of Cd at the UF were almost half of those found at PIA, both for the dry and rainy seasons (67.29 $\mu g\ kg^{-1}$ and 63.89 $\mu g\ kg^{-1}$, respectively), the values were still high. Likewise, the high values at the UF may be due to the bus fleet that transits the city, since the centre is the main location for shopping and services. Therefore, this chronic situation of emission of atmospheric contaminants - in significant areas of Guaruja - represents a risk to public health, especially to the most vulnerable people, such as children, the elderly and people with respiratory comorbidities (MURRAY et al., 2020). This can threaten the financial and health management of the City Hall when considering the costs associated with this public health framework.

Considering the high emission of atmospheric pollutants by the heavy fleet, combined with the high population density at Vicente de Carvalho District in conditions of precarious urban infrastructure, the expansion of qualified green spaces would mean an attribute of health promotion in the port region, especially due to the remarkable attenuation effect of atmospheric contaminants by vegetation in the study area (Figure 3) and also reported by several authors (LAI et al., 2019; MARTINS et al., 2021; RAMON et al., 2022).

The observed values of Cu evidenced a strong effect of the season on the concentration found in the plants. In the UF, for example, the values of Cu in the rainy season were 38% than in the dry season. This variation suggests a notable contribution from the light vehicular fleet of tourists who visit cities in January and February. Copper is a trace pollutant of light vehicles and has been widely

employed in studies that evaluate the impact of the vehicle fleet on air quality (CHAPARRO et al., 2013; ZHENG et al., 2021, MARTINS et al., 2021).

In addition, the bioindicators exposed in the PAR, the supposedly less affected area by air pollutants, were the ones that presented the highest medians in the study for Cu, both in the dry and rainy seasons (88.01 mg kg^{-1} and 141.5 mg kg^{-1}, respectively). This can be partially explained by the vehicle emissions and also by singular biomonitor attributes. Copper is an essential micronutrient for the plant and the values found during the dry season may be in the range of the plant's physiological needs (SALISBURY and ROSS, 1992; WANNAZ et al., 2006).

4. Final Remarks

From the quantification of airborne contaminants, as well as the statistical treatment of the data, it was possible to carry out an analysis on the inputs of Cd and Cu in the area of Vicente de Carvalho (PIA), which houses - in its entirety - the left bank of the Port of Santos, the centre of Guarujá (UF) and the Protected Area (PAR) of Serra do Guararu.

Based on the results, the highest levels of Cd were observed in PIA, where there is the greatest influence of diesel-powered vehicles - essentially trucks - which access the Porto de Santos throughout the year. For this reason, no significant differences were observed in Cd concentrations between the dry and rainy seasons.

In contrast, not the exposed sites, but the season was the most relevant parameter to be considered for the air input of Cu, since the metal is one of the best tracers of gasoline, it is commonly used to evaluate the adverse effects of the emissions of the light vehicle fleet. During the rainy season, which coincides with the summer holidays, when the city of Guaruja receives a sevenfold number of tourists greater than its local population.

The conclusions gathered by this research and others from previous works (THEOPHILO et al., 2021, LIMA et al., 2022) have been contributing to the Secretariat for the Environment of Guarujá (SEMAM) knows of the complexity of urban environmental problems. The results have provided inputs for SEMAM to formulate public policies whose goal is to achieve socio-environmental conditions fairer and more balanced. That is, the quantitative data, together with the perception of the actors involved, such as the residents of the region, play the role of instruments to support the management and formulation of environmental public policies.

For instance, with the research carried out by Theophilo et al., (2021), Ferreira et al. (2022), which has not yet published, and the partial results have presented herebefore, the Public Council of the Municipal Environment Secretariat (CONDEMA) was able to interfere with a petition to the public prosecution. Accordingly, the legislative body decided not to take the case to court, thus speeding up the proposal of afforestation in the district. This framework of environmental governance has gained strength in the city of Guaruja and may represent the transition from a barrier to sustainable development to a new force that emerges in facing the environmental challenges of the city (Guaruja, 2022).

SEMAM has been planting trees throughout the City, in view of their importance for biodiversity, oxygen production and mitigation of the effects of atmospheric pollution, since 2019. Moreover, meetings are held with representatives of port companies, so that the sector is charged with social, environmental and economic responsibility. From this perspective, the scenarios for the creation of environmental public policies in Guarujá and the legitimation of the corresponding legislation must be constituted by conjunctural aspects between the Public Power and private actions. In the case of this study, it is expected that the Porto de Santos becomes voluntarily, a partnership with SEMAM, for example, the execution of projects aimed at revitalizing public roads, which portray the municipal or even state political order, which constitutes an important object of reflection, since atmospheric pollution caused by vehicle emissions is a challenge not only for Brazil, but for all countries around the world.

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