(04-025) - Influence of natural and anthropogenic factors on air pollution by microplastic-like particles in Cochabamba

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Cochabamba is one of the cities with the worst air quality in Latin America. Suspended particulate matter is one of the main pollutants. This is associated with various characteristics present in the city, with the primary cause of pollution being automotive transport. Recently, the presence of microplastic-like particles (MP-like) in the air of Cochabamba was demonstrated. This contaminant is of interest due to its possible impact on people and ecosystems. Particles with an aerodynamic diameter of less than 2.5 micrometers in the air are important due to their ability to penetrate the respiratory system, longer suspension time, and transportation over long distances. This study determined the influence of different natural and anthropogenic factors on MP-like concentrations in the city's air. Statistical and correlation tools were employed, using MP-like monitoring data from various points in the city. The results show that most of the factors have a significant effect or trends on MP-like concentrations. However, the factor with the greatest influence on air MP-like concentrations is automotive transport, indicating that areas with high vehicular traffic have higher MP-like concentrations.

Keywords: Microplastic-like particles; Air quality; Automotive transport

Influencia de factores naturales y antropogénicos en la contaminación del aire por partículas microplastic-like en Cochabamba

Cochabamba es una de las ciudades con peor calidad del aire en Latinoamérica. El material particulado suspendido es uno de los principales contaminantes. Esto está asociado a diferentes características que se tienen en la ciudad, siendo la principal causa de contaminación el transporte automotriz. Recientemente, se demostró la presencia de partículas microplastic-like (MP-like) en el aire de Cochabamba. Este contaminante es de interés por su posible impacto sobre las personas y ecosistemas. Las partículas con un diámetro aerodinámico menor a 2.5 micrómetros en el aire son de importancia por su capacidad de penetración en el sistema respiratorio, mayor tiempo de suspensión y por transportarse largas distancias. Este estudio determinó la influencia de diferentes factores naturales y antropogénicos sobre las concentraciones de MP-like en el aire de la ciudad. Se emplearon herramientas estadísticas y de correlación con datos de monitoreo de MP-like realizados en diferentes puntos de la ciudad. Los resultados muestran que la mayoría de los factores tienen un efecto significativo, o tendencias, sobre las concentraciones de MP-like. Sin embargo, el factor que tiene mayor influencia sobre las concentraciones de MP-like en el aire es el transporte automotriz, mostrando que zonas con alto tráfico vehicular tienen mayores concentraciones de MP-like.

Palabras clave: Partículas microplastic-like; Calidad del aire; Transporte automotriz

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Agradecimientos: Agradecemos al Proyecto CReA y el VLIR-UOS por apoyar al trabajo del proyecto "Microplastics everywhere!".

1. Introduction

Air pollution is one of the current problems that society faces exposing most of the global population to levels above the World Health Organization (WHO) air quality guidelines (Belmonte et al., 2024).

This problematic is more concerning in regions like Bolivia, where the air quality is very poor, exceeding WHO air quality guidelines for particulate matter by almost three times and surpassing local normative standards (Gobierno Autónomo Departamental de Cochabamba, n.d.; WHO, 2021).

Moreover, it was found that microplastics (MPs) particles are present in the air, indeed, Cochabamba is the first city in Bolivia where it was evidenced MPs in a size below 10 µm are suspended (Oporto et al., 2023). The exposition of the population to MPs generates a risk for public health.

Inhalation of MPs is the principal mechanism of human exposure to MPs, leading to inflammation and oxidative effects. It was found that MPs in the respiratory system could lead to different effects in the health of humans and other organisms (Firouzsalari et al., 2024; Huang et al., 2024; S. Liu et al., 2024).

Smaller particles under 2.5 µm stay suspended longer times in the air and are transported on longer distances. These particles can penetrate the inner parts of the respiratory system (Oporto et al., 2021). So, this fraction requires more attention from researchers because it can generate more impact on human health depending on the exposition.

However, various factors can determine the air MPs concentrations, like vehicular traffic or rainy seasons (Sun et al., 2022; Syafei et al., 2019). Oporto et al (2023) shown that in Cochabamba city the air MPs concentrations vary depending on the city area, being the north zone with more vehicular traffic and different activities the most contaminated with respect to a suburban-agricultural zone in the south.

In Cochabamba the main air emissions come from road vehicles (Aguilar & Fernandez, 2023). Meteorological phenomena and geography influence the air quality of the city (Montenegro & Lujan, 2017), but the effects of these natural and anthropogenic factors on air MPs concentrations have not been studied yet.

MPs can come from different sources and their prevalence and therefore their concentration in the air can be influenced by different factors, natural or anthropogenic. Knowing the influence of different factors on the MPs air concentration can help to establish regulations to prevent air MPs pollution or to reduce the level of this pollutant in Cochabamba.

2. Goal

To evaluate the influence of natural and anthropogenic factors on air MPs-like particles concentration in Cochabamba.

3. Methodology

In Cochabamba, air pollution in the south and north zones are clearly marked. Thanks to monitoring stations, it was measured that in the north of the city, the level of particulate matter under 10 µm can be almost half of the concentration of the south part. Differences in meteorological phenomena, developed activities, and geography were also highlighted in the area (Montenegro & Lujan, 2017).

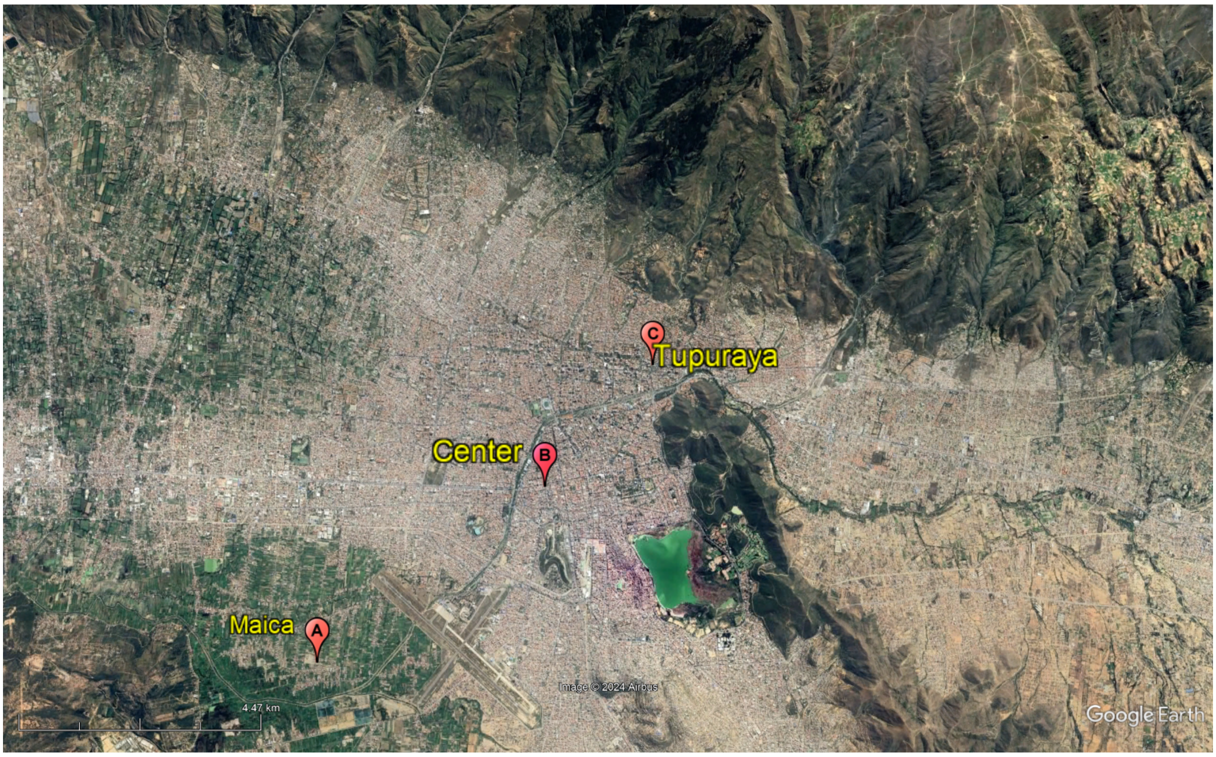
Hereby, the specificity of each zone can determine the air MPs concentration. Thus, in 3.1 the study area is described. The data collection methodology is presented in 3.2. Then in 3.3 part, the method of MPs-like characterization is described. Finally, the 3.4 part presents the statistical methods used in the study.

3.1. Study area

There are different sources of air pollution in Cochabamba, some of which are mobile, point, and area sources, but the largest source of atmospheric emissions comes from motor transportation (Aguilar & Fernandez, 2023).

In this study, three points were monitored in the city. The first point is in the Maica zone with low population and construction density, agricultural activities, and dirt roads. Then the central zone is characterized by a high population and construction density, high commercial and transport activities with paved roads. Finally, the Tupuraya zone (northern urban zone) has mid-high population and construction density, high commercial and transport activities with paved roads (Oporto et al., 2023).

Figure 1: MPs monitoring points in Cochabamba



Source: (Google LLC, 2024)

Cochabamba has a high thermal inversion in the south zone. This phenomenon doesn't allow air pollutants to disperse in the atmosphere and generates higher levels of air pollution in this zone. The north part of the city presents a thermal inversion but is not as marked as the south zone (Montenegro & Lujan, 2017).

The Maica area is mainly agricultural with an extension of 1.4 km^2, with medium vehicular traffic and paved main streets and secondary dirt roads. The Tupuraya zone is an urban zone with an extension of 2 km^2 with high vehicular traffic and paved streets (Oporto et al., 2021).

3.2. Data collection

For this study, two air quality monitoring campaigns were performed. The first campaign was in August of 2023 and the other in September of 2023. The air sampling was carried out by an active method. The particles under 2.5 μm were collected in a filter for 24 hours of exposure to an airflow of 4 L/min. The vehicular traffic was determined by counting how many vehicles circulated in the rush hours.

All the meteorological data correspond to the dates of air sampling. These data were collected by the National Service of Meteorology and Hydrology (SENAMHI, for its acronym in Spanish).

3.3. MPs-like quantification

In this study, various methods were reviewed and tested but the method used is presented as follows. The common steps of MPs extraction and quantification are particle extraction from air filter, digestion of organic matter, density separation, and microscopic observation.

For the extraction, a glass fiber filter was employed for the sampling over 24 hours from where the MPs were extracted by washing the filter with deionized ultra-pure water. The digestion was performed with 30% v/v H_2O_2 at 40°C temperature until organic matter was removed. $ZnCl_2$ was used to perform density separation with a density solution of 1.37 g/mL.

Finally, for the microscopic observation, fluorescence and polarized microscopes were employed with or without using staining with Nile Red and fluorescein (Abbasi et al., 2019; K. Liu et al., 2019; Lv et al., 2019; Oporto et al., 2021; Prata et al., 2021; Qiu et al., 2016; Wright et al., 2020). Fluorescent microscopy showed better results for the quantification of MPs in the air samples, including both counts of optical and polarized microscopy. For example, in one sample the optical counts showed 778 MPs particles, polarized counts were 75 MPs particles and in the fluorescent microscope the counts were 834 MPs particles. Thus, the samples of the monitoring campaigns were counted using fluorescent microscopy. The quantification of MPs-like was carried out with ImageJ (Schneider et al., 2012) and by counting directly from the microscopic observations.

This study only characterized physically the extracted particles. A chemical characterization is needed to ensure that the particles found are synthetic polymers (Rios Mendoza & Balcer, 2019). The procedure is used in most of the MPs extraction studies and allows the separation of particles with some similar properties to MPs. Therefore, the microparticles found can be described as microplastic-like (MPs-like).

3.4. Data analysis

Wind speed, thermal amplitude and precipitations were considered as natural factors and vehicular traffic volume as anthropogenic factor collected in field. No other anthropogenic factors were considered as it is the main air pollution source in the city (Aguilar & Fernandez, 2023; Oporto et al., 2021) and this sector almost duplicated its existing units in the last ten years (INE, 2024).

An ANCOVA analysis was performed to determine the individual influence of each factor over the air MPs-like concentration. Prior this, ANOVA, Shapiro-Wilk, Levene, and Wald-Holfowitz tests were carried out (Lim & Loh, 1996; Ramírez Ríos & Polack Peña, 2020; Ruxton et al., 2015; Siegel & Wagner, 2022).

4. Results and discussion

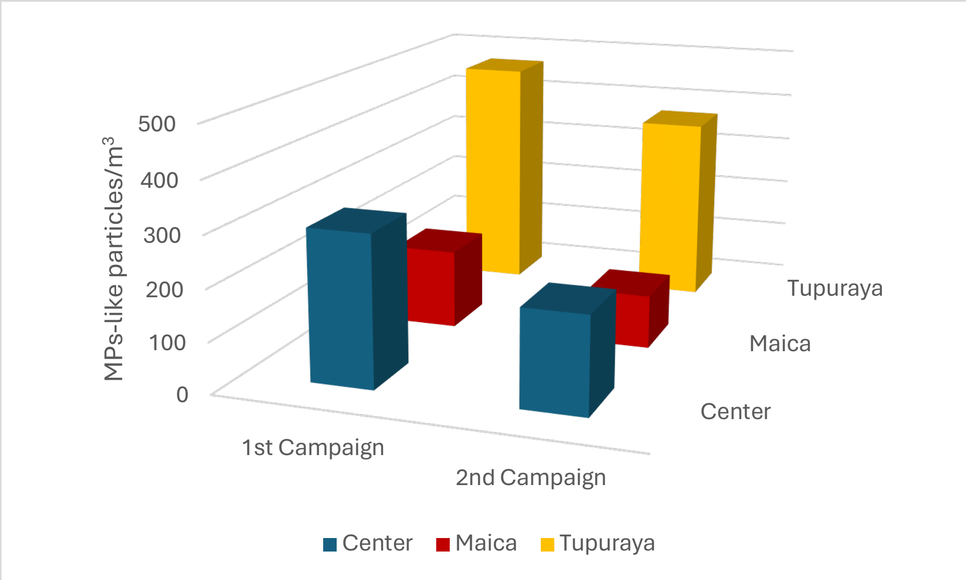
The results acquired in this study are presented below.

4.1. Monitoring

The data presented below were compiled in the field (MPs-like concentration, vehicular traffic) and generated by governmental meteorological stations (precipitations, wind, temperature)

In Figure 2 the concentration of MPs-like is presented for the 3 areas and the two campaigns.

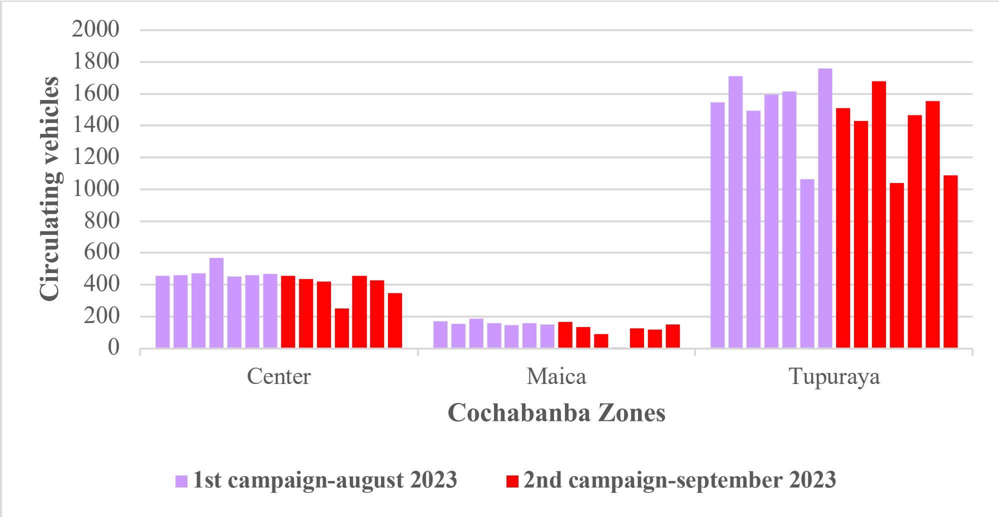
Figure 2 Concentration of air MPs-like particles in Cochabamba



It should be noticed that the Maica area is in the south zone of Cochabamba, with higher particulate matter concentration, under 10 µm, than the north zone (Gobierno Autónomo Departamental de Cochabamba, n.d.). This area shows a lower concentration of air MPs-like. It could be explained because the monitoring point is in an agricultural zone with less population and activities than other areas of the south zone. It was also measured $PM_{2.5}$ and shows the same results, similar or lower concentrations of this contaminant in La Maica. In average, the $PM_{2.5}$ concentration in the Maica zone was 49.7 µg/m^3, in the Center zone 49.1 µg/m^3 and in the Tupuraya zone 51.4 µg/m^3.

The central zone of Cochabamba has a higher construction density than the Tupuraya zone and more population density and commercial activities. However, in the Tupuraya zone the circulation of heavy-duty cars and particular cars is common. As presented in figure 3, there is more vehicular traffic in the Tupuraya zone than the Center zone. This zone has more activities and then public transportation. In the Tupuraya zone there are more particular cars circulating. It is important to notice that in the center of the city it is more common to see traffic jams, especially at noon and at night. In the Maica there are not too many cars circulating and predominates the public transportation or agricultural machinery.

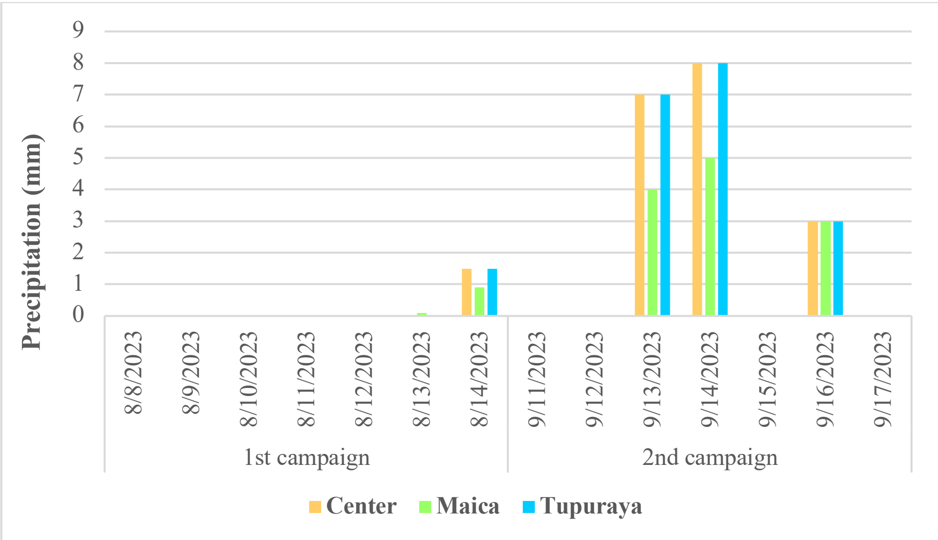
Figure 3: Vehicular traffic volume



Source: (SENAMHI, n.d.)

The precipitation rate is presented in Figure 4.

Figure 4: Precipitation in Cochabamba

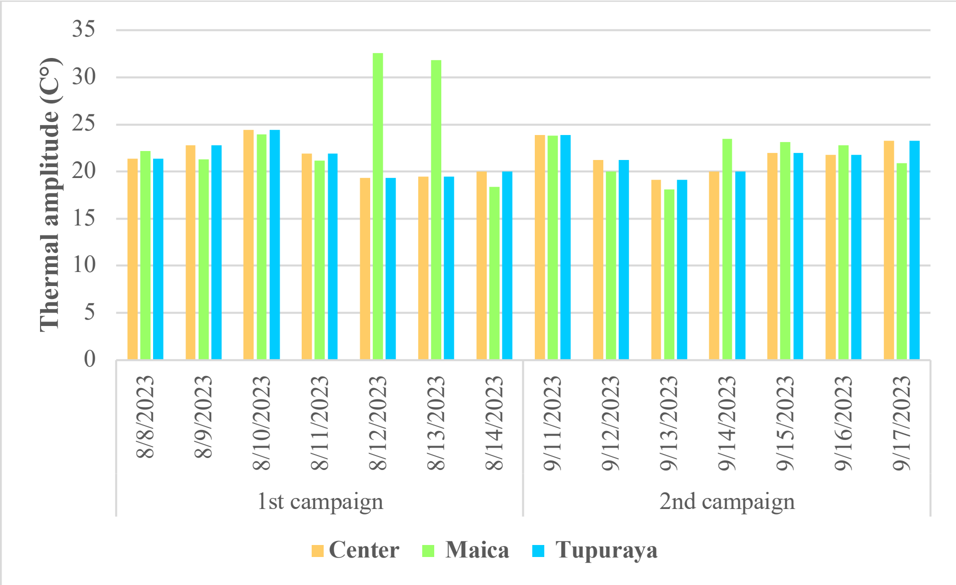


Source: (SENAMHI, n.d.)

The meteorological data were collected from the governmental monitoring points in the city. The Maica is further away from the other monitoring points and the Tupuraya and Center zone are closer between each other, this is why the precipitation in these two zones are the same and have a difference with the other zone.

Then the thermal amplitude was measured within the 3 areas (Figure 5). As in precipitation, there are no differences between the Maica compared to Tupuraya and Center zones. Somes days Maica shows a higher thermal amplitude, this could be because Tupuraya and Center zones generate an urban heat island effect and not the Maica zone.

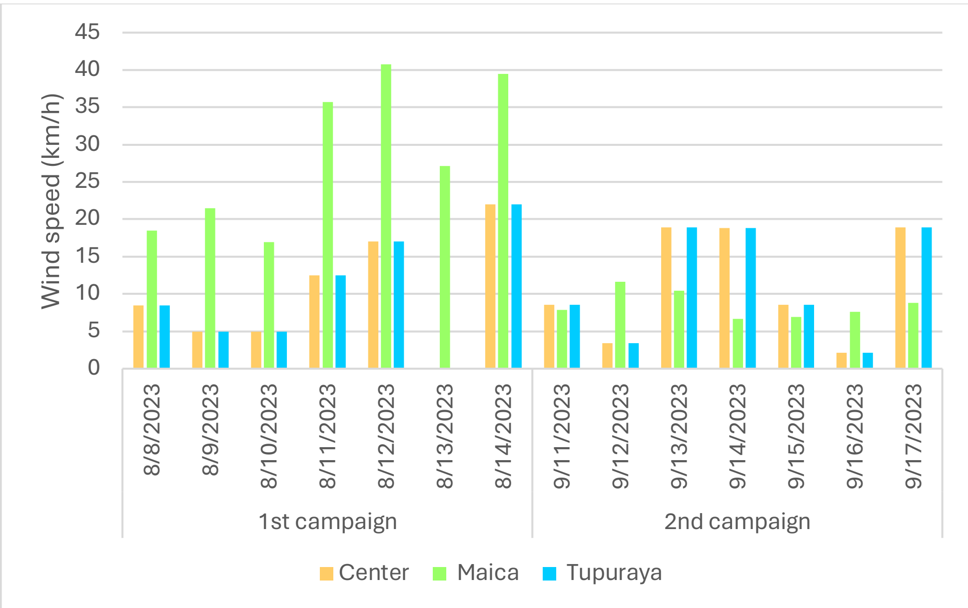
Figure 5: Thermal amplitude in Cochabamba



Source: (SENAMHI, n.d.)

As shown in Figure 6 the wind dynamics varies in different zones of Cochabamba because of its terrain heterogeneity and pressure differences in the region.

Figure 6: Wind speed in Cochabamba



Source: (SENAMHI, n.d.)

4.2. Factors influence

For the data treatment, it was determined first that the MPs-like concentration follows a normal distribution, then that the values difference is significative, and finally that the values are not random. The concentrations are aleatory, which means the values are different between each monitoring point, as shown in Table 1.

Table 1: Statistical tests

	Center	Maica	Tupuraya
Shapiro-Wilk test	sig: 0,594	sig: 0,346	sig: 0,282
Levene test	sig: 0,001	sig: 0,001	sig: 0,001
Walt-Holfowitz test	sig: 1,000	sig: 0,431	sig: 0,952

It should be noticed that regarding the independence of variables, the Maica results show a lower value than the other zones. It means the randomness between the independent and dependent variables is not as great as other zones. However, the results show randomness in all the zones. Finally, the ANOVA test shows a significance value of 0,000 showing that the concentrations found in each monitoring zone are significantly different and are not a mere coincidence.

To see the influence of each factor over the air MPs-like concentrations an ANCOVA analysis and Pearson correlation was performed.

Table 2: Vehicular traffic influence

Factors	Center	Maica	Tupuraya
sig.	0.000	0,003	0,002
Pearson	0,898	0,736	0,750

Vehicular traffic shows an influence over the air MPs-like concentration and a strong positive correlation (Table 2). These results indicate that air MPs-like concentration increases with vehicular traffic. This can be seen in Figure 3 and Figure 2 where Tupuraya zone has more vehicular traffic and more air MPs-like concentration, respectively, followed by Center zone and finally Maica zone with lower air MPs-like concentration and with lower vehicular traffic.

The abrasion is generated by the contact between the vehicle tires and the paved road. This process liberates particles in the air. There is also friction generated between the tire and the plastic residues that are on the road (Bodus et al., 2024; Mayer et al., 2024; Wu, 2017; Xiao et al., 2024). Another factor that should be considered is the driving patterns that vary depending on the zone. In the Center zone there are more bus stops, and traffic jams. The circulating velocity is lower than in the Tupuraya zone. In Tupuraya, the circulating velocity is more regular, there are fewer traffic jams, and the vehicles can circulate at higher speeds. Thus, these pattern differences could affect the air MPs-like concentration, especially in the 2.5 µm fraction (Lee et al., 2013).

Table 3: Thermal amplitude influence

Factors	Center	Maica	Tupuraya
sig.	0,474	0,809	0,881
Pearson	0,209	0,370	0,044

Regarding the results, the thermal amplitude does not influence air MPs-like concentration (Table 3). Temperature does not have a significant short-term effect on MPs-like pollution. Even though, thermal stress is linked to MPs weathering. This effect could be observed in longer-period studies (Lin et al., 2022; Rădulescu et al., 2022).

Table 4: Precipitation influence

Factors	Center	Maica	Tupuraya
sig.	0,004	0,003	0,554
Pearson	-0,721	-0,727	-0,173

Precipitation has a significant effect on air MPs-like concentration in the Center and Maica zones. The results of Table 4 present a strong negative correlation. In case of precipitation episodes, the air MPs-like particles settle on the ground, and a decrease of their concentration in the air is noticed (Kyriakoudes & Turner, 2023; Zhang et al., 2020).

However, in Tupuraya the precipitation does not have a significative effect, as is seen in Table 4. This could be due to the ambiguous seasonal variability and because the same meteorological station was considered for Center and Tupuraya zones (de Carvalho et al., 2021).

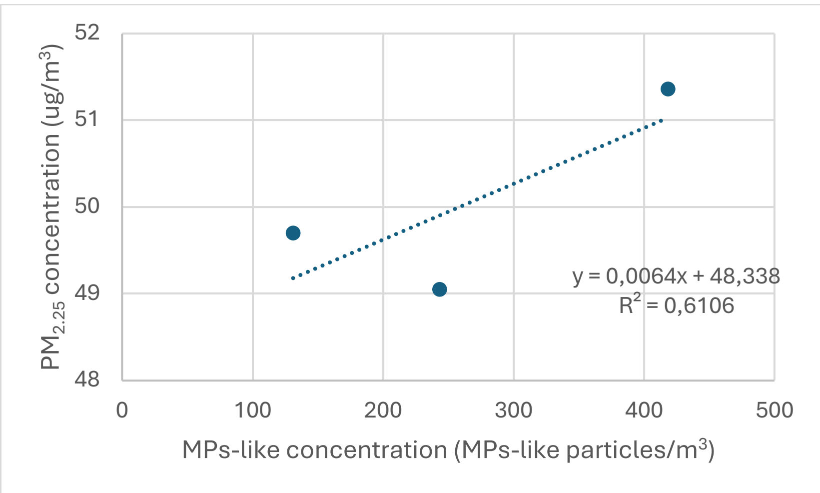
Table 5: Wind speed influence

Factors	Center	Maica	Tupuraya
sig.	0,219	0,073	0,831
Pearson	-0,351	0,494	-0.063

The wind speed factor does not show an influence on the air MPs-like concentration (Table 5). However, a tendency could be noticed. In the Center and Tupuraya zones, when wind speed increases, a decrease of air MPs-like is noticed. In the Maica area, this trend is the other way around. This could be due to the MPs-like dispersion by winds in the region, and the MPs-like are possibly transported to the Maica from other areas of the city. However, there are other factors, like terrain complexity, vertical mixing height, construction density and distribution, and vegetation, that should be considered to analyze air MPs-like dispersion (Oporto et al., 2023; Suder & Szymanowski, 2014).

Finally, a correlation analysis between the concentrations of $PM_{2.5}$ and MPs-like was performed, as it is shown in Figure 7.

Figure 7: Correlation between MPs-like and particulate matter under 2.5 µm



The correlation coefficient between particulate matter and MPs-like particles does not show a strong correlation but tends to be positive. It means that MP-like concentration increases with higher concentrations of $PM_{2.5}$. This tendency differs from the results shown in Oporto et al. (2023), where the air MPs-like concentrations decrease when there are higher concentrations of PM_{10}. This could be due to the road conditions. Thus, in the Maica area, the roads are poorly maintained and could suspend larger particles into the air. On the contrary, the roads in the Center and Tupuraya zones are paved, resulting in a greater abrasion of the tires, the garbage, and the pavement. This process generates particles of smaller size. As a confirmation, it should be noticed that in Oporto et al. (2023) work, it was found that the level of particulate matter (PM_{10}) was higher in the Maica zone (with lower vehicular traffic and activities). In this study, it was found that the levels of $PM_{2.5}$ is higher in zones with higher vehicular traffic, population, and commercial activities.

5. Conclusions

The monitoring in different zones in Cochabamba showed no identical air MPs-like concentrations. The study areas have diverse conditions (vehicular traffic, activities, meteorological phenomena) that was established in the present work has an influence on the air MPs-like concentration. A previous work (Oporto et al., 2023) showed that possibly vehicular traffic and other factors influence air MPs concentration.

The factor that has a major influence on air MPs-like concentration is vehicular traffic. It is also the main atmospheric pollution source in Cochabamba. However, it should be mentioned that no other anthropogenic activity was considered in this work. Vehicular traffic has a strong relation with air MPs-like showing that if there is more vehicular traffic, the air MPs-like concentration increases. Other parameters linked to vehicular traffic, as driving patterns and road conditions, also should be considered to better understand their impact on MPs-like atmospheric pollution.

Natural factors also influence air MPs-like concentrations, but it is not considered as relevant as vehicular traffic. Thus, precipitation has more influence than the other parameters. It is known that precipitation has a significant removal effect on air pollutants. Wind appears to not have a significant effect on air MPs-like concentrations. However, wind affects air pollutants dispersion, but it should be considered other parameters to study this influence. Thermal amplitude does not have a significant effect on air MPs-like considering an immediate effect. Indeed, the stress generated by this factor could be noticeable in long-term studies regarding plastic exposure and the weathering effects on MPs-like particles, that could affect their dispersion.

Particulate matter association with MPs-like varies depending on the size fraction of particles analyzed and the characteristics of the monitored sites. The dynamics of particulate matter have their own specificity regarding the fraction studied influencing its suspension and therefore its concentration in the air. Regarding particles below 2.5 µm, it was not found a strong correlation, but the relationship between both factors is positive. These results contrast with the conclusions of Oporto et al. (2023) who noticed that the particles of 10 µm showed a negative correlation with MPs-like. This study confirms that vehicular traffic plays an important role as an air MPs-like source in Cochabamba resulting in higher air MPs concentrations with higher vehicular traffic.

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