Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

EVALUATION OF AIR QUALITY BY PARTICULATE MATERIAL IN JUNIN AND HUANCAVELICA, PERU

Julio Angeles Suazo [1*], Roberto Angeles Vasquez[2], Esmila Yeime Chavarría Márquez[1], Carmencita Lavado-Meza [1], Leonel de la Cruz-Cerrón [3], Nataly Angeles Suazo [4], Liz Quispe Quincho[1], Hugo Abi Karam[5]

[1] Universidad Nacional Autónoma de Tayacaja Daniel Hernández Morillo; Escuela Profesional de Ingeniería Ambiental y Forestal, Tayacaja-Perú

[2] Universidad Nacional del Centro del Perú; Facultad de Ingeniería Civil, Huancayo-Perú

[3] Universidad Continental, Facultad de Ingeniería, Huancayo, Perú,

[4] Universidad Tecnológica del Perú; Facultad de ingeniería de Sistemas, Huancayo-Perú

[5] Universidade Federal do Rio de Janeiro, Rio de Janeiro-Brasil

* Correspondence: jangelesambiental@gmail.com

ABSTRACT

Anthropogenic atmospheric particles with a diameter of less than 2.5µm (PM2.5), and between 2.5 to 10 µm (PM10) are among the main contributors to air pollution and have become a serious pollution threat in the Junin and Huancavelica region of Peru, this increase could be due to the burning of vegetation in the Amazon region of Brazil. Therefore, data obtained with the low-cost PA-II Purpleair sensor were analyzed to measure particulate matter (fine and coarse fashions) in Junin region (Chanchamayo, station T. Huancayo, station T1 and Chupaca, station T3) and Huancavelica (Pampas, station T2). Likewise, the Hysplit model was used to quantify the transboundary wind trajectories from the Amazon region in Brazil to the Junin region in Peru. Shows that, during the rainy season, the maximum concentrations of PM2.5 and PM10 are 151 µg/m³ (station T1) and 178 µg/m³ (station T1) respectively. Finally, the results of the air quality index (AQI) for PM2.5 allow for the classification of the Huancayo and Chanchamayo stations with "very bad" and "moderate to bad" air quality, respectively. Also in Pampas and Chupaca the AQI is classified as very unhealthy and hazardous on almost 50% and 43% of days respectively.

Key Words	Particulate matter; Purple air, Hysplit; Peru; Pampas; Chupaca; Huancayo; Air pollution transport; air quality
DOI	https://doi.org/10.46488/NEPT.2025.v24i02.D1722 (DOI will be active only after the final publication of the paper)
Citation of the Paper	Julio Angeles Suazo, Roberto Angeles Vasquez, Esmila Chavarria-Marquez, Carmencita Lavado-Meza, Leonel de la Cruz-Cerrón, Nataly Angeles Suazo, Liz Quispe Quincho, Hugo Abi Karam, 2025. Evaluation of air quality by particulate material in Junin and Huancavelica, Peru. *Nature Environment and Pollution Technology*, 24(2), D1722. https://doi.org/10.46488/NEPT.2025.v24i02.D1722

INTRODUCTION

Atmospheric aerosols are a suspended mixture of solid particles or liquid droplets in the air, also known as particulate matter (PM).(Rabha & Saikia 2019); these exert a broader effect on atmospheric processes, radiative balance, climate, ecology, public health, and radiative forcing at both global and regional scales (Chang et al. 2021). Currently, air pollution is dominated by fine particulate matter whose aerodynamic diameter is less than or equal to 2.5 µm (PM2.5) resulting from the rapid urbanization and industrialization of major cities (Vo, Wu & Lee 2020). It has been considered that the increase of these particles is an important factor in the cooling of the earth-atmosphere system and partially offsets the greenhouse effect. (Suazo et al. 2020; Tosca et al. 2017; Vo, Wu & Lee 2020).

Air pollution is becoming increasingly important in the environmental scene due to its effects on health, as it has increased the risk of death and respiratory diseases among children (César et al. 2016; Perlroth & Branco 2017). In 2016, globally, one in four child deaths was associated with the effects of air pollution, this was responsible for 4.2 million premature deaths, of these, almost 300 000 were children under 5 years old (Adair, Heather, Arroyo 2018). On the other hand, in Huancayo (a province belonging to the Junín region, Peru), the mass concentration of PM2.5 from March to November 2017 shows the average annual mass concentration which ranged from 3.4 to 36.8. µg/m3 (De La Cruz et al. 2019). However, in August 2007, and January, April, and May 2008 they reported results for PM10 (64.54 ± 30.87 µg/m³) and PM2.5 (34.47 ± 14.75 µg/m³) which exceeded annual air quality standards. Peruvian. They also showed a higher concentration of PM10 and PM2.5 in the dry period (Suárez-Salas et al. 2017) .

However, meteorological parameters are a determining factor in PM concentrations, since the dispersion processes and the mechanisms for removing atmospheric particles depend on wind speed (Chakraborty et al. 2016; Dhar et al. 2019; Galindo et al. 2011; Haque, Kawamura & Kim 2016; Hu et al. 2018; Jayamurugan et al. 2013; Owoade et al. 2015; Zu et al. 2017; Zyromski et al. 2014).

Poor green policies, socioeconomic conditions and weak governance practices may explain this, including the lack of research in this field (Benegas et al. 2021; Dobbs et al. 2019). However, this situation is changing globally and there is increasing concern about the relationship between the presence of urban trees and the mitigation of pollution, noise and so-called heat island effects in cities around the world (Pimienta-Barrios et al. 2018; Soto-Estrada 2019; Zardo et al. 2017). In this trend, more and more studies and research highlight the need to integrate the benefits of urban trees into urban planning and management, with the aim of improving the quality of life of citizens (Dobbs et al. 2018; de Mola et al. 2017; Muñoz-Pacheco & Villaseñor 2022; Romero-Duque et al. 2020).

Therefore, this research consists of determining the concentration of particulate matter and its air quality in the Junín region (Huancayo, Chupaca and La Merced) and Huancavelica (Ahuaycha), Peru during the period 2020-2022 and 2024.

MATERIALS AND METHODS

Site study

The study area is in the Junín region, in the central Andes of Peru, and has different altitudes ranging from the lowland jungle at 250 m above sea level (a.s.l) to the cold Andean mountains at 5

500 m a.s.l., giving rise to a great diversity of climates, landscapes, and ecosystems (Junín Region(Flores-Rojas et al. 2019)al Government, 2016).
Precipitation in Peru is concentrated in the period between September and April, while in the period between May and August, there is very little precipitation, which is why there is a marked seasonality in the region (Aceituno 1989; Flores-Rojas et al. 2019; Garreaud 2009). The climate of the city of Huancayo is presented regularly based on data collected at the Huancayo Observatory (IGP), where the coldest temperatures are recorded in June and July (winter) and the highest values around October and December. The average annual temperature is 11.9 ± 1.2 ºC. Precipitation from June to July is recorded with the lowest amounts of rain, while from January to March the highest rainfall is recorded (February = 129.1 mm) and presents an average annual accumulated rainfall of 752 ± 44.3 mm (IGP, 2005). On the other hand, during the rainy season, humid air from the middle troposphere, coming from the Amazon, flows over the Central Andes, where it is responsible for the occurrence of summer convective storms in this region (Garreaud, Vuille & Clement 2003; Garreaud 1999; Vuille 1999; Vuille, Bradley & Keimig 2000; Vuille, Kaser & Juen 2008). Various authors demonstrated that the region is affected by the burning of biomass or anthropogenic emissions released from the city of Huancayo, which are transported and dispersed over the Peruvian Andes (Magalhães et al. 2019; Vuille & Keimig 2004)

The Pampas District is located in the province of Tayacaja, in the department of Huancavelica. The district is 3280 m above sea level and has an area of 90.96 km2, with a population density of 65.29 inhabitants/km2. The temperature varies according to the seasons of the year, ranging between 24ºC maximum and minus 12ºC minimum. Precipitation varies from 8 mm to 124 mm, with rainfall beginning to intensify from October to March (MINISTERIO DE VIVIENDA, 2002).

For the present study, the purple air sensor was used (data downloadable at: https://map.purpleair.com/) for six continuous particulate matter monitoring stations. (see Table 1):

Table 1: Measurements of particulate matter sensor

State / Country	**Province**	**Symbology**	**Coordinates**	
			Latitude	**Longitude**
Junín / Peru	Chanchamayo	T	-11.05	-75.33
Junín / Peru	Huancayo	T1	-12.05	-75.22
Huancavelica / Peru	Pampas	T2	-12.39	-74.87
Junín / Peru	Chupaca	T3	-12.06	-75.28

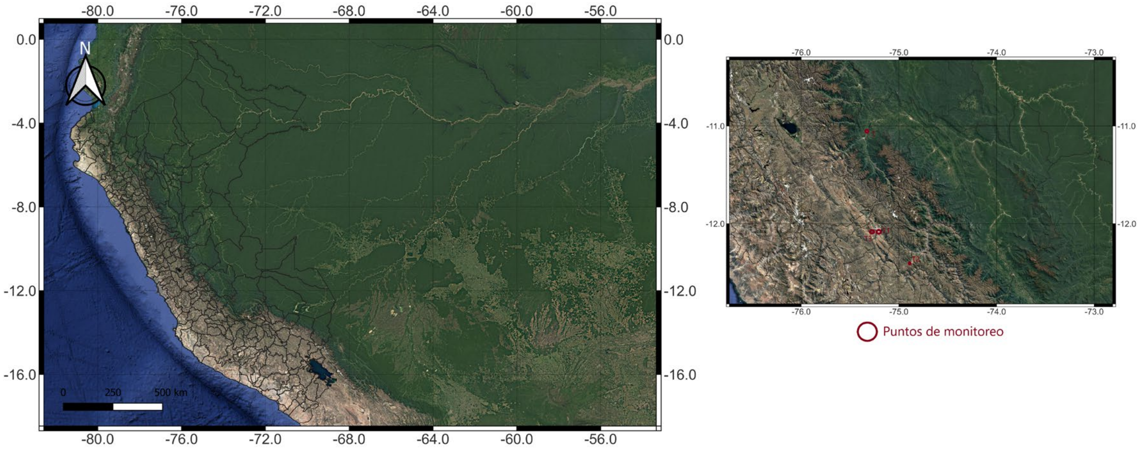

Fig. 1: A. Location of monitoring stations

2.2 The Purple Air PA-II Low-Cost PM Monitor

The PurpleAir sensor is a low-cost optical particle counter of PM1.0, PM2.5 and PM10 mass concentrations in $\mu g/m^3$, incorporating a temperature, relative humidity and pressure sensor with a wireless network communication module, where it records and transmits data via Wi-Fi to a cloud-based platform (Ardon-Dryer et al. 2020). Furthermore, the Purple Air PA-II monitors as a component of a large-scale calibrated monitoring network where it can lead to integrated solutions for high-resolution monitoring (Bi et al. 2020).

Air quality index

The air quality index (AQI) for particulate matter was calculated according to equation used for (Beringui et al. 2022).

Daily AQIs were calculated from the 24-hour average particulate matter concentration, and are classified into five classes, as presented in Table 2.

Table 2: Air quality index (AQI) range and air classification according to indexed values (Beringui et al. 2022, 2023).

Classes	Range	Air classification	Color identification
I	0-40	Good	green
II	41-81	Moderate	yellow
III	81-120	unhealthy	orange
IV	121-200	Very unhealthy	red
V	201-400	hazardous	purple

RESULTS AND DISCUSSIONS

Particulate matter

Huancayo/Junin

Fig. 2 shows that during the rainy season, the maximum mass concentrations of PM1, PM2.5, and PM10 are 97 $\mu g/m^3$ (station T1), 151 $\mu g/m^3$ (station T1) and 178 $\mu g/m^3$ (station T1) respectively. These results indicate that high loads of fine particles affect the study region, due to the long-range transport of regional fires driven by advection, so common during the dry season in the Amazon. At station T1 located in the Huancayo area, the rains were late, and its precipitation rate was low. This seasonal pattern is associated with differences in climatic conditions and emission sources characteristic of the rainy and dry periods. Likewise, it is shown that they exceed the quality standards established by Peru only for PM2.5 (PM2.5=50 $\mu g/m^3$; PM10=100 $\mu g/m^3$ for a period of 24 hours; available SUPREME DECREE Nº 003 -2017 -MINAM), however, for Brazil (PM2.5=25 $\mu g/m^3$; PM10=50 $\mu g/m^3$ for 24 hours; available Resolution CONAMA 491 of 11/19/2018) they exceed for PM2.5 and PM 10, and the same would happen with the standards established by the World Health Organization (PM2.5=15 $\mu g/m^3$; PM10=45 $\mu g/m^3$ for 24 hours; under the global air quality guidelines of WHO available). Also show the time series of the monthly mean of PM2.5 and PM10 for the study stations, illustrating the seasonal and monthly variability. All regions show maximum values before and after partial confinement due to COVID-19 (after June 2020), also in the dry season and can be attributed mainly to meteorological parameters (less precipitation) as happens in China, where in the humid season, due to the deposition process it can reduce the particles suspended in the atmosphere (Wang et al. 2018).

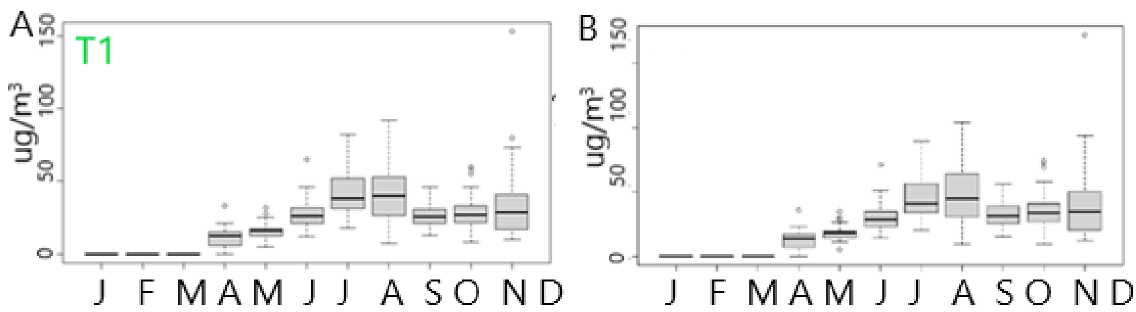

Fig. 2: Time series of monthly average A. PM2.5 and B. PM10 concentrations at the stations during 2020

La Merced/Junin

Likewise, in Fig. 3 during the period 2021 (November and December) and in the period 2022 (January to August), very noticeable maximum values are presented (August) in La Merced (station T), which exceed the ECAs established in the Peruvian regulations for the values of PM2.5 and PM10.

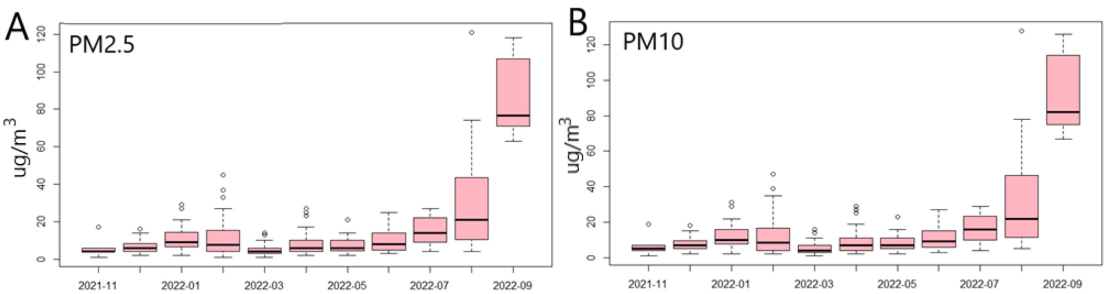

Fig. 3: Time series of monthly average concentrations of A. PM2.5, B.PM10 and C. time series at the La Merced station (T)

Pampas/Huancavelica

Likewise, in Fig. 4 during the period 2024 (February and July), very noticeable maximum values are presented (July) in Pampas (station T2), which it doesn't exceed the ECAs established in the Peruvian regulations for the values of PM2.5 and PM10.

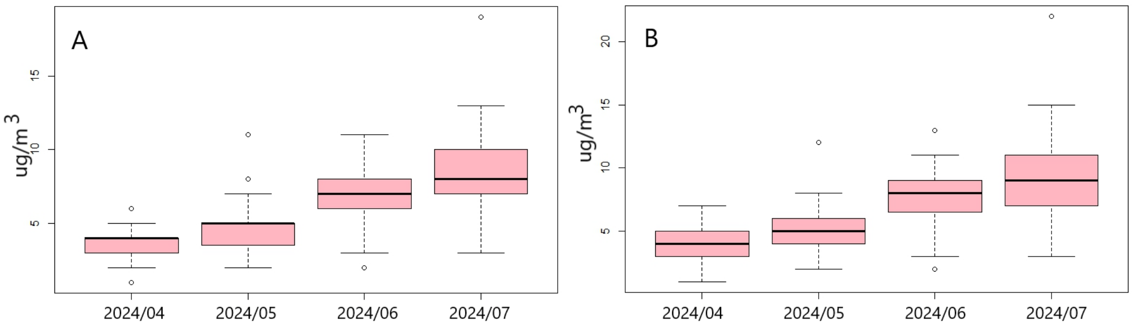

Fig. 4: Time series of monthly average concentrations of A.PM2.5, B. PM10 and C. time series at Pampas station (T2)

Chupaca/Junin

Also note that during February and March 2024 the concentrations of MP2.5 and MP10 (Fig. 5) present maximum values of 40 and 49 ug/m3 respectively in month august.

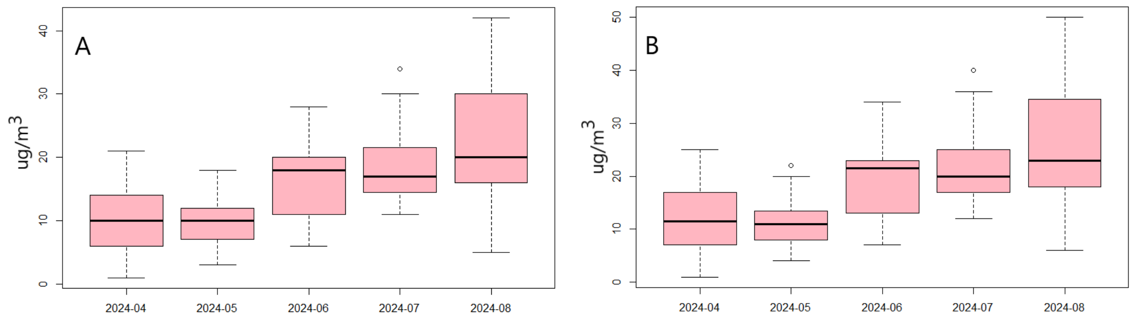

Fig. 5: Boxplot of A. PM2.5 and B. PM10 during february at august 2024 to Chupaca Station (T3)

Pollution roses due to particulate matter

Huancayo

The pollution rose diagrams (Fig. 6) show the relationship between WD and WS, and the concentration of pollutants at the monitoring stations. The dispersion of particles towards the south and southeast of Station T1 is indicated. Where it indicates that it can influence the increase in particulate matter resulting from atmospheric dispersion. Likewise, meteorology drives large daily, seasonal, and interannual variations in PM2.5, a clear example is in China by affects the transport of emissions and chemical production [62–65]. The relationships between PM2.5 and meteorological variables are complex and differ depending on the region and time of year (Shen, Mickley & Murray 2017). For example, PM2.5 pollution events during winter in central and eastern China are associated with low wind speed and high relative humidity (HR) [62], [67–70].

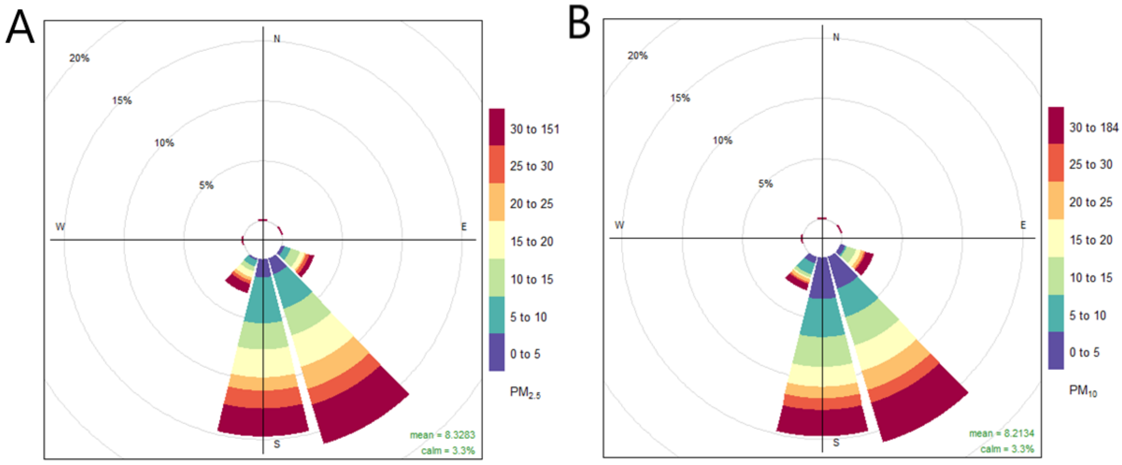

Fig. 6: Influence of wind direction and wind speed on A. PM2.5 and B. PM10 concentrations during 2020 for Huancayo station (T1).

Air quality index

The AQI for MP2.5 and MP10 was calculated for stations T and T1, where it presented for La Merced and Huancayo (Fig. 7 and 8 respectevely), AQI values lower than 40, classified as “good” 80% of the time in both sites for MP10. The concentrations of PM2.5 were higher than the limit established by Peruvian legislation. Likewise, in La Merced (Fig. 7) the air quality was classified as “moderate” to “very poor”. The concentrations obtained in July-August-2022 were higher than those in January-June-2022, indicating poor air quality. Some days during the partial confinement presented lower concentrations of PM2.5 than at the beginning of March, which is related to the decrease in the vehicle fleet for 2020 at station T1.

Overall, the air quality index ranged from “good” to “very bad” for both stations. However, during the days of partial confinement (March 2020) the index varied from "good" to "moderate" for PM10-T1. The T1 station is in a populated area, near roads with heavy traffic. Therefore, industrial activities, which did not come to a standstill during the partial lockdown, could be the reason for the poor air quality.

On most days the air quality for MP2.5 was classified as “terrible” since the concentrations were higher than the quality standards established by MINAM. Also, mention that, on some days of the evaluated period, data collection failed or was invalidated due to the monitoring station being maintained, so the AQI was not carried out and the days are not filled in the calendar plots.

These AQI results agree with studies carried out in other cities around the world. In India, air pollution decreased after the second week of lockdown and the AQI for a total of 91 cities was rated as “good” and “satisfactory”, and no city was rated as “poor” (Anjum, 2020). AQI for three cities in China (Wuhan, Jingmen, and Enshi) showed that 88% of days were classified as “moderate” or “good” during the lockdown, while before the lockdown the percentage of days was 66% (Xu et al. 2020). It should be noted that the AQI of Pampas (T2) (Fig. 9) presents 54.6% of days classified as good, 42.9% moderate and 2.5% unhealthy for MP2.5. For AQI of MP10 it is classified as good due to the low concentrations of MP10. Likewise, for the province of Chupaca, good air quality for coarse mode is

97.9 and moderate of 2.1% and unhealthy, moderate and good air quality for fine mode around 6.8%, 51.3% and 41.9% of days measurements (Fig. 10).
Therefore, based on the calculated values of the air quality index, we note that it is important to measure the PM2.5 levels to better manage air quality. Additionally, it is proposed to use deep learning and machine learning algorithms to forecast air quality and thus propose measures for the mitigation and control of air pollution (e.g (Saminathan & Malathy 2024))

It is also worth mentioning that PM2.5 affects health; a clear example is that PM2.5 is inversely related to hemoglobin and was positively associated with anemia, but the results were not statistically significant at the alpha level of 0.05 (Deng et al. 2024). On the other hand, Alzheimer's disease (AD) has been linked to air pollution, especially with particulate matter (PM); since PM is composed of several elements, including iron-rich particles that can reach the brain through inhalation; in addition, Lima, Peru, is one of the most polluted cities in Latin America, with a high rate of AD; exposure to Fe through inhalation of PM10 may be associated with the presence of AD in Lima (Fano-Sizgorich et al. 2024). However, to mitigate the health effects due to air pollutants; There is limited knowledge about the contribution of tree species and the general ecosystem services provided by urban trees under public management, especially in Latin America; they demonstrated that urban tree cover is very relevant to reduce these pollutants dangerous to public health by reducing PM, both PM2.5 and PM10 (Moreno et al. 2024).

Suspended particles, accepted as markers of air quality, are also indicators of health risks for the population, especially for children, due to their greater susceptibility to the quality of the air they breathe. There is a negative correlation with temperature and a positive correlation with humidity; the correlation with temperature was also very weak, compared to humidity (Zender-Świercz et al. 2024). Also, seasonal variations in PM2.5 pollution levels are also closely related to changes in the thermal stability of the planetary boundary layer (PBL). During winter, daily increases in PM2.5 concentrations are often linked to atmospheric warming above 1500 m, as increasing thermal inversions and lower PBL heights lead to the accumulation of pollutants (Liang et al. 2024).

Fig. 7: Air quality index of A. MP2.5 and B. MP10 in La Merced (T) during 2022

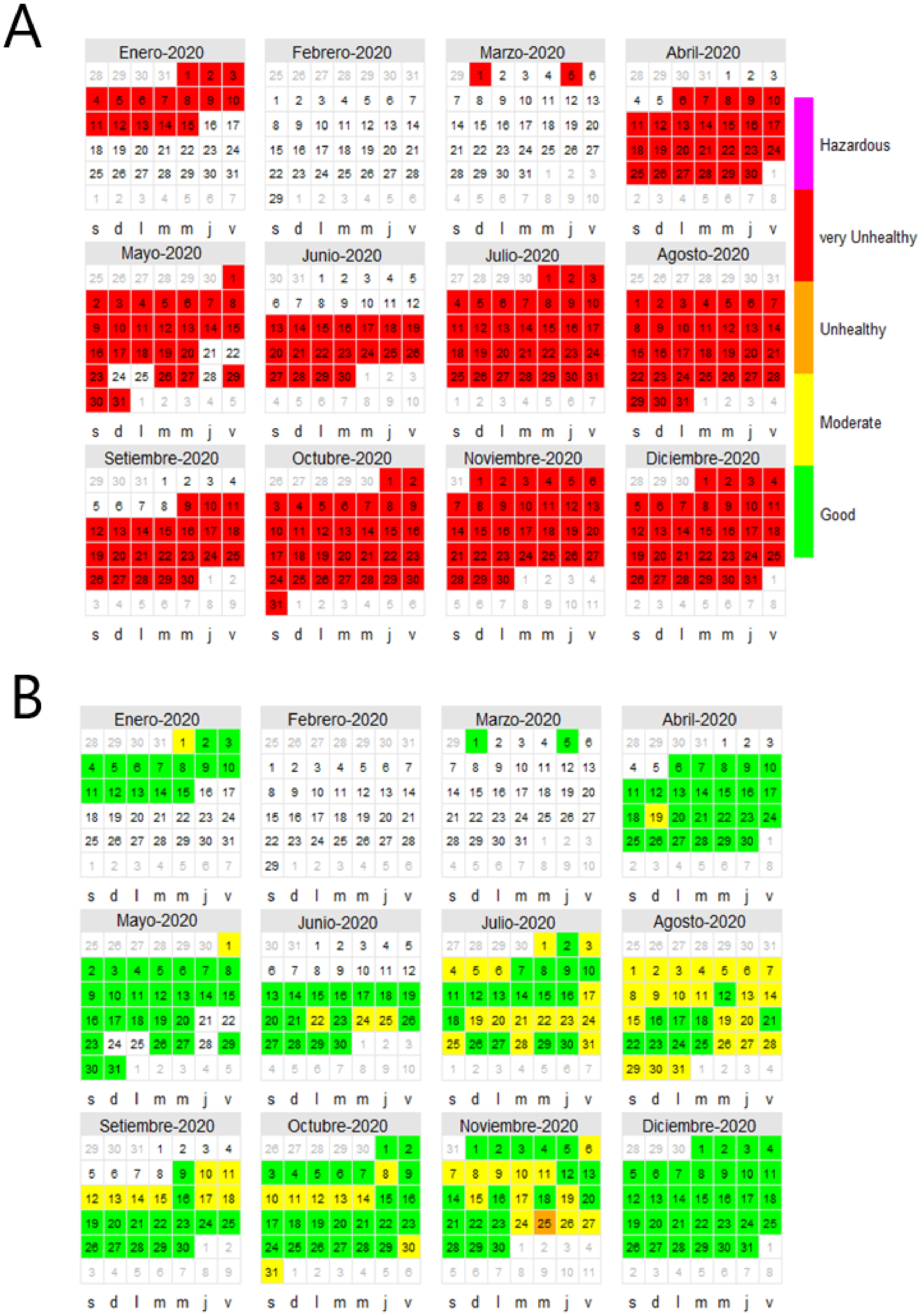

Fig. 8. Air quality index of A. MP2.5 and B. MP10 in Huancayo (T1) during 2020

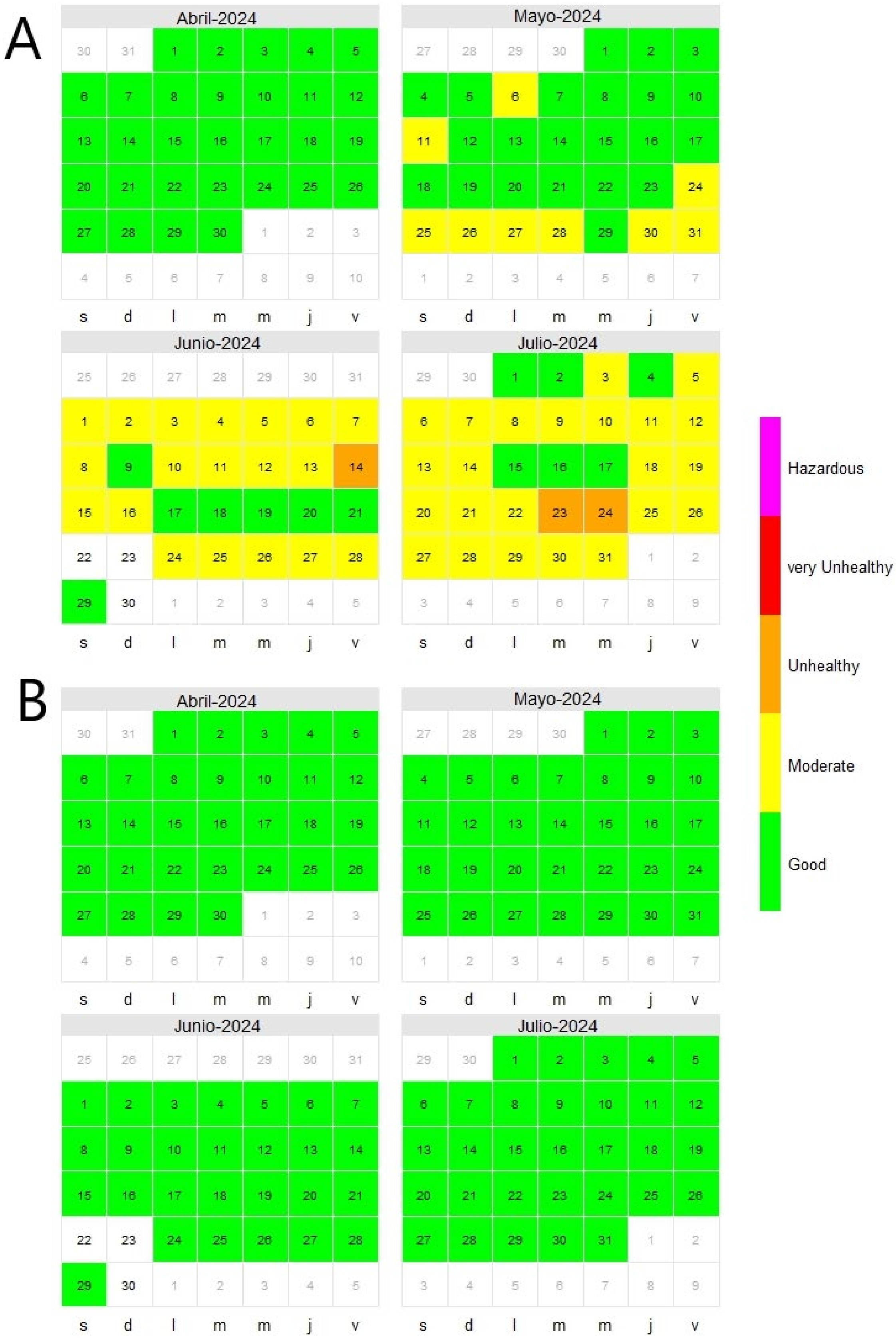

Fig. 9: Air quality index of A. MP2.5 and B. MP10 in Pampas (T2) during 2024

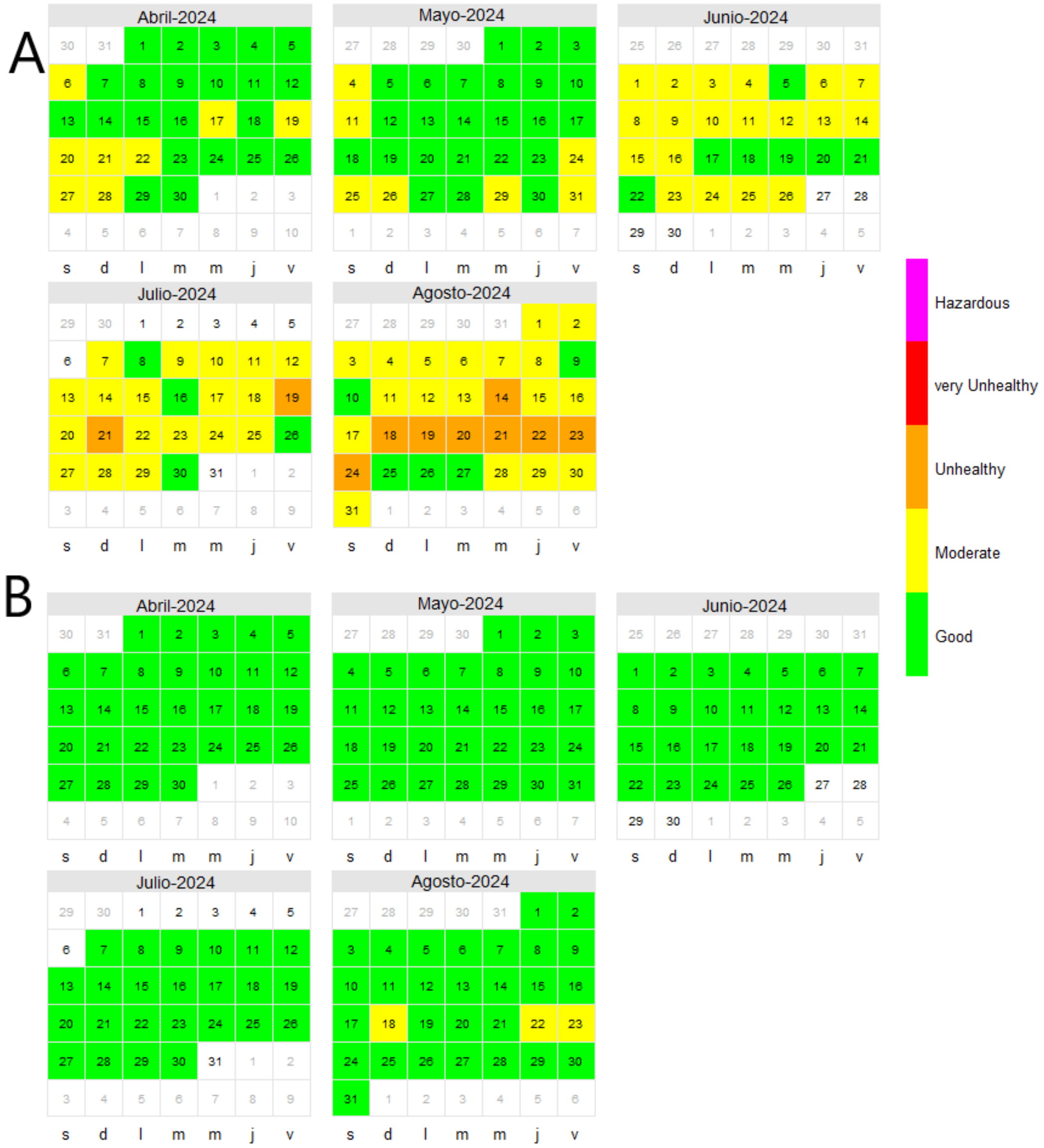

Fig. 10: Air quality index of A. MP2.5 and B. MP10 in Chupaca (T3) during 2024

CONCLUSIONS

This research concludes that, during the rainy season, the maximum mass concentrations of PM1, PM2.5, and PM10 are 97 µg/m³ (station T1), 151 µg/m³ (station T1) and 178 µg/m³ (station T1) respectively. Also, at station T1 located in the Huancayo area, the rains were late and the precipitation rate was low. This seasonal pattern is associated with differences in climatic conditions and emission sources characteristic of the rainy and dry periods.

Finally, the classification of the sites according to the AQI, where in 2020, Huancayo presented the air quality classified as "good to moderate" for MP10, and for MP2.5 it was classified as very unhealthy, while for La Merced it presented the days as "moderate" to "unhealthy" and 10% as very unhealthy. PM2.5 was the pollutant responsible for the reduction in air quality at both monitoring stations. Also, in Pampas and Chupaca the AQI is classified as moderate and good on almost 50% of days to fine mode. In La Merced, Huancayo, Chupaca and Pampas, fine particles predominate; these findings highlight the importance of implementing policies and measures to reduce particulate matter emissions, especially those related to motor vehicle fleets and vegetation burning, to improve air quality and reduce health risks.

Acknowledgements

To the Universidad Nacional Autónoma de Tayacaja Daniel Hernandez Morillo and Universidad Nacional del Centro del Perú as to the portal purpleair.

REFERENCES

Aceituno, P. 1989, 'On the Functioning of the Southern Oscillation in the South American Sector. Part II. Upper-Air Circulation', *Journal of Climate*, vol. 2, no. 4.

Adair, Heather, Arroyo, V. 2018, 'WHO | Air pollution and child health: prescribing clean air', *Who*.

Ardon-Dryer, K., Dryer, Y., Williams, J.N. & Moghimi, N. 2020, 'Measurements of PM2.5 with PurpleAir under atmospheric conditions', *Atmospheric Measurement Techniques*, vol. 13, pp. 5441–5458.

Benegas, L., Rojas, A., Iraheta, A. & Cárdenas, J. 2021, 'Análisis del componente arbóreo y su contribución a los servicios ecosistémicos en la ciudad de Turrialba, Costa Rica', *Ecosistemas*, vol. 30, no. 2.

Beringui, K., Justo, E., Ventura, L., Gomes, R., Lionel-Mateus, V., De La Cruz, A., de Almeida, A.C., Ramos, M., Angeles Suazo, J., Valle, P. & Gioda, A. 2023, 'The Contribution of Meteorological Parameters and the COVID-19 Partial Lockdown on Air Quality in Rio de Janeiro, Brazil', *Journal of the Brazilian Chemical Society*, vol. 34, no. 01, pp. 69–82.

Beringui, K., Justo, E.P.S., De Falco, A., Santa-Helena, E., Rocha, W.F.C., Deroubaix, A. & Gioda, A. 2022, 'Assessment of air quality changes during COVID-19 partial lockdown in a Brazilian metropolis: from lockdown to economic opening of Rio de Janeiro, Brazil', *Air Quality, Atmosphere and Health*, vol. 15, no. 7, pp. 1205–20.

Bi, J., Wildani, A., Chang, H.H. & Liu, Y. 2020, 'Incorporating Low-Cost Sensor Measurements into High-Resolution PM2.5 Modeling at a Large Spatial Scale', *Environmental Science and Technology*, vol. 54, no. 4.

César, A.C.G., Nascimento, L.F.C., Mantovani, K.C.C. & Pompeo Vieira, L.C. 2016, 'Material particulado fino estimado por modelo matemático e internações por pneumonia e asma em crianças', *Revista Paulista de Pediatria*.

Chakraborty, S., Fu, R., Massie, S.T. & Stephens, G. 2016, 'Relative influence of meteorological conditions and aerosols on the lifetime of mesoscale convective systems', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 113, no. 27.

Chang, D.Y., Yoon, J., Lelieveld, J., Park, S.K., Yum, S.S., Kim, J. & Jeong, S. 2021, 'Direct radiative forcing of biomass burning aerosols from the extensive Australian wildfires in 2019-2020', *Environmental Research Letters*, vol. 16, no. 4.

Deng, Y., Steenland, K., Sinharoy, S.S., Peel, J.L., Ye, W., Pillarisetti, A., Eick, S.M., Chang, H.H., Wang, J., Chen, Y., Young, B.N., Clark, M.L., Barr, D.B. & Clasen, on behalf of the HAPIN Investigators, T.F. 2024, 'Association of household air pollution exposure and anemia among pregnant women: Analysis of baseline data from 'Household Air Pollution Intervention Network (HAPIN)' trial', *Environment International*, vol. 190, no. February, p. 108815.

Dhar, R.B., Chakraborty, S., Chattopadhyay, R. & Sikdar, P.K. 2019, 'Impact of Land-Use/Land-Cover Change on Land Surface Temperature Using Satellite Data: A Case Study of Rajarhat Block, North 24-Parganas District, West Bengal', *Journal of the Indian Society of Remote Sensing*, vol. 47, no. 2.

Dobbs, C., Escobedo, F.J., Clerici, N., de la Barrera, F., Eleuterio, A.A., MacGregor-Fors, I., Reyes-Paecke, S., Vásquez, A., Zea Camaño, J.D. & Hernández, H.J. 2019, 'Urban ecosystem Services

in Latin America: mismatch between global concepts and regional realities?', *Urban Ecosystems*, vol. 22, no. 1.
Dobbs, C., Hernández-Moreno, Á., Reyes-Paecke, S. & Miranda, M.D. 2018, 'Exploring temporal dynamics of urban ecosystem services in Latin America: The case of Bogota (Colombia) and Santiago (Chile)', *Ecological Indicators*, vol. 85.
Fano-Sizgorich, D., Vásquez-Velásquez, C., Ordoñez-Aquino, C., Sánchez-Ccoyllo, O., Tapia, V. & Gonzales, G.F. 2024, 'Iron Trace Elements Concentration in PM10 and Alzheimer's Disease in Lima, Peru: Ecological Study', *Biomedicines*, vol. 12, no. 9, p. 2043.
Flores-Rojas, J.L., Pereira-Filho, A.J., Karam, H.A., Vemado, F., Masson, V. & Silva-Vidal, F.Y. 2019, 'Modeling the effects of explicit urban canopy representation on the development of thunderstorms above a tropical Mega City', *Atmosphere*.
Galindo, N., Yubero, E., Nicolás, J.F., Crespo, J., Pastor, C., Carratalá, A. & Santacatalina, M. 2011, 'Water-soluble ions measured in fine particulate matter next to cement works', *Atmospheric Environment*, vol. 45, no. 12.
Garreaud, R., Vuille, M. & Clement, A.C. 2003, 'The climate of the Altiplano: Observed current conditions and mechanisms of past changes', *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 194.
Garreaud, R.D. 1999, 'Multiscale analysis of the summertime precipitation over the central Andes', *Monthly Weather Review*, vol. 127, no. 5.
Garreaud, R.D. 2009, 'The Andes climate and weather', *Advances in Geosciences*, vol. 22.
Haque, M.M., Kawamura, K. & Kim, Y. 2016, 'Seasonal variations of biogenic secondary organic aerosol tracers in ambient aerosols from Alaska', *Atmospheric Environment*, vol. 130.
Hu, R., Wang, H., Yin, Y., Zhu, B., Xia, L., Zhang, Z. & Chen, K. 2018, 'Measurement of ambient aerosols by single particle mass spectrometry in the Yangtze River Delta, China: Seasonal variations, mixing state and meteorological effects', *Atmospheric Research*, vol. 213.
Jayamurugan, R., Kumaravel, B., Palanivelraja, S. & Chockalingam, M.P. 2013, 'Influence of Temperature, Relative Humidity and Seasonal Variability on Ambient Air Quality in a Coastal Urban Area', *International Journal of Atmospheric Sciences*, vol. 2013.
De La Cruz, A.H., Roca, Y.B., Suarez-Salas, L., Pomalaya, J., Tolentino, D.A. & Gioda, A. 2019, 'Chemical characterization of PM 2.5 at rural and urban sites around the metropolitan area of Huancayo (Central Andes of Peru)', *Atmosphere*.
Leung, D.M., Tai, A.P.K., Mickley, L.J., Moch, J.M., Van Donkelaar, A., Shen, L. & Martin, R. V. 2018, 'Synoptic meteorological modes of variability for fine particulate matter (PM2.5) air quality in major metropolitan regions of China', *Atmospheric Chemistry and Physics*, vol. 18, no. 9.
Liang, Q., Zhang, X., Miao, Y. & Liu, S. 2024, 'Multi-Scale Meteorological Impact on PM2.5 Pollution in Tangshan, Northern China', *Toxics*, vol. 12, no. 9, pp. 1–15.
Magalhães, N. de, Evangelista, H., Condom, T., Rabatel, A. & Ginot, P. 2019, 'Amazonian Biomass Burning Enhances Tropical Andean Glaciers Melting', *Scientific Reports*, vol. 9, no. 1.
MINISTERIO DE VIVIENDA, P. n.d., *PLAN DE DESARROLLO URBANO AHUAYCHA*, no. 112.
Moch, J.M., Dovrou, E., Mickley, L.J., Keutsch, F.N., Cheng, Y., Jacob, D.J., Jiang, J., Li, M., Munger, J.W., Qiao, X. & Zhang, Q. 2018, 'Contribution of Hydroxymethane Sulfonate to Ambient Particulate Matter: A Potential Explanation for High Particulate Sulfur During Severe Winter Haze in Beijing', *Geophysical Research Letters*, vol. 45, no. 21.
de Mola, U.L., Ladd, B., Duarte, S., Borchard, N., La Rosa, R.A. & Zutta, B. 2017, 'On the use of hedonic price indices to understand ecosystem service provision from urban green space in five Latin American megacities', *Forests*, vol. 8, no. 12.
Moreno, R., Nery, A., Zamora, R., Lora, Á. & Galán, C. 2024, 'Contribution of urban trees to carbon sequestration and reduction of air pollutants in Lima, Peru', *Ecosystem Services*, vol. 67, no. March.

Muñoz-Pacheco, C.B. & Villaseñor, N.R. 2022, 'Urban Ecosystem Services in South America: A Systematic Review', *Sustainability (Switzerland)*.

Owoade, K.O., Hopke, P.K., Olise, F.S., Ogundele, L.T., Fawole, O.G., Olaniyi, B.H., Jegede, O.O., Ayoola, M.A. & Bashiru, M.I. 2015, 'Chemical compositions and source identification of particulate matter (PM2.5 and PM2.5–10) from a scrap iron and steel smelting industry along the Ife–Ibadan highway, Nigeria', *Atmospheric Pollution Research*, vol. 6, no. 1.

Pendergrass, D.C., Shen, L., Jacob, D.J. & Mickley, L.J. 2019, 'Predicting the Impact of Climate Change on Severe Wintertime Particulate Pollution Events in Beijing Using Extreme Value Theory', *Geophysical Research Letters*, vol. 46, no. 3.

Perlroth, N.H. & Branco, C.W.C. 2017, 'Current knowledge of environmental exposure in children during the sensitive developmental periods', *Jornal de Pediatria (Versão em Português)*.

Pimienta-Barrios, E., Robles-Murguía, C., Carvajal, S., Muñoz-Urias, A., Martínez-Chávez, C. & De León-Santos, S. 2018, 'SERVICIOS AMBIENTALES DE LA VEGETACIÓN EN ECOSISTEMAS URBANOS EN EL CONTEXTO DEL CAMBIO CLIMÁTICO', *Revista Mexicana de Ciencias Forestales*, vol. 5, no. 22.

Rabha, S. & Saikia, B.K. 2019, 'Advanced micro- and nanoscale characterization techniques for carbonaceous aerosols', *Handbook of Nanomaterials in Analytical Chemistry: Modern Trends in Analysis*.

Romero-Duque, L.P., Trilleras, J.M., Castellarini, F. & Quijas, S. 2020, 'Ecosystem services in urban ecological infrastructure of Latin America and the Caribbean: How do they contribute to urban planning?', *Science of the Total Environment*.

Saminathan, S. & Malathy, C. 2024, 'PM2.5 Concentration Estimation Using Bi-LSTM with Osprey Optimization Method', *Nature Environment and Pollution Technology*, vol. 23, no. 3, pp. 1631–8.

Shen, L., Mickley, L.J. & Murray, L.T. 2017, 'Influence of 2000-2050 climate change on particulate matter in the United States: Results from a new statistical model', *Atmospheric Chemistry and Physics*, vol. 17, no. 6.

Song, S., Gao, M., Xu, W., Sun, Y., Worsnop, D.R., Jayne, J.T., Zhang, Y., Zhu, L., Li, M., Zhou, Z., Cheng, C., Lv, Y., Wang, Ying, Peng, W., Xu, X., Lin, N., Wang, Yuxuan, Wang, S., William Munger, J., Jacob, D.J. & McElroy, M.B. 2019, 'Possible heterogeneous chemistry of hydroxymethanesulfonate (HMS) in northern China winter haze', *Atmospheric Chemistry and Physics*, vol. 19, no. 2.

Soto-Estrada, E. 2019, 'Estimation of the urban heat island in medellin, Colombia', *Revista Internacional de Contaminacion Ambiental*, vol. 35, no. 2.

Suárez-Salas, L., Álvarez Tolentino, D., Bendezú, Y. & Pomalaya, J. 2017, 'CARACTERIZACIÓN QUÍMICA DEL MATERIAL PARTICULADO ATMOSFÉRICO DEL CENTRO URBANO DE HUANCAYO, PERÚ', *Revista de la Sociedad Química del Perú*.

Suazo, J.M.A., Salas, L.S., Cruz, A.R.H.D. La, Vasquez, R.A., Aylas, G.R., Condor, A.R., Rojas, E.R., Ccuro, F.M., Rojas, J.L.F. & Karam, H.A. 2020, 'Direct radiative forcing due to aerosol properties at the peruvian antarctic station and metropolitan huancayo area', *Anuario do Instituto de Geociencias*, vol. 43, no. 4, pp. 404–12.

Tai, A.P.K., Mickley, L.J., Jacob, D.J., Leibensperger, E.M., Zhang, L., Fisher, J.A. & Pye, H.O.T. 2012, 'Meteorological modes of variability for fine particulate matter (PM2.5) air quality in the United States: Implications for PM2.5 sensitivity to climate change', *Atmospheric Chemistry and Physics*.

Tosca, M.G., Campbell, J., Garay, M., Lolli, S., Seidel, F.C., Marquis, J. & Kalashnikova, O. 2017, 'Attributing accelerated summertime warming in thesoutheast United States to recent reductions in aerosol burden: Indications from Vertically-resolved observations', *Remote Sensing*.

Vo, T.T.T., Wu, C.Z. & Lee, I.T. 2020, 'Potential effects of noxious chemical-containing fine particulate matter on oral health through reactive oxygen species-mediated oxidative stress:

Promising clues', *Biochemical Pharmacology*.
Vuille, M. 1999, 'Atmospheric circulation over the Bolivian Altiplano during dry and wet periods and extreme phases of the southern oscillation', *International Journal of Climatology*, vol. 19, no. 14.
Vuille, M., Bradley, R.S. & Keimig, F. 2000, 'Interannual climate variability in the Central Andes and its relation to tropical Pacific and Atlantic forcing', *Journal of Geophysical Research Atmospheres*, vol. 105, no. D10.
Vuille, M., Kaser, G. & Juen, I. 2008, 'Glacier mass balance variability in the Cordillera Blanca, Peru and its relationship with climate and the large-scale circulation', *Global and Planetary Change*, vol. 62, no. 1–2.
Vuille, M. & Keimig, F. 2004, 'Interannual variability of summertime convective cloudiness and precipitation in the central Andes derived from ISCCP-B3 data', *Journal of Climate*, vol. 17, no. 17.
Wang, X., Dickinson, R.R.E., Su, L., Zhou, C. & Wang, K. 2018, 'PM2.5 pollution in China and how it has been exacerbated by terrain and meteorological conditions', *Bulletin of the American Meteorological Society*, vol. 99, no. 1.
Wang, Y.S., Yao, L., Wang, L.L., Liu, Z.R., Ji, D.S., Tang, G.Q., Zhang, J.K., Sun, Y., Hu, B. & Xin, J.Y. 2014, 'Mechanism for the formation of the January 2013 heavy haze pollution episode over central and eastern China', *Science China Earth Sciences*, vol. 57, no. 1.
Xu, K., Cui, K., Young, L.H., Wang, Y.F., Hsieh, Y.K., Wan, S. & Zhang, J. 2020, 'Air quality index, indicatory air pollutants and impact of covid-19 event on the air quality near central china', *Aerosol and Air Quality Research*, vol. 20, no. 6.
Zardo, L., Geneletti, D., Pérez-Soba, M. & Van Eupen, M. 2017, 'Estimating the cooling capacity of green infrastructures to support urban planning', *Ecosystem Services*, vol. 26.
Zender-Świercz, E., Galiszewska, B., Telejko, M. & Starzomska, M. 2024, 'The effect of temperature and humidity of air on the concentration of particulate matter - PM2.5 and PM10', *Atmospheric Research*, vol. 312, no. October.
Zhang, R.H., Li, Q. & Zhang, R.N. 2014, 'Meteorological conditions for the persistent severe fog and haze event over eastern China in January 2013', *Science China Earth Sciences*, vol. 57, no. 1.
Zou, Y., Wang, Y., Zhang, Y. & Koo, J.H. 2017, 'Arctic sea ice, Eurasia snow, and extreme winter haze in China', *Science Advances*, vol. 3, no. 3.
Zu, Y., Huang, L., Hu, J., Zhao, Z., Liu, H., Zhang, H., Ying, Q. & Chen, M. 2017, 'Investigation of relationships between meteorological conditions and high PM10 pollution in a megacity in the western Yangtze River Delta, China', *Air Quality, Atmosphere and Health*, vol. 10, no. 6.
Zyromski, A., Biniak-Pieróg, M., Burszta-Adamiak, E. & Zamiar, Z. 2014, 'Evaluation of relationship between air pollutant concentration and meteorological elements in winter months', *Journal of Water and Land Development*, vol. 22, no. 1.