Journal of Radioanalytical and Nuclear Chemistry (2023) 332:3507–3514
https://doi.org/10.1007/s10967-023-08805-8

Determination of atmospheric aerosol components in an urban area to evaluate the air quality and identify the sources of contamination

Patricia Bedregal[1] · Marco Ubillus[1] · Cynthia Cáceres-Rivero[1] · Paula Olivera[1] · Roy Garay[2] · Jhojan Rojas[2] · Rafael Zafra[3] · Renato Urdanivia[4]

Received: 21 September 2022 / Accepted: 27 January 2023 / Published online: 15 February 2023

Abstract
The need to generate objective evidence and reliable information for decision makers to improve environmental policies for a better air quality, led us to evaluate the atmospheric aerosol components in the urban area of Carabayllo, by monitoring $PM_{2.5}$ and PM_{10} to determine mass concentration and analyzing PM_{10} using k_0-INAA and ICP–MS for metals quantification, ion chromatography for anions and the NIOSH method to determine organic and elemental carbon. The results obtained from mass concentration of $PM_{2.5}$ and PM_{10} exceeded the permissible breathing annual average of WHO guidelines of 15 μgm^{-3} and 45 μgm^{-3}, respectively, which evidence an unhealthy air quality. Likewise, using the model Positive Matrix Factorization five sources of pollutants were defined: metallurgical industry, sea salt, industrial activity, dust and non-exhaust emissions and vehicle emissions.

Keywords Aerosols · Particulate matter · Atmospheric aerosol components · Source of contamination

Introduction

As it is well known, aerosols or particulate matter, PM, are solid or liquid, larger than a molecule but small enough to remain suspended in the atmosphere [1]. The origin of PM is due to natural or anthropogenic sources, being the last ones considered pollutants. The composition of unpolluted air is nitrogen 78% by volume, oxygen 20.95%, argon 0.93% and carbon dioxide 0.032%. These four components make 99.99% clean, dry air. Another major component of clean air is water, which is found in varying amounts. Depending on temperature and evaporation rate from available water sources, it ranges from 1 to 3%. The minor components are numerous and several of them come from various natural processes. H_2S, SO_2 and CO are released into the atmosphere by volcanic activity. The putrefaction of plants and animals under conditions where there is no oxygen produces CH_4, NH_3 and H_2S. Nitrogen oxides (NO_2, NO) are produced by electrical discharges during storms and tons of CO are generated in forest fires [2]. The size of the PM matters and it range from 0.001 to 100 µm in diameter and the shape of aerosols range from spherical to quite irregular, e.g. fume and dust which are solid PM, range between 0.0001–1 µm and 1–10,000 µm, respectively. Mist and spray, approximately between 0.01–1000 µm and 10–10,000 µm, respectively [3]. There is a clear, available and sustained evidence of the risk to human health and the ecosystems by high concentrations of PM [4]. Atmospheric particles contain inorganic ions, metallic compounds, elemental carbon, organic compounds, and crustal compounds. Primary particles are emitted directly from sources; whereas secondary particles are formed from gases through chemical reactions in the atmosphere involving atmospheric oxygen (O_2) and water vapor (H_2O); reactive species such as ozone (O_3); radicals such as the hydroxyl (COH) and nitrate (CNO_3) radicals; and pollutants such as sulfur dioxide (SO_2), nitrogen

✉ Patricia Bedregal
pbedregal@ipen.gob.pe

1 Laboratorio de Técnicas Analíticas, Instituto Peruano de Energia Nuclear, IPEN, Av. Canada 1480, San Borja, Lima 15034, Peru

2 Subdirección de Control Ambiental, Servicio Nacional de Meteorología e Hidrología, SENAMHI, Jr. Cahuide 785, Jesús María, Lima, Perú

3 Facultad de Química, Universidad Nacional Federico Villarreal, Jr. Chepen 290, El Agustino, Lima, Perú

4 Dirección de Evaluación Ambiental, Organismo de Evaluación y Fiscalización Ambiental, OEFA, Av. Faustino Sánchez Carrión 603, Jesús María, Lima, Perú

oxides (NO_X), and organic gases from natural and anthropogenic sources [5]. Two types of PM are mostly evaluated, fine particles less than 2.5 μm in diameter ($PM_{2.5}$) and coarse particles, less than 10 μm in diameter (PM_{10}), both can cause health problems ranging from respiratory problems, chronic diseases, lung cancer, pneumonia to reaching the bloodstream and entering the cardiovascular system, being responsible for neurological disorders and cardiovascular accidents. There is even evidence that long-term exposure would affect the immune system making it susceptible to any type of respiratory disease, including COVID-19 [6].

Good air quality in megacities should be a priority issue to be considered and routinely assessed in order to implement environmental strategies, improve legislation and prevent health and climate change problems. The last WHO global air quality guidelines (2021) [7] recommend the target values of 15 μg m^{-3} and 45 μg m^{-3} for $PM_{2.5}$ and PM_{10}, respectively; annually and during 24 h, which are values more strict than the before ones (2005), $PM_{2.5}$ (25 μg m^{-3}) and PM_{10} (50 μg m^{-3}) [8]. However, developing countries have higher target values. The air quality standard (ECA, for its Spanish acronym) in Peru is 50 μg m^{-3} and 100 μg m^{-3} for $PM_{2.5}$ and PM_{10}, respectively [9]. In addition, air quality bodies in Peru conduct monitoring of PM_{10}, $PM_{2.5}$, nitrogen dioxide, sulphur dioxide, hydrogen sulphide, carbon monoxide and ozone, but they do not measure the PM components. WHO has highlighted that more than 7 million premature deaths are associated with exposure to air pollution and could become a public health problem in many countries [6], with developing countries being the most vulnerable. Peru is one of them and for this reason, the authors decided to take action and monitor an urban area, called Carabayllo, located in the city of Lima.

The city of Lima concentrates most of the population, making it one of the mega-cities of Latin America, where approximately one third of Peru's population lives. This growth has meant that many of the industries that were once located on the periphery of the city are now immersed in population centers. Moreover, as published in the National Road Safety Strategic Plan 2017–2021 [10], Lima is the home of two third of the national vehicle fleet, which has increased indiscriminately in the last seven years, unfortunately not in quality and for example, from 2 million 286 thousand vehicles in 2009 increased to 5 million 244 thousand in 2015.

Particulate matter air pollution has been extensively investigate in many countries, like China and USA then, in some countries of Europe and quite less in Latin America (Scopus data base, number of publications), due to its impact on the air quality, human health and climate change [11–17]. The studies comprise the determination of chemical composition of PM after the sampling using high volume samplers and quartz filters, low volume samplers and Teflon filters to proceed with the analysis of a series of species to, finally identify the sources and their contribution to the atmosphere and the impacts on air quality.

The objective of this survey was to obtain scientific evidence on the quality of air in the assessed locality and to identify possible sources of pollution in order to provide it to decision-makers with the aim of improving legislation and the quality of life of the inhabitants.

Experimental

Sampling site and sampling campaign

The district of Carabayllo [18] was chosen as the first evaluation site. It has an area of 416 000 km^2 and a population of 301 878 inhabitants. Its geographical coordinates are 11° 53′ 24″ South and longitude 77° 1′ 37″ West. It has a strategic location with respect to the access routes for agricultural products from the highlands and the jungle to international shipping points by road or air. Carabayllo was a zone of agricultural land, but in 1960 human settlements began to be installed, which continued to expand in the uncultivated areas of the foothills and hills, occupying agricultural areas, mainly by urban developments. By 1975, the district continued to grow in terms of population, with invasions and without planning. To date, there are areas in the district where the roads have not been paved, a number of mechanics' workshops have been set up, and traffic has intensified. Samples were collected at the monitoring site used by the National Service of Hydrology and Meteorology [19], located in an urban area at a latitude of 11° 54′ 7.9 S and a longitude of 77° 2′ 1″ W, corresponding to 190 m above sea level.

Particulate matter sampling started on April 03 2019, using a high volume sampler Thermo Scientific® [20] for particles smaller than 10 microns (HV PM_{10}) and a low volume sampler Partisol for particles smaller than 2.5 microns (LV $PM_{2.5}$) Thermo Scientific® [21]. The first sampler used a 203 mm × 254 mm Whatman quartz filters and the other used a Whatman 47 mm diameter Teflon filters. In both cases, sampling was carried out for 24 h, according to UNE guidelines [22] and the filters were replaced every 2 days. This criterion was adopted in order to have 10 samples of each particulate matter size per month and to provide good statistics during the 10-month study. Following the protocol of the laboratory, the quartz filters were heated at 600 °C for 6 h before being weighed and placed in the sampler to ensure that they were free of organic matter. After sampling, the quartz filters were removed from the sampler, folded and placed between two sheets of paper and packed in an envelope to be taken to the laboratory. The Teflon filters were removed from the sampler and placed in their corresponding

petri dishes. Transfer to the laboratory was done in storage boxes at a controlled temperature of 10 °C.

$PM_{2.5}$ and PM_{10} mass concentrations determination

Eighty-two HV PM_{10} samples and ninety-two LV $PM_{2.5}$ were collected. The determination of the mass concentration was carried out gravimetrically by weighing the filters before and after sampling using a Mettler Toledo analytical balance, $d = 0.1$ mg. Each month, a blank filter was taken to sampling in order to obtain the field filter. The mass concentration result (μg m^{-3}) is calculated as the difference in mass of the sampled and unsampled filter (μg), divided by the sample volume, determined as the flow rate (m^3 h^{-1}) multiplied by the sampling time (h).

Analytical techniques to species determination in PM_{10}

The quartz filter was divided and cut into sections for species analysis:

k_0-Instrumental Neutron Activation method: Neutron activation analysis is a nuclear analytical technique used for the identification and quantification of chemical elements in different types of matrices. It is one of the most reliable techniques for trace element analysis. Among its analytical characteristics that apply for this type of study, is that it is non-destructive, i.e. the sample does not require dissolution, which means that there would be no loss due to incomplete digestion or the possibility of contamination by over-handling of the sample [23]. One of the important advances in the technique was the development of the k_0 method in 1975 [24], which main advantage is the use of a single comparator, especially when large volumes of samples have to be analyzed. It requires a calibration of the irradiation site f and α, and the calibration of the detectors determining peaks efficiency.

In order to fit the sample inside the irradiation can and to define the best geometry for irradiation and measurement, the sections of the filter to be analyzed by the k_0-method was cut it into 30 × 30 mm pieces. Zn standard solutions SRM-NIST 3168a was used to prepare comparators by depositing and weighing approximately 534 μg [25] on 30 × 30 mm piece of filter paper Whatman 42. Similarly, a suitable volume of the mixed Mo–Au–Co solution was deposited on a filter paper to obtain the ratio of the thermal and epithermal neutron flux rate ($f = \Phi_{th}/\Phi_e$), and the deviation of the epithermal neutron flux rate distribution, alpha (α), parameters of the irradiation site [26–28].

The samples, comparators and monitors were packed into polyethylene bags and placed in a stacked manner inside the aluminum can to be irradiated for 4 h in one position of the core grid in the RP-10 research reactor of the RACSO Atomic Centre of the Peruvian Institute of Nuclear Energy (IPEN). The reactor operates at a power of 6 MW. The parameters of the irradiation positon were $f = 28$; $\alpha = 0.063$; the thermal flux was $\Phi th = 3 \ldots E^{13}$ cm^{-2} s^{-1} and the epithermal flux, $\Phi e = 1 \ldots E^{12}$ cm^{-2} s^{-1}. After a decay time of 5 days, a first measurement was performed for 5000 s and a second one after 20 days for 20,000 s. The Zn comparator was measured for 600 s between 15 and 20 days of decay, using a gamma spectrometry system Canberra GC4018, 40% efficiency, FWHM = 1.8 keV at 1332.5 keV Co-60 HPGe detector. Considering that the sample geometry was different from the one used in the laboratory i.e. pellets of 13 mm in diameter and 2 mm thickness, a new efficiency curve was determined for this new geometry of 30 × 30 mm of the sample filter [29]. Gamma spectrum analysis was done using Canberra software Genie 2000 and for concentration calculation, an in-house developed software application was used based on an excel spreadsheet and macros written in the Visual Basic for application (VBA) tool from Microsoft [30]. Under those conditions the elements Ag, As, Ba, Br, Ce, Co, Cr, Cs, Fe, K, Na, Sb, Sc, Rb and Zn were quantified for this study. Other elements, such as Hg and Se were not possible to determine because there were not detected.

The k_0 factors used for concentration calculation and other relevant nuclear data (Q_0, $\hat{E}_r$, $T_{1/2}$, isotopic abundance, etc.) were adopted from the updated k_0 data base 2020.

The quality control of the method was carried out by analyzing the SRM-NIST 1643 water standard reference material. For this purpose, a volume of the solution was deposited and weighed on a piece of Whatman 42 filter paper of the same geometry as the sample and comparator and the same analysis protocol was followed for the measurement and calculation of the concentration of the quantified analytes.

Inductively Coupled Plasma–Mass Spectrometry (ICP–MS) and Ion Chromatography (IC): For ICP–MS analysis, a 44.45 cm^2 area of the filter was used, digesting the sample with HNO_3 and HCl suprapur quality Merck, for metal trace analysis (metal concentration are in the ppb range) and using standard multi-element solutions, following the recommendations of the Environmental Protection Agency [31]. Al, Ca, Cd, Cu, Hg, K, Mg, Mn, Ni, Pb, Ti, Se and V were quantified. The anions F^-, Cl^-, NO_3^- and SO_4^{-2} by ion chromatography were characterized taken 22.23 cm^2 of sample quartz filter. The validity of the results analyzed by ICP–MS was ensured by the participation in the Worldwide Open Proficiency Test for Analytical Laboratories involved in Air Pollution Studies, PTXRFIAEA14, organized by the International Atomic Energy Agency [32], where the z-scores for As, Cu, Mn, Ni, Pb, V and Zn were 0.06, 0.92, 1.21, − 1.60, − 0.23, − 0.38 and − 0.41, respectively.

Organic carbon (OC) and elemental carbon (EC): The analysis of OC and EC was performed using the method NIOSH (National Institute of Occupational Safety and

Table 1 Mean, standard deviation (*s*), number of samples (*n*), and minimum (Min) and maximum (Max) results obtained of mass concentration of $PM_{2.5}$ μg m^{-3} during sampling time, including year season

	Year	Seasons			
		Fall	Winter	Spring	Summer
Mean	32.9 ± 2.1	35.3 ± 3.3	40.7 ± 3.3	29.4 ± 3.8	23.2 ± 2.2
s	10.1	7.8	9.0	7.7	5.2
n	91	22	28	16	22
Min	15.3	22.9	24.6	19.1	15.3
Max	54.9	50.8	54.9	46.5	33.8

Table 2 Mean, standard deviation (*s*), number of samples (*n*), and minimum (Min) and maximum (Max) results obtained of mass concentration of PM_{10} μg m^{-3}, during sampling time including year season

	Year	Seasons			
		Fall	Winter	Spring	Summer
Mean	111.3 ± 4.6	129 ± 11	111.3 ± 6.6	102.1 ± 9.1	95.6 ± 2.4
s	21.3	25.6	17.1	15.4	5.3
n	83	22	26	11	19
Min	80.9	84.8	83	81	83.7
Max	168.9	168.9	136	129.7	102.9

Health), a thermo-optic method [33, 34]. The detection and quantification limits for carbon were 0.05 μg cm^{-2} and 1.0 μg cm^{-2}, respectively.

Results and discussion

The results of the PM_{10} and $PM_{2.5}$ sampling, carried out from April 2019 to March 2020, just before the start of the COVID-19 pandemic restrictions, are shown in Tables 1 and 2 below. The results obtained are worrying as they exceed the optimal values given by the WHO [7] and even, in several cases, the most conservative values of the Peruvian legislation [9], Figs. 1 and 2. $PM_{2.5}$ and PM_{10} are highest in the autumn and winter seasons and in both cases, there is a trend to descending in spring and summer. Evaluating the results of $PM_{2.5}$, the mean mass concentration during the monitoring campaign exceed the double the WHO value and only two days in winter and one day in autumn seasons exceed the ECA-PER of 50 μg m^{-3}.

Since the beginning of the monitoring, the mass concentration of $PM_{2.5}$ decreased by 66% by the end of the campaign, as shown in the mean results for each season. It can be said that the WHO target value according to the 2021 guidelines was not accomplished, which would mean a non healthy air quality during the time of the monitoring. Following the air quality standard, ECA-PER, only 3 days of the monitoring period, the air quality was unhealthy.

Although the PM_{10} results follow the same trend as $PM_{2.5}$ the correlation coefficient, calculated using an Excel spreadsheet, between the two variables is only 0.2206, indicating a weak correlation. The mass concentration in this case has descending 74% from autumn to summer. The average aerosols of 10 microns or less exceed the WHO target value by 2.5 times and the Peruvian ECA by 11.3%. The cases of concentrations exceeding the ECA are autumn > spring > winter > summer. The quality of air in this case is unhealthy. The same trend regarding the descending seasonal mass concentration has been found by other authors [35]. Those authors

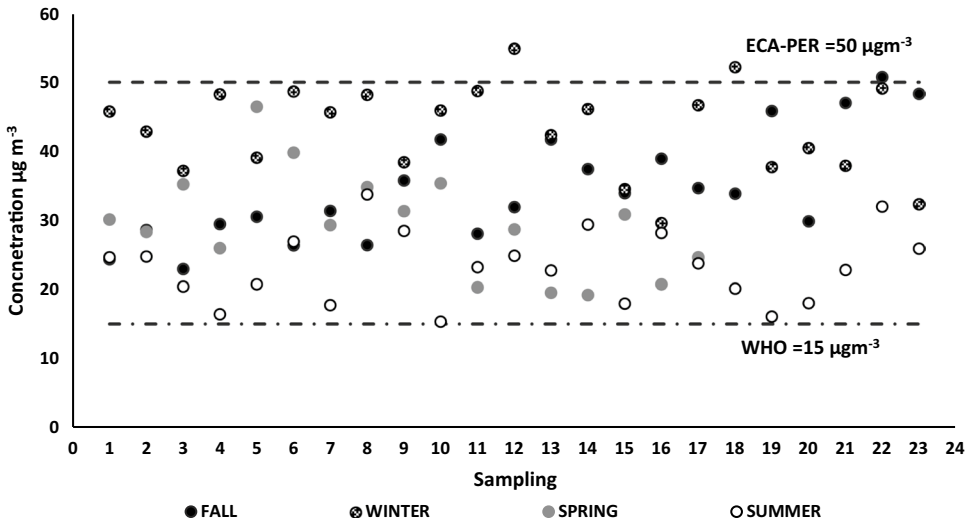

Fig. 1 Distribution of mass concentration of $PM_{2.5}$ and comparison with WHO target value and ECA of Peru

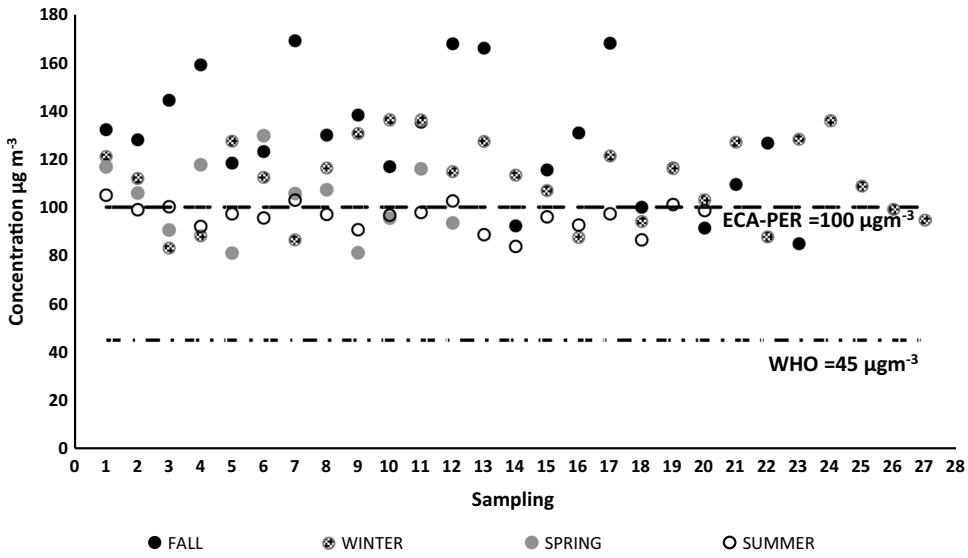

Fig. 2 Distribution of mass concentration of PM_{10} and comparison with WHO target value and ECA of Peru

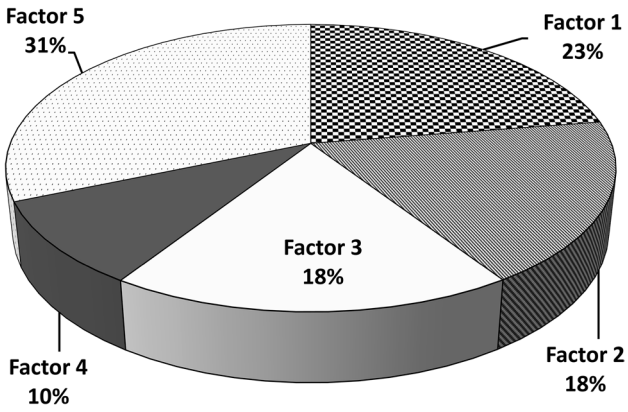

Fig. 3 PM_{10} source contribution to air pollution at Carabayllo site

also shown how it is possible to reduce the air pollution with a series of control policies, laws and regulations. They issued the "Air Pollution Prevention and Action Plan" (APPCAP), by setting specific quantitative targets and took action on the control measures on coal/fired emissions during the heating seasons. With that Action Plan, from 2013 to 2019, China reduced the concentration of $PM_{2.5}$ from 89.5 µg m^{-3} to 42 µg m^{-3}. Those values are lower than those obtained at the Carabayllo monitoring site of this study.

The Positive Matrix Factorization, PMF model [36] was used and run it very well with the data and uncertainties calculated. It decomposes a matrix of speciated sample data into two matrices: factor contributions and factor profiles, in orden to understand the factors or sources impacting the speciared sample data [37]. The profiles and distribution of pollution sources has been evaluated in 54 samples of PM_{10}, using 33 species, Figs. 3 and 4. The final solution of the model gave us five factors of contribution to the atmospheric contamination. The contribution of factor 1 is 23% and it was defined mainly as metal industry because the high concentration of CO, CE, Ag, Cd, Ce, Co, Cr, Fe, Hg, Pb, Sc, Zn. The various metal mechanical workshops, smelters developed in the area contribute with high values of heavy metals. Factor 2 and factor 3 have the same contribution, 18%. Factor 2 was identified as sea salt, because of the highest percentage of Br, Na, Cl^- and F^-. Lima is a coastal city, bordered on the west by the Pacific Ocean, and the presence of those elements is the fingerprint of marine source. The factor 3 was catalogued as industrial activity. The high percentage of metals such as Al, Cd, Co, Cu, Hg, Ni, Pb, Ti and V confirm the profile assigned. In the neighboring district, two kilometers away, there is a paper factory and a building products factory, as well as several factories producing bricks that can be contributing to the contamination. Because of the long residence times, transport of particulate material in the atmosphere can extend over long distances e.g. 100–1000 km [3].

Factor 4 has been associated to dust and non-exhaust contribution. Several elements have high percentage of concentration. The elements Al, Ca, Mg, Mn, Ti correspond to crustal origin and other metals such as Cd, Co, Ce, Cr, Cu, Fe, Ni, Pb, SO_4^{-2} from anthropogenic origin, comes from road re-suspended dust and the friction of the brakes and tires from vehicles. The high percentage of K can also indicate biomass burning. As mentioned, several streets in the district are not paved; brick factories and vehicular traffic contribute to this profile. The last factor number 5 has the highest contribution, 32%. It was characterized by a high percentage of OC, EC, Ba, Br, Cr, Cu, Ni, Pb, Sb, V, Zn, NO_3^- and SO_4^{-2} and may represent different sources of combustion. The presence of EC, V, Ni, Pb, Sb, SO_4^{-2} is

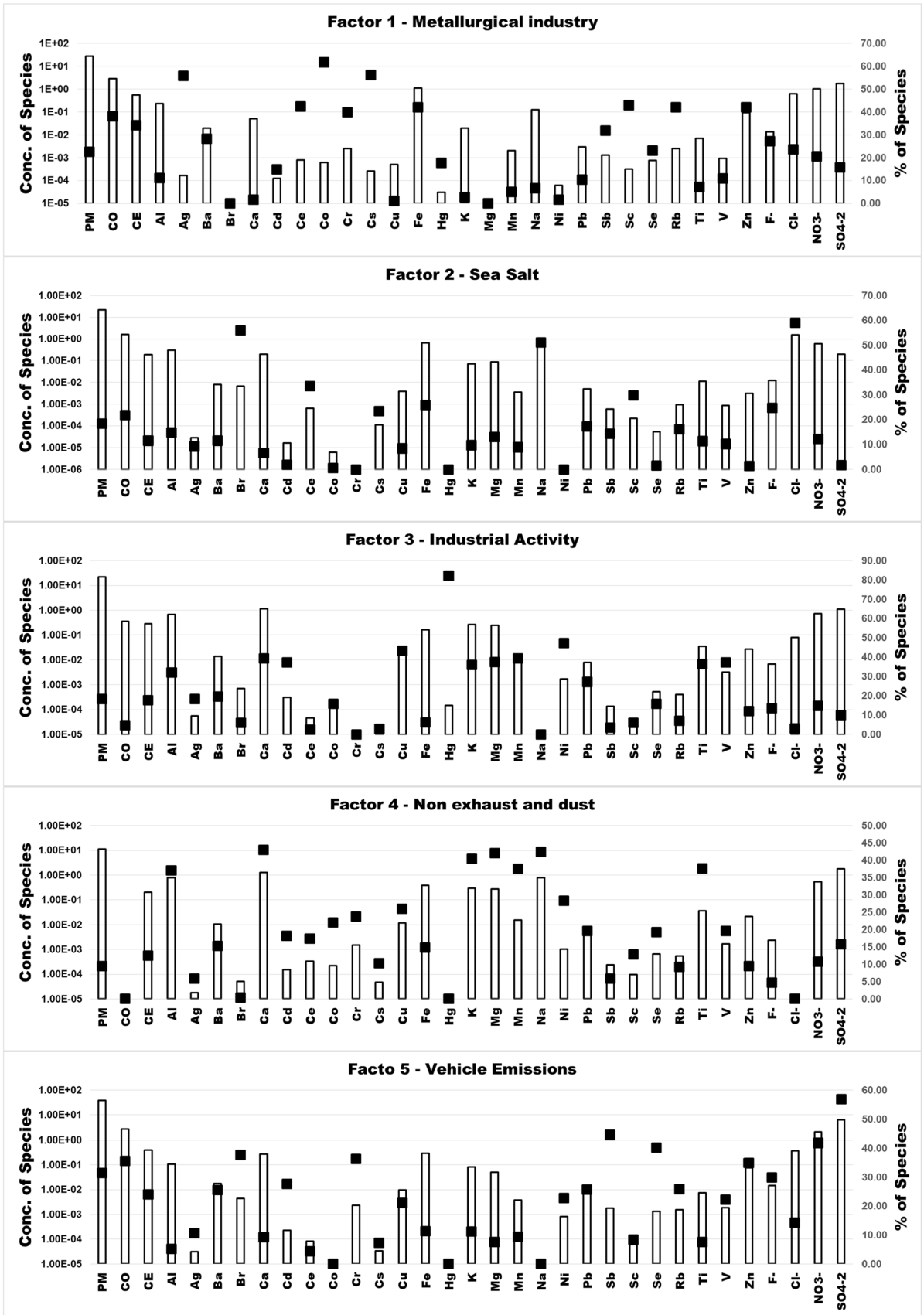

Fig. 4 PM_{10} chemical species profiles (concentration μg m^{-3})

Table 3 Results of quality control for k_0-INAA (μg kg^{-1}), Quantification limits (QL)

Elements	Lab results	SRM certified values	QL	En-number
As	61.1 ± 3.3	58.98 ± 0.70		0.63
Co	25.0 ± 1.5	26.4 ± 0.32		0.91
Na	24,906 ± 1230	20,230 ± 250		3.72
Fe		95.7 ± 1.4	< 110	
Sb	53.3 ± 2.6	56.88 ± 0.6		1.34
Zn		76.5 ± 2.1	< 2000	

characteristic of exhaust emissions from oil-fueled vehicles [38–42].

The results of the quality control of the k_0-INAA method are shown in Table 3. As it can be seen, the results obtained are satisfactory, with the exception of Na, where En value is higher than 1. This high result may be due to contamination by handling, at the time of sample preparation and being close to the limit of quantification for sodium.

Conclusion

Based on the results of mass concentration obtained in $PM_{2.5}$ and PM_{10}, which exceed the permissible values recommended by WHO, the air quality in the Carabayllo district is not healthy.

It was identified five sources that contributes to high percentage of species in the atmosphere: vehicle exhaust 32%, metallurgical industry 22%, sea salt 18%, industrial activity 18%, and dust and no-exhaust emissions 10%.

The scientific evidence showed in this study, is by far good enough to implement environmental strategies for the inhabitants of Carabayllo.

The analytical techniques used in this evaluation demonstrate its complementary.

Acknowledgements The authors would like to thank to the Environmental Analysis Laboratory of the University of Costa Rica for their collaboration with some sample analysis and the International Atomic Energy Agency for providing the materials and equipment for this study.

References

1. Environmental Protection Agency (2004) Air quality criteria for particulate matter EPA/600/P-99/002aF
2. Brimblecombe P (1996) Air composition and chemistry University Press. Great Britain, Cambridge
3. Fergusson J (1990) The heavy elements. Chemistry, environmental impact and health effects. Pergamon Press, New York
4. Shaughnessy WJ et al (2015) Health effects of ambient levels of respirable particulate matter (PM) on healthy, young/adult population. Atmos Environ 123:102–111
5. Environmental Protection Agency (2004) Air quality criteria for particulate matter, National center for environmental assessment-RTP office of research and development U.S. environmental protection agency research Triangle Park, NC
6. Why air pollution is a major public health emergency (2020). https://fb.watch/bqGFBDz41G/
7. World Health Organization global air quality guidelines. Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide (2021) ISBN 978-92-4-003422-8
8. World Health Organization .Air Quality Guidelines Global update (2005) ISBN 92-890-2192-6
9. Ministerio del Ambiente (2017) Estándares de Calidad del Aire, DS-003-2017-MINAM
10. Ministerio de Transportes y Comunicaciones (2021). https://www.mtc.gob.pe/cnsv/documentos/PlanEstrategico.PDF
11. Di Vaio P, Magli E, Caliendo G, Corvino A et al (2018) Heavy metal size distribution in PM_{10} and environmental-sanitary risk analysis in Acerra (Italy). Atmosphere 9:58
12. Oakes M, Burke J, Gary A, Norris GA, Kovalcik K, Pancras J, Landis M (2016) Near-road enhancement and solubility of fine and coarse particulate matter trace elements near a major interstate in Detroit. Mich Atmos Environ 145:213–224
13. Horacio Rojas-Rodriguez, Agnes Soares da Silva, José Luis Texcalac-Sangrador, Grea Litai Moreno-Banda (2016) Air pollution managenent and control in Latin America and the Caribbean: implications for climate change. Rev Panam Salud Pública 40(3):150–59
14. Shaughnessy W, Venigalla M, Trump D (2015) Health effects of ambient levels of respirable particulate matter (PM) on healthy, young-adult population. Atmos Environ 123:102–111
15. Theodosi C, Grivs G, Zarmpas P, Chaloulakou A, Mihalopoulos N (2011) Mass and chemical composition of size-segregated aerosol (PM_1, $PM_{2.5}$, PM_{10}) over Athens, Greece: local versus regional sources. Atmos Chem Phys 11:11895–11911
16. Chow J, Lowenthal D, Antony Chen L-W, Wang X, Watson J (2015) Mass reconstruction methods for $PM_{2.5}$: a review. Air Qual Atmos Health 8:243–263
17. Grivas G, Cheristanidis S, Chaloulakou A (2012) Elemental and organic carbon in the urban environment of Athens. seasonal and diurnal variations and estimates of secondary organic carbon. Sci Total Environ 414:535–545
18. Alvarez R, Batazar V, Velasquez R (2010) Plan urbano del distrito de Carabayllo. Municipalidad de Carabayllo. http://www.municarabayllo.gob.pe/Distrito
19. Boletín Mensual Vigilancia de la Calidad del Aire en Lima Metropolitana Servicio Nacional de Meteorología e Hidrología del Perú Senamhi (2018) 18(9)
20. Jutze G, Foster K (1967) Recommended standard method for atmospheric sampling of fine particulate matter by filter media-high volume sampler. J Air Pollut Meas Commit 17(1):17–25
21. Thermo Scientific (2011) Partisol 2000i/air sampler. Instruction manual part no. 110735-00
22. UNE-EN 12341, Asociación Española de Normalización y Certificación (2015) Ambient air. Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2.5}$ mass concentration of suspended particulate matter
23. Greenberg R, Bode P, De Nadai Fernandes EA (2011) Neutron activation analysis: a primary method of measurement Spectrochem Acta Part B 193–241
24. Simonits A, De Corte F (1975) Single comparator methods in reactor neutron activation analysis. J Radioanal Nucl Chem 2:31–46

25. Bedregal P, Ubillus M, Poma V, Cohen IM (2018) The preparation of monitors and comparators for k0-INAA using standard solutions. J Radioanal Nucl Chem 315:695–701
26. Simonits A, De Corte F, Hoste J (1976) Zirconium as a multi-isotopic flux ratio monitor ad a single comparator in reactor-neutron activation analysis. J Radioanal Nucl Chem 31:467–486
27. De Corte F, Simonits A, Hoste J, De Wispelaere A (1987) Accuracy and applicability of the *k*0-standardization method. J Radioanal Nucl Chem Articles 113:145–161
28. Simonits A, De Corte F, Hoste J, De Wispelaere A (1987) Nuclear data measurements for zirconium isotopes used for activation analysis and neutron metrology. J Radioanal Nucl Chem Articles 113:187–197
29. Bedregal P, Mendoza P, Ubillus M, Montoya E (2010) k_0-INAA method accuracy using Zn as comparator. Nucl Instrum Methods Phys Res A 622:419–424
30. Montoya E, Pardo J,.Mendoza P, Ubillus M, Bedregal P, Torres B (2008) k_0-based INAA using MS-excel and canverra genie 2000, Informe Cientifico Tecnologico IPEN ISSN 1684-1662
31. Environmental Protection Agency EPA/625/R-96/010a (1999) Determination of metals in ambient particulate matter using ICP/MS. Compendium of methods for the determination of inorganic compunds in ambient air. IO/3.5, USA
32. International Atomic Energy Agency (2019) Worldwide open proficiency test for analytical laboratories involved in air pollution studies PTXRFIAEA14. Determination of elemental composition of an Urban Dust Loaded on Air Filters
33. Peterson MR, Richards MH (2002) Thermal-optical transmittance analysis for organic, elemental, carbonate, total carbon, and OCX2 in $PM_{2.5}$ by the EPA/NIOSH method. In: Proceedings, symposium on air quality measurement methods and technology Pittsburgh, 83-81-83-19
34. Chow J, Watson J, Crow D, Lowenthal D, Merrifield T (2010) Comparison of IMPROVE and NIOSH carbon measurement. Aerosol Sci Technol 34–1:23–24
35. Li W, Shao L, Wang W, Li H, Wang X, Li Y, Li W, Jones T, Zhang D (2020) Air quality improvement in response to intensified control strategies in Beijing during 2013–2019. Sci Total Environ 744:140776
36. Comero S, Capitani L, Manfred B (2009) Positive Matrix Factorisation (PMF) An introduction to the chemometric evaluation of environmental monitoring data using PMF JRC scientific and technical reports European commission joint research centre institute for environment and sustainability EUR 23946 EN. ISBN 978-92-79-12954-4. ISSN 1018-5593. https://doi.org/10.2788/2497
37. Brown S, Eberly S, Paatero P, Norris G (2015) Methods for estimating uncertainty in PMF solutions: examples with ambient air and water quality data and guidance on reporting PMF results. Sci Total Environ 518–519:626–635
38. Mantas E, E. Remoundaki E, Halari I, et al (2014) Mass closure and source apportioment of $PM_{2.5}$ by possitve matrix factorization analysis in urban Mediterranean environment. Atmos Environ 94:154–163
39. Masiol M, Squizzano S, Ceccato D, Rampazzo G, Pavoni B (2012) Determining the influence of different atmospheric circulation patterns on PM_{10} chemical compositionin a source apportionmment study. Atmos Environ 63:117–124
40. Pandolfi M, Gonzalez-Castanedo Y, Alastuey A et al (2011) Source apportionment of PM_{10} and $PM_{2.5}$ at multiple sites in the strait of Gibraltar by PMF: impact in shipping emissions. Eviron Sci Pollut Res 18:260–269
41. Amato F, Pandolfi M, Escrig A, Querol X, Alastuey A, Pey HJ, Perez N, Hopke PK (2009) Quantifying road dust resuspension in urban environment by multilinear engine: a comparison with PMF2. Atmos Environ 43:2770–2780
42. Amato F, Pandolfi M, Viana M, Querol X, AlastueyA MT (2009) Spatial and chemical patterns of PM_{10} in road dust deposited in urban environment. Armos Environ 43:1650–1659