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AG EDITOR

REVIEW

Atmospheric pollution by PM 2.5 and microplastics: risks and scientific advances

Contaminación atmosférica por PM 2.5 y microplásticos: riesgos y avances científicos

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ABSTRACT

Introduction: pollution by fine particulate matter (PM2.5) and microplastics (PMs) appeared as a growing environmental and public health problem. PM2.5 particles, with a diameter of less than 2,5 µm, penetrated deeply into the respiratory system, while PMs, plastic fragments smaller than 5 mm, acted as carriers of pollutants. Scientific evidence indicated that their combination could increase respiratory, cardiovascular and oncological risks.
Development: international and local studies reported variable concentrations of PM2.5, from low values in Villavicencio and Tarapoto to critical levels in Shanghai, New Delhi and Brazilian cities, where WHO recommendations were widely exceeded, especially in winter. Research such as that of Zhu et al. and Abbasi identified PMs in PM2.5 fractions, using techniques such as FTIR spectroscopy and scanning electron microscopy (SEM/EDS). The main sources were documented to include transportation, industrial emissions, domestic combustion and degradation of major plastics. Meteorological factors such as temperature, humidity and wind speed influenced particle dispersion. Spatial and temporal variability evidenced the need for integrated and accurate monitoring systems.
Conclusions: the interaction between PM2.5 and PMs generated a complex environmental risk scenario, requiring public policies to reduce emissions and regulate the use of plastics. Methodological advances improved detection, although limitations persisted in understanding their chronic effects. Evidence supported that early and coordinated action was key to mitigate impacts on health and the environment.

Keywords: PM2.5; Microplastics; Public Health; Atmospheric Pollution; Environmental Monitoring.

RESUMEN

Introducción: la contaminación por material particulado fino (PM2.5) y microplásticos (MPs) se presentó como un problema ambiental y de salud pública creciente. Las partículas PM2.5, con diámetro inferior a 2,5 µm, penetraron profundamente en el sistema respiratorio, mientras que los MPs, fragmentos plásticos menores a 5 mm, actuaron como portadores de contaminantes. La evidencia científica indicó que su combinación pudo incrementar riesgos respiratorios, cardiovasculares y oncológicos.
Desarrollo: estudios internacionales y locales reportaron concentraciones variables de PM2.5, desde valores bajos en Villavicencio y Tarapoto hasta niveles críticos en Shanghái, Nueva Delhi y urbes brasileñas, donde se superaron ampliamente las recomendaciones de la OMS, especialmente en invierno. Investigaciones como las de Zhu et al. y Abbasi identificaron MPs en fracciones de PM2.5, empleando técnicas como espectroscopia FTIR y microscopía electrónica de barrido (SEM/EDS). Se documentó que las fuentes principales incluyeron transporte, emisiones industriales, combustión doméstica y degradación de plásticos mayores. Factores

meteorológicos como temperatura, humedad y velocidad del viento influyeron en la dispersión de las partículas. La variabilidad espacial y temporal evidenció la necesidad de sistemas de monitoreo integrados y precisos.
Conclusiones: la interacción entre PM2.5 y MPs generó un escenario de riesgo ambiental complejo, requiriendo políticas públicas para reducir emisiones y regular el uso de plásticos. Los avances metodológicos mejoraron la detección, aunque persistieron limitaciones para comprender sus efectos crónicos. La evidencia respaldó que la acción temprana y coordinada fue clave para mitigar impactos sobre la salud y el ambiente.

Palabras clave: PM2.5; Microplásticos; Salud Pública; Contaminación Atmosférica; Monitoreo Ambiental.

INTRODUCTION

Air pollution from fine particulate matter (PM2.5) has become one of the most significant environmental and public health problems worldwide. PM2.5 particles, with a diameter of less than 2.5 micrometers, can penetrate deep into the respiratory system, reaching the pulmonary alveoli and causing adverse effects including respiratory and cardiovascular diseases and lung cancer. The World Health Organization (WHO) considers air pollution to be one of the ten main threats to global health, estimating that PM2.5 pollution is responsible for 62 % of deaths attributable to poor air quality and a significant loss of disability-adjusted life years (DALYs).(1)

Several studies have documented the presence and variability of PM2.5 in different regions. In cities such as Villavicencio (Colombia) and Tarapoto (Peru), measured levels have remained below national standards, although with variations influenced by meteorological factors such as temperature, humidity, and wind speed. In contrast, research in megacities in China, India, and Brazil has shown concentrations that far exceed WHO recommendations, especially during winter, revealing daily peaks associated with mobility patterns and industrial emissions.(2)

In addition, in recent years there has been growing concern about the interaction between PM2.5 and microplastics (MPs). The latter, defined as plastic fragments smaller than 5 mm, come from both primary sources (industrial microspheres and pellets) and secondary sources (fragmentation of larger objects) and have been found in various environments, including the air. Studies using advanced techniques such as Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) have detected plastic particles of sizes comparable to PM2.5 in urban and indoor environments, suggesting an additional potential risk to human health due to their ability to transport chemical and biological contaminants.(3)

The identification and characterization of PM2.5 and MPs requires accurate and standardized analytical methods, such as gravimetric sampling, the use of selective separators such as WINS or VSCC, and composition analysis using FTIR and SEM/EDS. The complexity of these particles and their diverse origins make it difficult to assess their ecological and health risks, but the available evidence highlights the need to strengthen monitoring and control programs.(4)

In this context, this paper addresses the issue of PM2.5 and its relationship with microplastics, integrating international and local case studies, as well as methodological advances in their detection and characterization, in order to provide information to support public policies and mitigation strategies aimed at protecting health and the environment.

DEVELOPMENT

A author studied the concentration and impacts of suspended particles (PM2.5) in the city of Villavicencio, Colombia, in October 2018, at three locations in the city using three different meters (A, B, C), finding a maximum concentration of 30,11 µg/m3. This was below the national standard for 24 hours (37 µg/m3).

A study collected PM2.5 samples in five megacities in northern and southeastern China (Beijing, Tianjin, Shanghai, Nanjing, Hangzhou) from August to September 2019, using a smart total suspended particulate matter sampler with an average flow rate of 100 L/min, and demonstrated that Shanghai is the most polluted city in terms of PM2.5, with a concentration of 56 µm/m3. In addition, FTIR spectroscopy analysis was applied to identify plastic and non-plastic particles present in the filters. The detector was operated in the 675-4000 cm wavelength range, with a collection time of 3 s and integration of 16 scans at a resolution of 8 cm, and the presence of plastic particles was found.

A study collected suspended dust daily for 5 days in the city of Asaluyeh, Iran, over the course of a year using a low-volume sampling device and a modified filter with an inlet tube and a sampling head to investigate the presence of microplastics, which were characterized using fluorescence microscopy, polarized light, and SEM to quantify and classify them. The results revealed two locations with fibrous particles ranging from 2 µm to 100 µm, demonstrating that microplastics do cause health damage, but their precise functions remain unclear and require further study.

Sicilianoa et al.[1] in their article mention air quality standards in Brazil according to the WHO, demonstrating that in the studies they conducted, they found evidence that when monitoring PM2.5 air conditions in Brazil, the results show that at point 1, the maximum value is 60 mg/m3 evaluated over 24 hours, which exceeds the WHO standard of 10 and 25 ug/m3, considering that point 1 does not comply with the means of protection and well-being of the population.

A study present an analysis of the variability, trend, and exceedance of PM2.5 measured at the US Embassy and Consulate in five Indian megacities (Chennai, Kolkata, Hyderabad, Mumbai, and New Delhi) between 2014 and 2019. Of all the cities, Delhi is the most polluted, followed by Kolkata, Mumbai, Hyderabad, and Chennai. The results show different diurnal, seasonal, and monthly variations in the five cities due to the different locations of the sites and the local climate. All cities show higher and lower concentrations in the winter and monsoon months, respectively, with the exception of Chennai, which saw the lowest levels in April. All cities consistently show morning peaks (~08:00–10:00) and the lowest level in the late afternoon (~15:00–16:00). The study concludes that PM2.5 levels in cities exceed WHO standards and Indian NAAQS by 50 % and 33 % of days per year.

A study evaluated the air quality index (AQI) in their research, classifying it into different groups to predict the AQI in the city of Chennai. They collected a dataset, which they then processed to be replaced. The deep learning mechanism they used accurately predicted AQI values and helped plan the development of a sustainable metropolitan city. The expected AQI value can control the level of pollution by incorporating the coordination of public transport signals, encouraging people to use public transport, and planting more trees in some places.

A study aimed to evaluate the air quality index in the city of Kerman in different seasons in 2015. The data obtained for PM2.5 in the spring season showed that days 33 and 9 of spring had unfavorable conditions in relation to PM2.5 pollutants. Therefore, the pollutant responsible for air pollution in Kerman was PM2.5. When comparing the AQI in different seasons of 2015, it indicates that it has a desirable air quality index.

A study mention in their article that air deterioration has become a serious threat, causing adverse health effects and millions of premature deaths in China. Their research aimed to examine the spatial-temporal characteristics of ambient air quality in five provinces. They evaluated PM2.5, which exceeded the Grade II standards of the China Ambient Air Quality Standards (CAAQS) as well as the air quality guidelines recommended by the WHO. In addition, the average air quality index (AQI), calculated from ground-based data, improved by 21,3 %, the proportion of Class I air quality (0–50) improved by 114,1 %, and the number of pollution days decreased by 61,8 % in NWC. All pollutants (except ozone) AQI and PM2.5 ratios showed the highest pollution levels in winter and the lowest in summer. The AQI was positively correlated with PM2.5, while it was negatively correlated with PM2.5, with different temporal and seasonal variations. The proportion of days with PM2.5, the primary pollutants decreased.

Theory of suspended particles PM2.5. Suspended particles (PM) are commonly classified as PM10, PM2.5, and PM0.1, which are PM less than 10, 2.5, and 0.1 µm in diameter, respectively; Atmospheric PM with a diameter of less than 2.5 µm (PM2.5) is an air pollutant of particular concern and, according to a recent review.

Air pollution is one of the 10 major global health threats. Exposure to particulate matter (PM) is associated with the global burden of disease and non-accidental mortality. A growing number of studies suggest that PM can induce respiratory diseases, lung cancer, and cardiovascular events.

Among these, environmental pollution by PM2.5 accounts for 62 % of all deaths attributable to air pollution and 55 % of disability-adjusted life years (DALYs) lost, i.e., 4,14 (95 % uncertainty interval [UI]: 2,50–3,36) million deaths and 118 (95 % UI: 95,9-138) million DALYs (Institute for Health Effects, 2020). The Global Burden of Disease (GBD) study reveals that environmental pollution from PM has risen from 13th place (1990) to 7th place (2019) as the leading risk factor for DALYs attributable worldwide. The global cost of health conditions attributable to PM2.5 environmental pollution increased to $3,552 trillion in 2013. Exposure to PM2.5 has been shown to affect lung function.[11]

Accumulated experimental evidence has demonstrated that PM2.5 can be easily inhaled and deposited in the trachea, bronchi, and even the alveoli, producing adverse effects on the respiratory system and function. A recent in vivo study found that exposure to PM2.5 increases lung susceptibility, despite a gradual recovery of lung injury after cessation of PM2.5 exposure. Given the above, it is well known that particles that enter through the nose or mouth and settle in the upper respiratory tract are inhaled (≤10 µm), and particles that can accumulate and deposit in the lungs are known as respirable particles (≤2,5 µm).[2]

Characteristics of PM 2.5. Sources of PM 2.5 pose a health risk due to the combined effects of environmental (outdoor) and domestic (indoor) air deterioration and can originate as a result of anthropogenic or natural activities. In urban areas, vehicles with diesel exhaust are the main sources followed by energy propagation, building heating systems, industrial emissions, and domestic combustion. Cooking, heating, and particle resuspension are also significant. followed by energy transmission, building heating systems, industrial emissions, and domestic combustion. Cooking, heating, and particle resuspension are also significant, produced by burning fuels such as coal and wood in inappropriate environments.

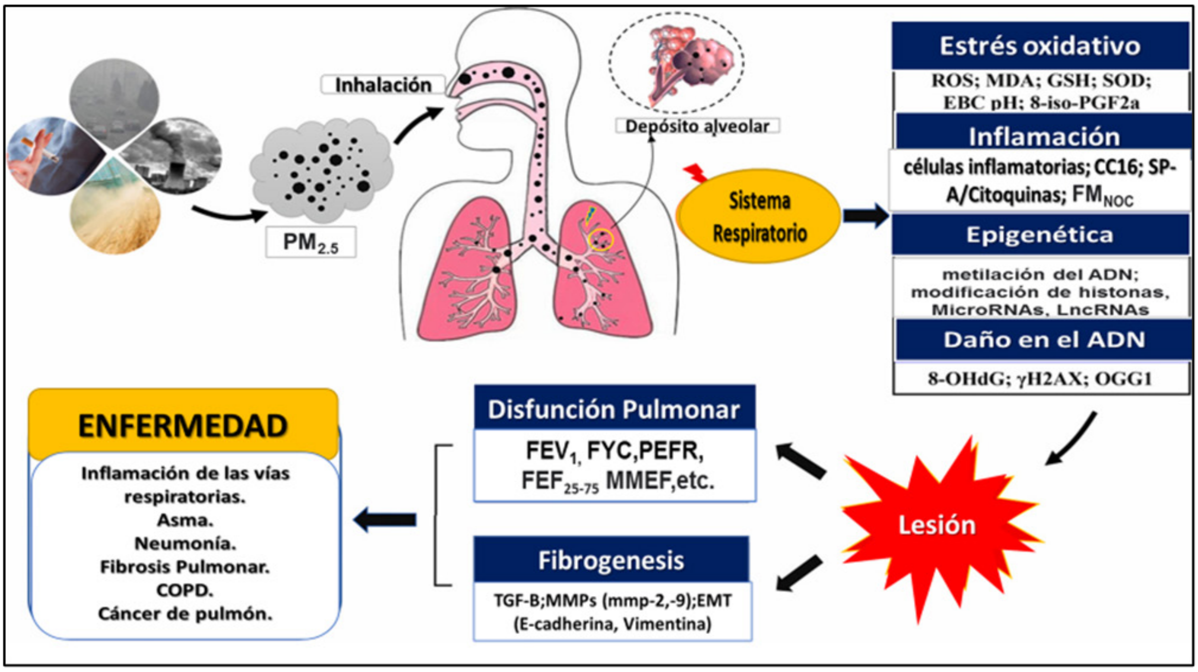

Figure 1. Effect of PM 2.5 on human health

Function of Particulate Matter Collection Equipment (PQ200) -(MICRO VOL 1100). The reference method for collecting suspended material is gravimetry, which was sponsored by Supreme Decree No. 10-2019-MINAM (2019).

In the case of particulate matter smaller than 2,5 micrometers (PM2.5), a mechanism is needed to record the sampling frequency (mechanical or digital) to verify its stability during the observation period. In this case, the sampling flow rate can only be set in the low capacitance range (10,44 l/min = 1 m3/h). The particle separation system in a low-volume sample for PM2.5 has two stages:

In the first stage, it attempts to select particles smaller than 10 microns in size. The selective inlet to the sampler differs from the high flow head in the size and number of nozzles. This is due to the lower gas flow connected to the collected sample (10,44 l/min). In the second stage, particles up to 2,5 microns in size are transported to selective PM2.5 separators of the WINS (Well Impactor Ninety-Six) or VSCC (Very Sharp Cut Cyclone) type, and small particles larger than 2.5 microns are separated and then captured with a sampling filter.[13]

Weather station, a place where observations and measurements of different weather conditions are specifically carried out using appropriate equipment and tools to establish atmospheric characteristics in different regions of the territory (Technical Manual: MT-DRD-001 – SENAMHI).[14]

Plastic production has increased considerably in the last 70 years, and it can be said that we live in a plastic world (Campanale et al., 2020). The increase in production also leads to an increase in plastic waste, which unfortunately promotes the widespread accumulation of plastic in the environment. Plastics are classified as macroplastics (>25 mm), mesoplastics (5–25 mm), and microplastics (0,1 mm).

Regarding studies conducted in Tarapoto to investigate the presence of particulate matter (PM2.5), a study measured PM2.5 in three cities in Peru (Tarapoto, Lima, and Juliaca), demonstrating that the city of Tarapoto has a concentration of 30,91 µg/m3 of PM2.5, Juliaca a concentration of 19,80 µg/m3, and Lima a value of 14,58 µg/m3, values that would not exceed the ECA (50 µg.m3). Meanwhile, a study evaluated the air quality in the city of Tarapoto and its relationship with temperature, relative humidity, and wind speed. The data was exported to COMET software and a concentration of 11 ug/m3 for PM2.5 was determined, combined with a temperature of 23,3 °C and relative humidity of 23 %, showing the relationship between particulate matter and meteorological variables, but this relationship is not significant except for PM2.5, which has a wind speed. In other words, the higher the wind speed, the lower the concentration of suspended particles, and vice versa.[15]

In this case, in the district of Morales, PM2.5 particulate matter concentrations exceed Environmental Quality Standards (ECA) at the sampling sites, determining high levels of concentration by atmospheric pollutants, which in turn have been influenced by meteorological conditions (temperature, relative humidity, wind speed).[16]

PM has been widely recognized as an emerging universal pollutant in the terrestrial and aquatic environment.

Microplastics Theory. Microplastics are most commonly defined as plastic particles >1 µm and <5 or 1 mm along their longest dimension. We will use the definition of <5 mm for our consideration of microplastics, as this will include much of the literature. The number of peer-reviewed publications on microplastics has increased

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rapidly over the past decade, with studies finding microplastics in nearly all environmental systems, as well as in human food and beverages. However, the implications of microplastics in the environment are unclear, with some studies suggesting negative impacts on organisms, such as lower growth rates, higher levels of contaminants, and deformities, while others find neutral results. The most common types of MP are high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and polyamide (PA). MPs are found in a variety of environments, including aquatic environments, the atmosphere, soil, and food products.[17]

Plastic degradation varies depending on chemical composition, including additives used during production; for example, a HDPE plastic bag takes between 10 and 20 years to decompose, while a PET bottle takes between 450 and 1000 years. In addition, the use of everyday products containing MP, such as cosmetics and clothing (made from polyester and polyamide fibers), is a source of release of these materials into the environment. Mass production of plastics began about 70 years ago and is expected to double in the next 20 years.[18]

This reported variability highlights the nature of microplastics as a diverse set of contaminants, with a range of polymers, particle sizes, colors, morphologies, and associated contaminants (Rochman et al., 2019). Coupled with the fact that microplastics are often found in irregular concentrations with complex mixtures of particle types, it is currently difficult to determine the ecological risk posed by microplastics in the environment.[19]

With global plastic generation reaching 400 million tons per year by 2025, it is likely that 11 billion metric tons of plastics will accumulate in the environment. In five decades, plastic production has become a $600 billion global industry. It is likely that around 60 % of the plastics manufactured worldwide have already accumulated in the environment (UNEP Beating Plastic Pollution). Only 9 % of plastic waste is recycled (in developed countries alone), and the remaining 91 % remains in the environment for centuries.[20]

Classification of Microplastics (MP). Primary microplastics are manufactured to be <5mm in size. They include pre-production pellets used to manufacture plastic products and microbeads used as abrasives for industrial purposes or in personal care products. Secondary microplastics are small plastic fragments that are not intentionally produced, but are the result of the breakdown and fragmentation of larger plastic items through biological, physical, and chemical processes. Secondary microplastics can form during product use (e.g., microfibers that detach from clothing during washing or tire wear particles).

Human exposure to microplastics. Humans are exposed to MP in environments through ingestion (e.g., by introducing MP into the air through the mouth or by eating seafood), skin contact, or inhalation, and the resulting adverse health impacts are a major global concern. However, empirical studies on human exposure to MP are lacking. The presence of fibrous plastic particles in the air in urban environments has been reported, and it has been indicated that fibrous materials are generally more abundant indoors, but their size is smaller. Based on median concentrations of PM and micro-rubber in street dust in the jurisdiction of Asaluyeh.[21]

Microplastics in the air and human exposure. Despite their ubiquity in all aspects of life and ecology, little is known about the health consequences of MP exposure in humans. While the distribution of MP in aquatic systems has been studied, plastic particles have also been found in the air, for example in dust and street air and in atmospheric fallout. PM that enters through the nose or mouth can lodge in the upper respiratory tract and be inhaled, but substances can reach the deepest parts of the lung. Deposition in the respiratory tract depends on size and respiratory area, with deposition falling above 5 mm in diameter.[22]

Sources of microplastics. Microplastics enter the environment through various sources and pathways (figure 2). Because microplastics are small and often the worn-out remains of their original product, it can be difficult to trace them back to their source.[23]

The relationship between microplastics and PM2.5. Few studies have been published on the characteristics or distribution of microplastics in air particles smaller than 2,5 μm or 10 μm (PM2.5/PM10), and microplastic deposition rates in air vary with atmospheric elevation. Airborne microplastics move more than those found in sediments or water.

The main synthetic plastics widely used in everyday life are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC), which penetrate the environment. Through photochemical reactions under sunlight, airborne microplastics could break down and release these chemical additives and others, such as monomers, which can negatively affect human health.

Particles (PM2.5) and microplastics could act as carriers of polycyclic aromatic hydrocarbons (PAHs) that may increase the potential risk of cancer. Therefore, research on the distribution of microplastics in the air could also provide important information for human and ecological risk assessments.

A study explored the distributions, compositions, and morphology of microplastics present in indoor and ambient air in New Jersey, United States. Microplastic fibers, pieces, and films of polystyrene (PS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PP) were identified in offices, hallways, classrooms, and single-family homes in this study. They found that deposition rates of synthetic fibers with a length of 35 μm to 1000 μm were higher in single-family homes ((1,96 ± 1,09) × 104 fibers/ m2 / day) and lower in the classroom ((6,20 ± 0,57) × 103 fibers/m2/day) microplastics with similar textures but different sizes were identified both in total atmospheric deposition and in particle samples (PM2.5 and PM10). These results reveal the properties of airborne microplastics in urban environments that are important for understanding their fate, transport, and potential health risks.

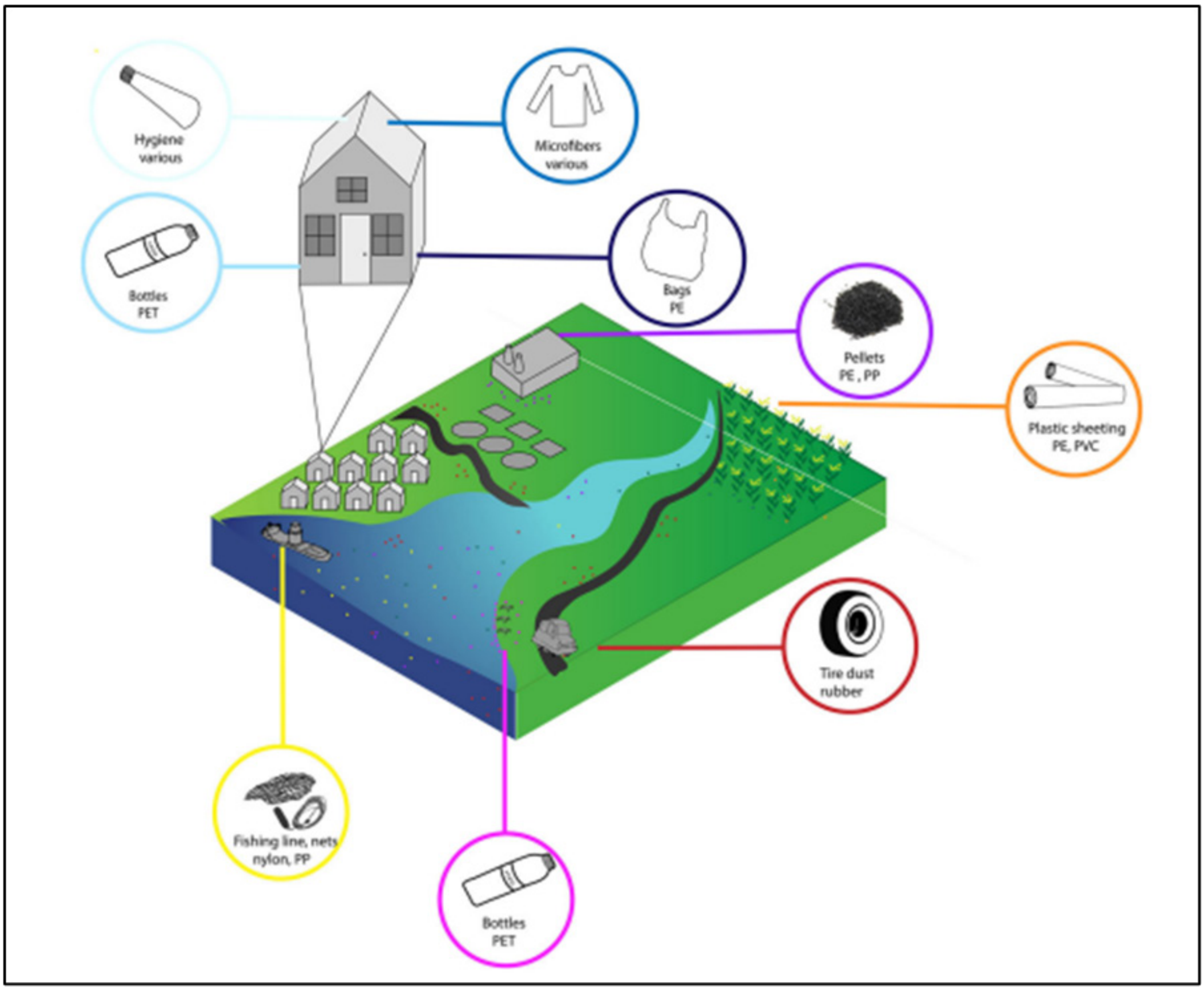

Figure 2. Various sources of microplastic pollution

A study conducted research in Sambalpur, one of the most important cities in the western regions of the state of Odisha, in eastern India, to measure pollutant gases and particles and calculate the air pollution index (API) at four representative sampling stations (Budharaja, Modipara, Sakhipara, and Kacheri) based on the guidelines of the Central Pollution Control Board (CPCB), New Delhi. The results for PM2.5 particles (36,38 to 64,00 µg/m3) were found to be above the annual permissible limit set by the CPCB. Meteorology and wind rose played a role in the dispersion and dilution of pollutants, in addition to being favored by the topography and anthropogenic activities in the area, where the highest average air temperature was recorded in April (26,4 ˚C) and May (26,2 ˚C), and the lowest was (21,5 ˚C). A significant positive correlation between temperature and wind speed in our analysis reinforces this fact (r = 0,98). ˚C) and May (26,2 ˚C), and the lowest was 21,5 ˚C. A significant positive correlation between temperature and wind speed in our analysis reinforces this fact (r=+0,338, p<0,05). Air quality in the area ranged from light air pollution to moderate air pollution, which is mainly attributed to particulate matter (PM2.5).[24]

The main methods for determining the type of microplastics are constructing characteristic wave numbers of microplastics and spectral data combined with machine learning. Unfortunately, microplastics have strong adsorption and accumulation capacity due to their large specific surface area, which provides a rich contact site for other toxic substances, such as additives, heavy metal elements, organic pollutants, and plasticizers (figure 3).[25]

Currently, as a state-of-the-art environmental pollutant, microplastics have gradually attracted global academic attention.

The visual inspection method could select and classify microplastics and observe the color and size of the tested object with a microscope or with the naked eye.

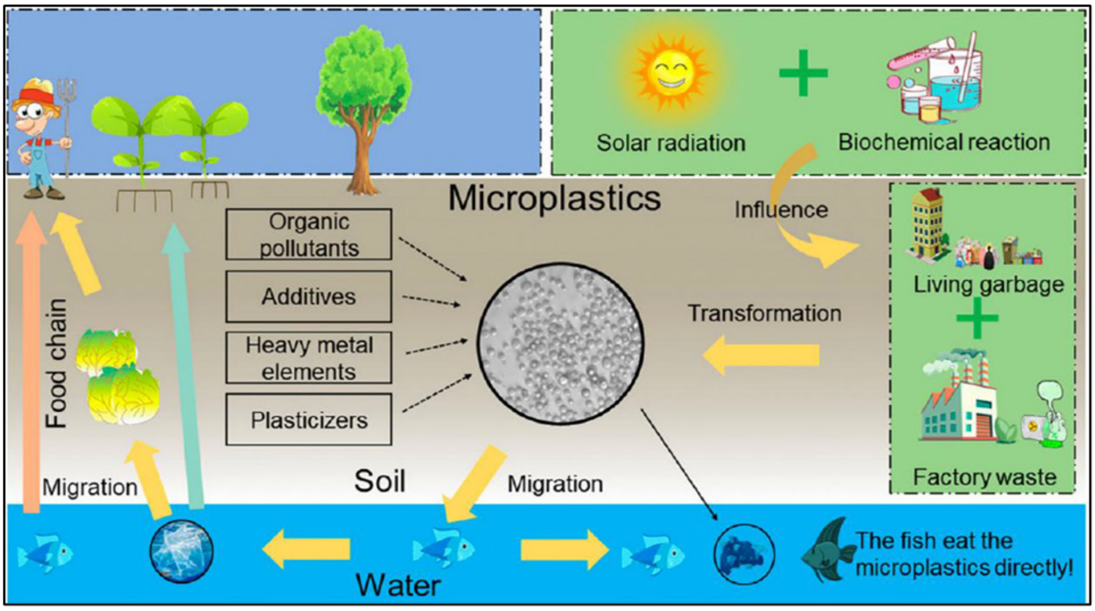

Figure 3. The origin, migration, and damage of microplastics

Among the methods for characterizing PM2.5 are: SEM – FTIR, which allows the identification of possible inorganic and organic particles

FTIR spectroscopy measures the infrared (IR) radiation absorbed by the PM sample, allowing the molecular composition to be studied. The infrared spectrum symbolizes the fingerprint (PM) of a sample with an absorption peak corresponding to the vibrational frequency between the bonds of the atoms that make up the material.[26] Because each different polymeric material is a unique combination of atoms, the two compounds do not produce exactly the same infrared spectrum; therefore, the chemical structure of a polymer molecule can be determined by FTIR.[27,28]

According to Heng Tong Fluorine, perfluorododecyliodide has the chemical name "iodopentacosafluorododecane" and describes the plastic found as having no compatibility with other similar materials.[29,30]

Estabilidad y reactividad	
Estabilidad química	Estable a temperaturas y condiciones de almacenamiento normales
Incompatibilidad con otros materiales	Ninguno razonablemente previsible
Descomposición	Se descompone con el calor Temperatura de descomposición: >250 °C (>482 °F) Durante la combustión se pueden formar productos de descomposición peligrosos, incluidos dióxido de carbono, monóxido de carbono, fluoruro de hidrógeno, gases tóxicos o partículas. Estos productos pueden causar irritación grave en los ojos, la nariz, la garganta y los pulmones o efectos tóxicos. Se descompone cuando se expone a la luz ultravioleta
Polimerización	La polimerización no ocurrirá

Figure 4. Stability and reactivity

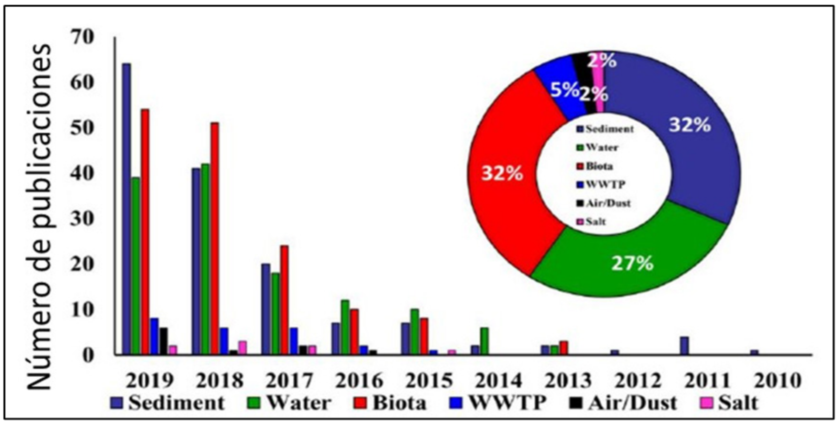

Figure 5. Results from literature using FTIR

Published articles were classified into several environmental matrices (sediment, water, wastewater treatment plants, biota, dust/air, and salt).

Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM), also referred to as SEM analysis or SEM technique, has been used globally in many fields of study. This method is very effective in the study of organic and inorganic material compounds at the nanometer to micrometer level. SEM works with high magnification, reaching 300 000x and even 1 000 000x to display highly accurate images of a wide range of materials. Energy dispersive X-ray spectroscopy (EDS) works together with SEM to identify qualitative and semi-quantitative results. These techniques, together, have the potential to gather fundamental information about the composition of the material of the scanned samples, which could not be provided by common laboratory tests.[31,32]

Meteorological variables. Temperature is a variable of the movement of particles in the environment. A body depends on the speed of movement of the particles that make it up, or on the frequency of vibration. It is the agreement between the equilibrium vapor pressure of water at a given temperature and the partial pressure of water vapor. Relative humidity depends on the pressure of the system and the temperature. This is the basic amount of air that is generally caused by the movement of high or low air pressure due to temperature changes.[33]

Air Quality Standards (ECA) represent measures that establish concentrations or levels of substances, physicochemical or biological parameters present in the air, soil or water in their receptive state without potential risk to human or environmental health (Section 31.1 of Article 31 of General Environmental Law No. 28611).

Parámetros	Periodo	Valor [ug/m^3]	Criterios de evaluación	Método de Análisis
Material Particulado con Diámetro menor a 2.5 micras (PM $_{2.5}$)	24 horas	50	NE más de 7 veces al año	Separación inercial/filtración (Gravimetría)
	Anual	25	Media aritmética anual	

Figure 6. Environmental Quality Standard Parameters

Air Quality Index - INCA. These are categories that have an optimal value ranging from 0 to 100 and are in accordance with the ECA air compliance standards. They are divided into four categories.[34,35] When the air quality is good, it will be green and pose no risk when breathed. Yellow indicates that the air quality is moderate, while orange indicates poor air quality that is harmful to health, and red warns that the air quality exceeds pollutant values and may be deadly (RM-N°-181-2016-MINAM).

Valor del Índice	Calidad del Aire	Color
0-50	Buena	Verde
51- 100	Admisible	Amarillo
101 – 150	Mala	Rojo
>150	Muy mala	Marrón

Figure 7. Air Quality Index Values

CALIFICACIÓN	CUIDADOS	RECOMENDACIONES
Buena	La calidad del aire es buena y no representa daño alguno para la salud.	La calidad del aire es tolerable y cumple con el ECA de aire. Se puede realizar actividades en el exterior.
Moderada	Las poblaciones vulnerables (niños, ancianos, mujeres embarazadas, personas con enfermedades respiratorias y cardiovasculares crónicas) pueden experimentar ciertos problemas de salud.	La calidad del aire es pasable y cumple con la ECA de aire. Se pueden practicar actividades al aire libre con ciertas restricciones para personas sensibles.

Mala	Las personas sensibles pueden experimentar problemas de salud. El público en general puede verse afectado.	Esperar el informe de calidad del aire. Evite las actividades al aire libre.
Umbral de Cuidado	Las concentraciones de contaminantes afectan la salud de todos y pueden tener serias implicaciones para poblaciones vulnerables como niños, ancianos, mujeres embarazadas y personas con enfermedades respiratorias.	Avisar a la Autoridad de Salud para que denomine los niveles de estados de alerta con respecto al DS N° 012-2005-SA.

Figure 8. Air Quality Index (INCA) precautions and recommendations

Material Particulado ($PM_{2.5}$) promedio 24 horas		
Intervalo del INCA	Intervalo de concentraciones (ug/m³)	Ecuación
0 – 50	0 – 12.5	1(PM2.5)= [PM2.5]' 100/25
51 – 100	12.6 – 25	
101 – 500	25.1 – 125	
>500	>125	

Figure 9. Calculation of the Air Quality Index (INCA)

Values proposed by the WHO. According to the WHO, approximately 58 % of premature deaths related to air pollution in 2016 were due to myocardial ischemia and stroke, 18 % were due to chronic obstructive lung disease and acute respiratory infections, and 6 % were due to lung cancer.[36]

Valores Fijados por las Directrices Material Particulado Final ($PM_{2.5}$)
5 µg/m³ de media anual
15 µg/m³ de media diaria

Figure 10. WHO air quality guideline values

Table 1. Analytical methods for the characterization of PM2.5 particulate matter

Technique	Purpose	Nature of the technique	Reference
D.S No. 10-2019-MINAM	Monitoring method for particulate matter concentration	Passive method	National Protocol for Air Quality Monitoring.
EPA 40 CFR (top art 50)	Analysis method for determining particulate matter $PM_{2.5}$	Passive Method	Peruvian Technical Standard (NTP 900,069-2017)

Table 2. Analytical methods for the characterization of microplastics (MPs)

Technique	Purpose	Nature of the technique	Reference
Thermogravimetric analysis (TGA)	Determines the thermal degradation pathway of microplastics	Destructive to sample	Yu et al. (2019)
Differential scanning calorimetry (DSC)	Determines the endothermic phase, transition, melting characterization, and reaction kinetics of microplastics	Destructive to sample	Majewsky et al. (2016
Thermogravimetric analysis: solid phase extraction process/ gas chromatography with thermal desorption mass spectrometry (TGA-SPE/TDS-GC-MS)	Enables unambiguous and convenient detection of characteristic decomposition products of microplastics	Destructive for sample	Dumlchen et al. (2015)

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X-ray diffraction	Analysis of structural and functional groups, degree of crystallinity	Destructiveness depends on the sample preparation method used	Ariza-Tarazona et al. (2019)
Nuclear magnetic resonance (NMR)	Structural and functional group, analysis, identification of exact structure, chemical fractions, and conformational state	Laborious non-destructive sample preparation for sample	Peez et al. (2019)
Scanning electron microscopy/ energy dispersive spectroscopy (SEM/EDS)	Characterization of surface structure and elemental composition in microplastics	Destructive for sample	Wang, Wagner et al (2017)
Gel permeation chromatography (GPC) with fluorescence detection (FLD)	Semi-quantitative selective determination of microplastics	Laborious sample preparation destructive to sample	Biver et al. (2018)
Fourier transform infrared spectroscopy (FTIR)	Detect common contaminants present in certain elements with the help of interferometry.	Destructive to sample	Chialanza et al. (2018)

CONCLUSIONS

In conclusion, pollution from fine particulate matter (PM2.5) and microplastics (MPs) represents a growing challenge for public health and the environment, given its wide geographical distribution, diversity of sources, and complexity in detection and characterization processes. The studies reviewed show that, although in some cities such as Villavicencio and Tarapoto, PM2.5 concentrations remain below national limits, in others, such as Shanghai, New Delhi, and certain Brazilian cities, levels far exceed WHO recommendations, especially in seasons such as winter, coinciding with unfavorable meteorological factors and high anthropogenic emissions.

The interaction between PM2.5 and microplastics adds an additional dimension to the problem, as these similarly sized plastic particles can be transported through the air, act as vectors for chemical and biological pollutants, and potentially increase the risks of respiratory and cardiovascular diseases and cancer. Although progress has been made in identification methodologies such as FTIR spectroscopy and scanning electron microscopy (SEM/EDS), there are still limitations in standardization and in the complete understanding of long-term impacts, particularly with regard to chronic human exposure to inhalable PMs.

Evidence indicates that sources of PM2.5 mainly include fossil fuel combustion, industrial emissions, transportation, and domestic activities, while microplastics come from both direct industrial processes and the degradation of larger plastic products. This combination of air pollutants creates a complex scenario, as the presence of PM in PM2.5 fractions can increase the transport capacity of toxic compounds such as polycyclic aromatic hydrocarbons, with potentially serious health consequences.

The spatial and temporal variability in PM2.5 and MP concentrations highlights the influence of meteorological factors such as temperature, humidity, and wind speed, as well as the need to strengthen environmental monitoring systems. Tools such as the Air Quality Index (AQI) are useful for risk communication and decision-making, but they need to be integrated with data on microplastics to provide a more complete picture.

In this context, it is imperative to implement public policies that reduce PM2.5 emissions, regulate the use and disposal of plastics, and promote interdisciplinary research on the interaction between these pollutants. Likewise, investment in accurate and accessible detection technologies will improve surveillance and, thereby, enable the development of mitigation strategies that safeguard human health and ecosystem integrity. The available scientific evidence supports that early and coordinated action is key to addressing this global challenge.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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