Article Type: Research

OPEN ACCESS

Evaluation of Particulate Matter Emissions and Air Filtration Environmental Efficiency in Asphalt Plants

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Received: 28 June 2025 / Accepted: 27 September 2025 / Published: 25 October 2025

***Abstract*:** Air pollution from asphalt plants is a major environmental and health concern, especially in developing regions. This study evaluated concentrations of suspended particulate matter (PM_{10} and $PM_{2.5}$) around several medium- and small-scale asphalt plants located in semi-urban and rural areas. Field measurements using standard air sampling methods were conducted to determine ambient PM levels, and the efficiency of various dust control systems (baghouse filters, cyclone separators, and wet scrubbers) was assessed. Results showed that plants without advanced filtration had PM levels far above national and WHO standards. Baghouse filters achieved the highest removal efficiency, while older or poorly maintained systems were far less effective. Environmental inspections revealed visible dust accumulation on nearby vegetation and buildings, and possible contamination of surface water from airborne particles. The study highlights the urgent need for stricter air quality regulations, better maintenance of filtration systems, and wider adoption of efficient emission control technologies in smaller asphalt plants. Implementing these improvements could substantially reduce air pollution and improve local environmental and public health conditions.

Keywords: Asphalt plants, Particulate matter, Air pollution, Filtration systems, Environmental impact.

I. Introduction

Asphalt plants are industrial facilities used for the production of asphalt concrete, a composite material primarily used for road construction, parking lots, and airport runways. Asphalt is produced by combining aggregates (such as sand, gravel, or crushed stone) with bitumen, a petroleum-based binder (Praticò, 2017). The production process involves heating, drying, and mixing these components at high temperatures, which requires significant energy input and generates various air pollutants, particularly particulate matter (Zaumanis & Mallick, 2015). There are generally two main types of asphalt plants: batch mix plants and drum mix plants. Batch mix plants produce asphalt in discrete batches, allowing for greater control over mixture composition and quality. These are more common in projects requiring customized mixes or smaller production volumes (Yan et al., 2023). Drum mix plants, on the other hand, operate continuously, offering higher production rates and efficiency. They are often used in large-scale projects where uniform mix and speed are priorities (Shao et al., 2017). Further classification divides asphalt plants into stationary and mobile types (Subhy et al., 2019). Stationary plants are typically large, permanent installations with high output capacity, ideal for long-term projects. Mobile asphalt plants, in contrast, are designed for portability and quick setup, making them suitable for temporary roadwork in remote or scattered locations (Gumarova et al., 2022). Both types can vary significantly in terms of scale, emissions control technology, and environmental performance (Florkova et al., 2021).

Asphalt production involves multiple components: aggregate handling systems, dryers, burners, mixing units, storage silos, and emission control units (Zhang et al., 2019). The drying and heating phases, where aggregates are exposed to flames or hot air, are particularly responsible for the release of fine particulate matter and gaseous pollutants (Tarsi et al., 2020). Without effective filtration systems, these emissions can negatively impact air quality in surrounding areas (Thives & Ghisi, 2017). Small and medium-scale asphalt plants are prevalent in developing countries, including regions with expanding infrastructure demands (Bueno et al., 2021). These facilities often lack advanced air pollution control equipment due to budget constraints, limited regulatory enforcement, or technical know-how (Okeke et al., 2016). Figure 1 illustrates a schematic of common asphalt production facilities. As a result, they contribute disproportionately to localized air pollution despite their smaller size (Qu et al., 2021). Airborne particulate matter emitted from asphalt plants includes PM_{10} and $PM_{2.5}$—particles small enough to penetrate deep into human lungs and even enter the bloodstream (Kharat, 2022). These particles pose serious health risks, including respiratory illnesses, cardiovascular problems, and exacerbation of asthma (Gibson et al., 2012). Additionally, particulate emissions can settle on soil and water surfaces, causing broader ecological disruptions (Bingül & Altıkat, 2020).

Asphalt plants emit a range of pollutants that can have direct and indirect effects on public health (Qu et al., 2021). Among the most concerning are fine particulate matter ($PM_{2.5}$ and PM_{10}), which are small enough to be inhaled deep into the lungs (Thives & Ghisi, 2017). Chronic exposure to these particulates is associated with increased risks of respiratory diseases such as bronchitis, asthma, and lung cancer, especially among vulnerable populations like children, the elderly, and individuals with pre-existing conditions (Li et al., 2024). In addition to respiratory issues, airborne particulates and volatile organic compounds (VOCs) released from asphalt production may contribute to cardiovascular diseases (Li et al., 2021). Studies have linked long-term exposure to air pollution from industrial sources with elevated blood pressure, heart attacks, and stroke (Chen et al., 2022). These health impacts can lead to reduced life expectancy and increased healthcare costs in communities located near asphalt plants (Bingül & Altıkat, 2020).

The environmental footprint of asphalt plants extends beyond air pollution. Particulate emissions eventually settle onto nearby land, contaminating the soil with heavy metals and hydrocarbons (Praticò, 2017). Over time, these pollutants can accumulate in the upper soil layers, altering the physical and chemical properties of the soil and affecting its fertility (Wang et al., 2021). This contamination can disrupt local agriculture, reduce crop yields, and even introduce toxins into the food chain (Santolini et al., 2024). Water resources are also at risk from asphalt plant operations (Bingül & Altıkat, 2020). During rainfall, accumulated dust and pollutants on surfaces may be washed into nearby water bodies or seep into the groundwater (Florkova et al., 2021). Runoff from production sites may contain petroleum residues, suspended solids, and other chemical byproducts, which degrade water quality and harm aquatic life (Praticò, 2017). This is particularly dangerous in rural areas where water sources may be unmonitored or directly used for drinking and irrigation (Kharat, 2022).

The biodiversity of nearby ecosystems can suffer as a result of air and soil pollution from asphalt plants (Thives & Ghisi, 2017). Dust settling on vegetation can inhibit photosynthesis, reduce plant growth, and damage leaf surfaces. Wildlife species that depend on clean air, soil, and water for survival may be displaced or experience population declines (Bonthoux et al., 2019). These disruptions can ripple through food chains and destabilize entire ecosystems over time. Communities living near asphalt plants often report a decline in their quality of life due to unpleasant odors, constant noise, and visible dust (Bruno et al., 2024). Psychological stress from living near a known pollution source, especially without proper regulation or information, can also contribute to mental health issues (Li et al., 2024). In some cases, property values may decline, creating an additional socio-economic burden for affected residents. The environmental justice aspect of asphalt plant pollution is also worth noting (Bingül & Altıkat, 2020). Small and medium-scale plants are frequently located in low-income or underserved areas where residents have limited resources to advocate for stricter regulations or relocation (Qu et al., 2021). As a result, these populations face a disproportionate share of the environmental and health risks associated with asphalt production (Bueno et al., 2021). To address these challenges, it is essential to implement regular environmental monitoring, enforce strict emission limits, and ensure that filtration systems are not only installed but also properly maintained (Zhang et al., 2019). Public health policies should include awareness campaigns and health screenings in high-risk areas (Thives & Ghisi, 2017). A holistic approach that balances industrial needs with environmental sustainability and human well-being is key point (Bingül & Altıkat, 2020).

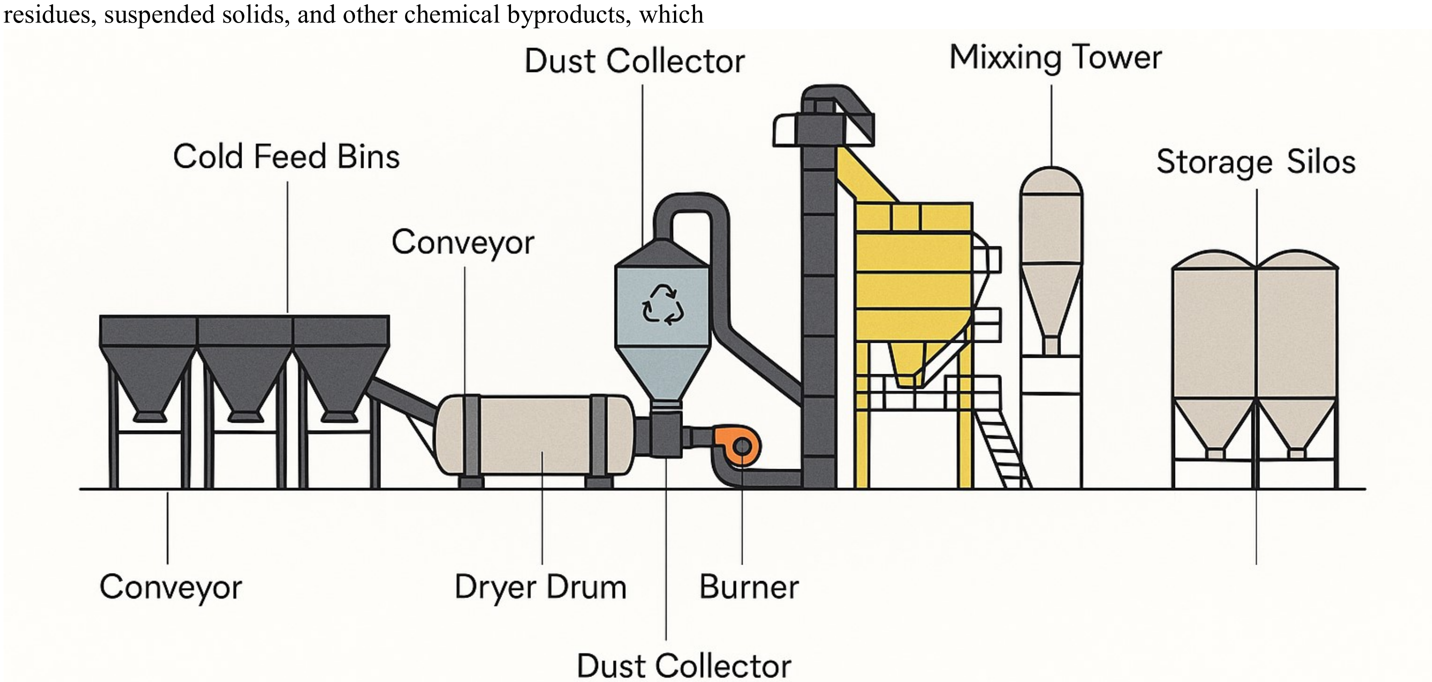

Fig. 1 Typical schematic for an asphalt plant

The primary objective of this study is to assess the levels of airborne particulate matter (PM_{10} and $PM_{2.5}$) emitted from asphalt production plants in Iran, with a focus on small- and medium-scale facilities. These types of plants are widespread across the country due to growing infrastructure demands, especially in developing urban and rural regions. The research seeks to measure pollutant concentrations in and around these facilities and evaluate how effectively current filtration systems mitigate harmful emissions. A secondary goal is to classify and compare the performance of various emission control technologies used in Iranian asphalt plants, including baghouse filters, cyclones, and wet scrubbers. By conducting case studies across different climatic and geographical regions within Iran, this research aims to highlight how environmental conditions and plant design influence pollution levels and filtration efficiency. This analysis will provide valuable data for industry stakeholders and environmental authorities. In addition, this study explores the broader environmental and public health implications of PM emissions from asphalt plants. Specifically, it aims to identify patterns of impact on surrounding soil, water bodies, and residential zones. The results will help guide policy recommendations, regulatory standards, and potential technological upgrades tailored to the context of Iran's industrial landscape. This paper serves as an introductory step toward a more comprehensive understanding of the environmental footprint of asphalt production in Iran. The subsequent sections will offer deeper analysis, including technical data, health correlations, and environmental monitoring results. Given the widespread use of asphalt and the current lack of stringent pollution controls in many plants, the necessity of this research lies in its potential to inform sustainable practices and protect public health on a national scale.

II. Asphalt Plants in Iran

Asphalt plants in Iran play an important role in the country's infrastructure development, supplying the necessary materials for road construction, airport runways, and urban development projects (Kowsar, 1977). These plants operate in both public and private sectors and are distributed across provinces, particularly in areas with ongoing construction and transport network expansion (Aflaki & Tabatabaee, 2009). With the Iranian government prioritizing national infrastructure projects under programs like road connectivity, regional highways, and rural development, asphalt production remains a high-demand industry (Zehtab et al., 2020).

The typical structure of an asphalt plant in Iran includes several key components: cold feed bins for aggregates, a conveyor system, a rotary dryer drum for heating aggregates, a burner system, a mixing tower where bitumen and aggregates are blended, a dust collector, and asphalt storage silos (Dezfuli & Akhound, 2022) as illustrated in Figure 2. Some plants also feature pre-heating systems and quality control labs. The general production process involves heating aggregates, mixing them with bitumen, and storing the final hot mix until transportation to construction sites (Pouranian & Shishehbor, 2019). Most asphalt plants in Iran are of medium or small scale, especially in less urbanized or mountainous regions. These plants tend to rely on conventional or semi-modern equipment and sometimes lack comprehensive environmental controls (Hashjin et al., 2023). While larger facilities, often operated by major contractors or government entities, are better equipped with emission reduction systems, many smaller operators use outdated technologies due to financial constraints and limited access to modern equipment (Zehtab et al., 2020).

The production of asphalt is essential for Iran's transportation infrastructure, which is constantly under pressure from growing urban populations and aging road systems (Pouranian & Shishehbor, 2019). The availability of domestic raw materials like bitumen (a byproduct of Iran's petroleum industry) supports the industry's economic viability (Dezfuli & Akhound, 2022). Asphalt plants also create employment opportunities in civil engineering, logistics, and construction. However, regulatory oversight of asphalt plants in Iran varies significantly between regions. While there are national standards issued by organizations like the Department of Environment (DoE) and the Ministry of Roads and Urban Development, enforcement is often inconsistent. In some regions, routine environmental monitoring is weak, and many plants operate without up-to-date environmental impact assessments (EIAs) or effective emission control audits.

The main environmental concern linked to asphalt production in Iran is the release of airborne pollutants—primarily PMs, VOCs, nitrogen oxides (NO_x), and sulfur compounds (Pouranian & Shishehbor, 2019). These pollutants can contribute to air quality degradation in surrounding areas, especially when facilities are located near residential or agricultural zones (Zarei et al., 2020). The lack of proper filtration systems in many plants intensifies this issue (Fomani et al., 2024). In addition to air pollution, dust and emissions from asphalt plants can settle on soil and crops, potentially affecting agricultural productivity (Kowsar, 1977). During rainy seasons, runoff from asphalt production sites may carry hydrocarbons and suspended solids into nearby streams or groundwater reserves (Aflaki & Tabatabaee, 2009). Given that many plants are located near or within rural communities, the impact on water quality and soil health can be particularly severe (Pouranian & Shishehbor, 2019). From a health perspective, workers and nearby residents may face increased risks of respiratory diseases, skin irritation, and long-term chronic illnesses linked to prolonged exposure to $PM_{2.5}$ and PM_{10} (Zehtab et al., 2020). In regions with limited healthcare access, these risks are further exacerbated (Hashjin et al., 2023).

Fig. 2 An example view of small-scale asphalt plant in Iran

Despite these concerns, asphalt plants offer clear advantages in terms of localized production, fast material delivery to project sites, and cost-effective sourcing of bitumen and aggregates (Aflaki & Tabatabaee, 2009). They also enable more flexible project management, especially in remote or rural development zones (Kowsar, 1977). However, the benefits must be weighed against operational limitations such as aging equipment, limited investment in environmental safeguards, and workforce training gaps (Zehtab et al., 2020). To address the environmental and operational shortcomings of asphalt plants in Iran, a coordinated approach is needed. This includes stricter regulatory enforcement, government incentives for pollution control upgrades, mandatory training for plant operators, and increased investment in emission monitoring (Pouranian & Shishehbor, 2019). Without such interventions, the ecological and public health impacts of this critical industry will continue to pose serious challenges, especially as national infrastructure demands intensify (Hashjin et al., 2023).

While these facilities are essential for economic growth, they also contribute substantially to environmental degradation. One of the most pressing issues is air pollution, as many Iranian asphalt plants (especially small and medium-sized ones), operate with outdated or poorly maintained filtration systems (Shafabakhsh et al., 2021). The resulting release of particulate matter (PM_{10} and $PM_{2.5}$), sulfur oxides, and volatile organic compounds directly affects local air quality. Dust and airborne particles released from these facilities often settle on agricultural lands and open spaces surrounding the plants (Hajikarimi et al., 2021). In provinces with extensive farming activities, such as Mazandaran, Isfahan, and Fars, this has led to visible dust accumulation on crops, which reduces productivity and contaminates the food chain (Khodadadi et al., 2020). Soil composition in affected areas also deteriorates over time, with increased presence of heavy metals and hydrocarbons that alter the physical and chemical balance of the land (Ameri, 2011).

Water pollution is another growing concern in Iran, especially in regions where asphalt plants are located near rivers, qanats, or groundwater reserves (Shafabakhsh et al., 2021). Runoff from production sites (carrying bitumen residues, chemical additives, and fine particulates), can leach into these sources, polluting drinking water and irrigation supplies (Ameri, 2011). In arid and semi-arid areas like Yazd or Kerman, where water scarcity is already a critical issue, any degradation in water quality has severe consequences for public health and agricultural viability (Kowsar, 1977). The heat and noise generated by asphalt plants also contribute to ecological disturbance. Excessive heat emissions create localized “hot spots” that affect nearby vegetation and microclimates, especially in areas with limited tree cover (Aflaki & Tabatabaee, 2009). Continuous noise and mechanical vibrations disrupt wildlife behavior and contribute to stress in both animals and human populations living nearby. This is especially problematic in rural or natural areas where biodiversity is more vulnerable (Pouranian & Shishehbor, 2019).

Another overlooked but important consequence is the uncontrolled spread of emissions to residential zones. In many Iranian towns and villages, asphalt plants are located dangerously close to homes, schools, and community centers (Pouranian & Shishehbor, 2019). Due to poor urban planning and insufficient zoning regulations, residents (often unaware of the risks); are exposed to harmful pollutants on a daily basis (Kowsar, 1977). Long-term exposure has been associated with higher rates of respiratory illnesses, especially in children and the elderly (Hashjin et al., 2023). Given these widespread and multifaceted environmental challenges, the necessity of this research becomes clear (Aflaki & Tabatabaee, 2009). There is an urgent need to systematically assess pollutant levels, evaluate the effectiveness of existing control technologies, and raise awareness among both policymakers and the public (Fomani et al., 2024). Understanding the environmental footprint of asphalt production in the Iranian context will provide a scientific basis for future reforms, investment in cleaner technologies, and enforcement of national environmental standards.

III. Materials and Methods

The purpose of this section is to describe the methodology used to measure and analyze PM levels emitted by selected asphalt plants across different regions in Iran. To ensure representative sampling, both ambient air monitoring and localized measurements near the emission sources were conducted. The selection of PM as a primary pollutant in this study is due to its direct health impacts, ease of quantification, and regulatory relevance. In the context of Iran, where industrial air pollution is a growing concern and regulation enforcement is often limited, PM monitoring offers a practical and high-impact tool for environmental evaluation.

A. Particulate Matter Assessment

Particulate matter (PM) is one of the most critical indicators of air pollution, especially in industrial environments like asphalt plants (Anderson et al., 2012). PM consists of a heterogeneous mixture of airborne particles, both solid and liquid, that vary in size, composition, and origin (Daellenbach et al., 2020). The most commonly measured fractions are PM_{10} and $PM_{2.5}$, which are defined by their aerodynamic diameter (≤10 microns and ≤2.5 microns, respectively). These particles are especially dangerous because they can penetrate deep into the respiratory system, leading to serious health effects (Thurston et al., 2011). Figure 3 illustrates the commonly used classifications for PMs. Asphalt production processes, particularly the drying and heating of aggregates and the combustion of fuel, are known sources of significant PM emissions (Qu et al., 2021). PM sampling was carried out using high-volume air samplers, following the protocols outlined in the U.S. Environmental Protection Agency (EPA) regulations, specifically 40 CFR Part 50, Appendix J for PM_{10} and Appendix L for $PM_{2.5}$ (Trumbore et al., 2015). These samplers are capable of drawing in large volumes of air through pre-weighed glass fiber filters over extended periods (typically 8 to 24 hours), allowing for precise determination of PM concentrations. The filters were conditioned under standard laboratory conditions (20-23°C and 30-40% RH) before and after sampling to minimize error due to moisture variation (Trumbore et al., 2005).

B. Sampling and Tests

Sampling points were selected at multiple distances from the central emission source (e.g., 100m, 300m, and 500m) to account for dispersion effects and wind direction. The meteorological conditions at each site, including wind speed, temperature, and humidity, were recorded using portable weather stations to support interpretation of spatial variability in PM levels. This allowed the study to estimate exposure gradients and better understand pollutant transport in the vicinity of the asphalt plants. To complement the gravimetric method, real-time monitoring was conducted using portable, laser-based aerosol monitors such as the DustTrak™ DRX or equivalent models. These devices offer the advantage of immediate, continuous data collection with temporal resolution at intervals as short as one minute. This approach was particularly useful during plant operation hours, allowing the researchers to correlate emission peaks with specific stages of asphalt production (e.g., drying, mixing, loading). Real-time data also helped identify process-related anomalies and potential operational inefficiencies. The results obtained from both gravimetric and real-time measurements were used to calculate daily average PM concentrations. These values were then translated into Air Quality Index (AQI) scores using the national AQI formula published by the DoE.

The AQI scale categorizes air quality from "Good" to "Hazardous" based on PM concentration ranges. For reference, the WHO recommends 24-hour mean limits of 25 µg/m³ for $PM_{2.5}$ and 50 µg/m³ for PM_{10}. These benchmarks were used to assess compliance and to highlight health risks. To ensure data quality and repeatability, each measurement cycle was repeated at least three times on different days with similar weather conditions. The data were checked for outliers and validated using co-located duplicate instruments at a subset of sampling points. Calibration of equipment was performed before and after the campaign using certified reference materials and manufacturer protocols. This level of methodological rigor ensured that the PM data were robust and suitable for use in further health and environmental risk assessments.

C. Air Quality Index

The AQI is a standardized metric used to communicate the potential health risks associated with air pollution. It translates pollutant concentration levels—such as those of PM_{10} and $PM_{2.5}$—into a single number and category that reflects the severity of air quality conditions (Horn & Dasgupta, 2024).

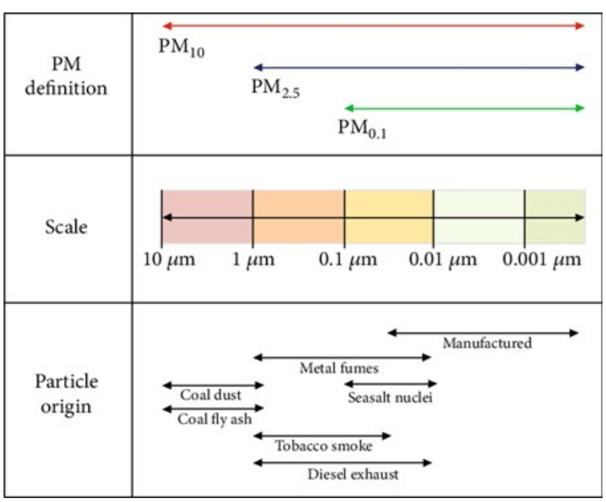

Fig. 3 Classification of PMs and sources of particles (Nurcahyanto et al., 2022)

AQI values help authorities and the public understand how clean or polluted the air is, and what associated health effects may be expected within short-term exposure periods as 24 hours (Cheng et al., 2007). In this study, AQI values were calculated for both PM_{10} and $PM_{2.5}$ based on field measurements taken from around selected asphalt plants in Iran. The formula used to calculate AQI is as follows:

$$AQI = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} \cdot (C - C_{low}) + I_{low} \qquad (1)$$

where, C is the observed pollutant concentration (µg/m³), C_{high} and C_{low} are the upper and lower bounds of the concentration breakpoint range containing C. I_{high} and I_{low} are the corresponding upper and lower bounds of the AQI value for that range. This linear piecewise function maps the observed pollutant concentration onto a defined AQI scale. To perform this conversion, each country defines specific breakpoint tables, which may vary slightly in thresholds and categorization. We applied and compared two AQI frameworks included the U.S. EPA and the DoE AQI models.

The Iranian AQI model, while structurally similar, uses slightly different breakpoint values and often adopts more conservative thresholds in certain categories (Kalantari et al., 2024). For instance, the "Unhealthy for Sensitive Groups" category for $PM_{2.5}$ may begin at a lower concentration compared to the U.S. model. The Iranian DoE model also adapts AQI messaging based on local climatic and population vulnerability contexts (Janjani et al., 2020). In our study, we used both AQI models to convert raw PM concentration data into AQI values. This dual-model approach allowed for a comparative interpretation of how air pollution is assessed under different regulatory systems. It also highlighted the sensitivity of air quality classification depending on the model applied, which is particularly relevant in Iran where regulatory enforcement is evolving and public awareness is increasing. The use of both models added robustness to the health impact interpretation of the data (Yousefi et al., 2019). For example, a $PM_{2.5}$ concentration of 38 µg/m³ may be classified as "Moderate" under U.S. standards but "Unhealthy for Sensitive Groups" under Iranian DoE criteria, leading to different policy or public health responses. This comparison underscores the importance of contextualizing AQI models in national environmental assessments. Tables 1 and 2 are provided a comparison for AQI classification for both Iran and U.S. EPA models.

The U.S. EPA AQI model is internationally recognized for its methodological clarity, widespread adoption, and compatibility with standardized air quality monitoring protocols. Its well-established breakpoint ranges and communication strategy make it highly effective for public health alerts and policy-making (Zahedi et al., 2024). A major advantage of this model is its rigorous scientific foundation and consistency across pollutant types, enabling direct comparability between regions and long-term trend analysis (Sowlat et al., 2011). For international studies or projects with global benchmarks, the U.S. model provides a highly reliable and harmonized framework (Yousefi et al., 2019). In contrast, the DoE AQI model has the advantage of being tailored to local environmental, climatic, and population-specific contexts (Zahedi et al., 2024). The slightly modified breakpoints for $PM_{2.5}$ and PM_{10} allow the Iranian model to reflect national risk assessments and public health priorities more precisely. In regions where air quality conditions often exceed WHO limits, using a locally adjusted model ensures better sensitivity to chronic exposure conditions and may trigger earlier warnings for vulnerable groups (Yousefi et al., 2019). Moreover, it is more relatable for domestic policy implementation and environmental reporting within Iran. However, both models have their limitations (Sowlat et al., 2011). The U.S. model, despite its scientific robustness, may under-represent health risks in countries with higher pollution baselines or different exposure patterns (Yousefi et al., 2019). Conversely, the Iranian model, though locally adapted, lacks international comparability and may not be as transparent or widely validated as its U.S. counterpart (Jafari et al., 2017). The use of both models in this study helped balance these strengths and weaknesses—providing both global relevance and local precision in interpreting the impacts of PM pollution from asphalt plants.

In this study, the AQI will be calculated for both PM_{10} and $PM_{2.5}$ concentrations collected around selected asphalt plants using a two-step approach. First, the raw data obtained from gravimetric sampling and real-time monitoring devices will be averaged over a 24-hour period to align with the standard exposure interval used by both the U.S. EPA and Iranian DoE AQI frameworks. This 24-hour mean value represents the daily concentration that is used to assess potential health risks associated with short-term exposure to particulate matter. Once the daily average concentration is determined, the value will be inserted into the official AQI formula to interpolate the corresponding AQI score. The study uses the linear breakpoint method, where the observed pollutant concentration is mapped onto the defined AQI scale based on predetermined concentration ranges (breakpoints). These breakpoints are sourced from the latest official tables published by both the U.S. Environmental Protection Agency and Iran's Department of Environment. Each AQI score will also be assigned a health impact category (e.g., "Good," "Moderate," "Unhealthy for Sensitive Groups"), allowing for qualitative interpretation alongside the numerical result. By applying both AQI models in parallel, the study enables a comparative interpretation of air quality conditions at the study sites. This approach provides two perspectives: one that is internationally standardized (U.S. EPA) and another that reflects local regulatory context and population sensitivity (Iran DoE). This dual-model calculation ensures that the resulting AQI values are both globally understandable and locally meaningful, offering a robust framework for evaluating the environmental and public health impacts of particulate emissions from asphalt plants.

IV. Results and Discussion

This study set out to assess the concentration of airborne particulate matter (PM_{10} and $PM_{2.5}$) around small- and medium-scale asphalt plants in various regions of Iran, and to evaluate the performance of existing pollutant filtration systems. Given the widespread presence of such plants across the country and their proximity to residential, agricultural, or ecologically sensitive areas, the environmental impact of their operations required detailed investigation. The study also aimed to calculate and compare AQI values based on both international (U.S. EPA) and local (Iranian DoE) standards. Field measurements were carried out at multiple asphalt plants located in diverse climatic zones, including arid (e.g., Yazd), semi-humid (e.g., Tehran outskirts), and agricultural regions (e.g., Isfahan province). Sampling stations were strategically placed at different distances from the plants to capture spatial variation in PM dispersion. Gravimetric sampling was conducted alongside real-time monitoring to ensure both quantitative accuracy and temporal responsiveness. Weather conditions, topography, and operational status of emission control systems were recorded during each sampling session.

Table 1 Comparative AQI Breakpoints for $PM_{2.5}$ and PM_{10}: U.S. EPA vs. Iranian DoE

AQI Category	AQI Range	U.S. EPA (µg/m³)		DoE (µg/m³)	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Good	0 – 50	0.0 – 12.0	0 – 54	0.0 – 15.0	0 – 50
Moderate	51 – 100	12.1 – 35.4	55 – 154	15.1 – 35.0	51 – 100
Unhealthy for Sensitive Groups	101 – 150	35.5 – 55.4	155 – 254	35.1 – 55.0	101 – 175
Unhealthy	151 – 200	55.5 – 150.4	255 – 354	55.1 – 150.0	176 – 260
Very Unhealthy	201 – 300	150.5 – 250.4	355 – 424	150.1 – 250.0	261 – 425
Hazardous	301 – 500	250.5 – 500.0	425 – 600	250.1 – 500.0	426 – 600

Table 2 AQI category and impacts (Yadav and Jain, 2020)

AQI	Color code	Impacts
Good		Minimal impact.
Moderate		May cause minor breathing discomfort to sensitive people.
Unhealthy for Sensitive Groups		May cause breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults.
Unhealthy		May cause respiratory illness to the people on prolonged exposure and discomfort to people with heart disease.
Very Unhealthy Hazardous		May cause respiratory effects, even on healthy people and serious health experienced light physical activities even during day or short period. Extreme conditions for prolonged exposure.

In parallel, the study analyzed the type, design, and operational status of filtration technologies installed in each plant. These included baghouse filters, cyclone separators, and wet scrubbers, with significant variation in maintenance practices and functional effectiveness observed among sites. Some plants operated without any formal air purification system, relying instead on basic venting or outdated dust traps, especially in more remote or low-budget facilities.

Collected PM concentration data were processed and converted into 24-hour averages for both PM_{10} and $PM_{2.5}$. These values were then translated into AQI scores using both the U.S. EPA and Iranian DoE models. The comparison of AQI outputs under both systems provided insight into the health implications from local and global regulatory perspectives. In some cases, the Iranian model classified conditions as more severe due to its slightly lower breakpoints in key AQI categories. Beyond air quality analysis, qualitative observations were made regarding environmental conditions around the plants. These included visible dust accumulation on nearby crops, building surfaces, and in open-air workspaces. In some areas, signs of water pollution—such as murky runoff and oily residues near drainage canals—were recorded, raising further concerns about the multi-pathway impacts of asphalt emissions on the surrounding ecosystem and public health. Generally, the study integrated air pollution data, technical assessment of filtration systems, and regulatory modeling to build a comprehensive profile of environmental risk associated with asphalt production in Iran. This section now proceeds to present the quantitative results of PM sampling and AQI calculations, followed by interpretation of the data in the context of health standards, regulatory compliance, and recommendations for system improvement.

Figure 4 illustrates how $PM_{2.5}$ concentrations vary with increasing distance from three selected asphalt plants (Sites A, B, and C). As expected, there is a clear decreasing trend in $PM_{2.5}$ levels as the distance from the plant increases. At 100m, Site C showed the highest concentration at 62.5 µg/m³, significantly above WHO's 24-hour guideline of 25 µg/m³. This suggests limited filtration or high process intensity at that site. Sites A and B also recorded elevated concentrations (55.2 and 48.9 µg/m³, respectively), indicating substantial particulate release near the source. At 500m, all three sites showed reduced concentrations, but levels remained above the WHO threshold, especially at Site C (38.6 µg/m³). This sustained elevation beyond 300m suggests that meteorological conditions or poor dispersion characteristics may be influencing pollutant retention. The data confirm that proximity to asphalt plants substantially increases $PM_{2.5}$ exposure, reinforcing the need for stronger emission controls and regulatory buffer zones. On the other hand, Figure 5 presents PM_{10} concentrations at the same distances. Across all sites, PM_{10} levels at 100m were notably high by exceeding 125 µg/m³. Site C again recorded the highest levels (130.8 µg/m³), pointing to a consistent pattern of higher emissions. Even at 500m, Site C remained at 95.6 µg/m³, well above both Iranian and WHO recommended daily limits. Sites A and B followed similar decreasing trends, although slightly lower in magnitude. Compared to $PM_{2.5}$, PM_{10} tends to disperse less effectively in dry or windy conditions common in Iran, which may explain the slower rate of decline across distance. This observation aligns with findings from other regional studies, where coarse particles linger longer in ambient air due to their mass. These results reinforce concerns about long-range dust pollution from asphalt production and the importance of filtration system efficiency in managing coarse particulate emissions.

Figure 6 translates $PM_{2.5}$ concentration data into AQI health categories using Iranian and U.S. models. At 100 m, Sites A and C fall into the "Unhealthy" category, while Site B registers as "Unhealthy for Sensitive Groups". At 300m, conditions improve slightly, but Site C remains in the "Unhealthy" range, indicating persistently high emissions. By 500 m, most sites reach "Moderate", though still not "Good," highlighting the extended impact range of these facilities. This visualization underscores the public health risks near asphalt plants, particularly for vulnerable groups such as children and individuals with respiratory conditions. Comparing AQI categories across distances helps visualize not just numerical declines but also the shifting level of health concern. The graph confirms the practical value of AQI as a communication tool and supports its integration into local regulatory frameworks. Also, figure 7 illustrates the AQI categories derived from PM_{10} concentrations at three asphalt plant sites (A, B, and C) across distances of 100, 300, and 500 m. At 100 m, both Site A and Site C fall into the "Unhealthy" category, indicating that the PM_{10} concentrations exceed 150 µg/m³, a level associated with significant health risks.

Site B, though slightly lower, still registers as "Unhealthy for Sensitive Groups". These findings suggest that residents and workers within 100 m of these facilities are at elevated risk, those with respiratory or cardiovascular conditions. At 300 m, air quality improves marginally. Site A drops into the "Unhealthy for Sensitive Groups" category, while Site B enters the "Moderate" range. However, Site C remains at "Unhealthy", reflecting its persistently high PM_{10} emissions. At 500 m, Site C finally improves to "Unhealthy for Sensitive Groups", while Sites A and B stabilize in the "Moderate" category. These trends confirm that PM_{10} pollution from asphalt plants can impact air quality far beyond the plant boundary, particularly when filtration systems are inadequate or poorly maintained.

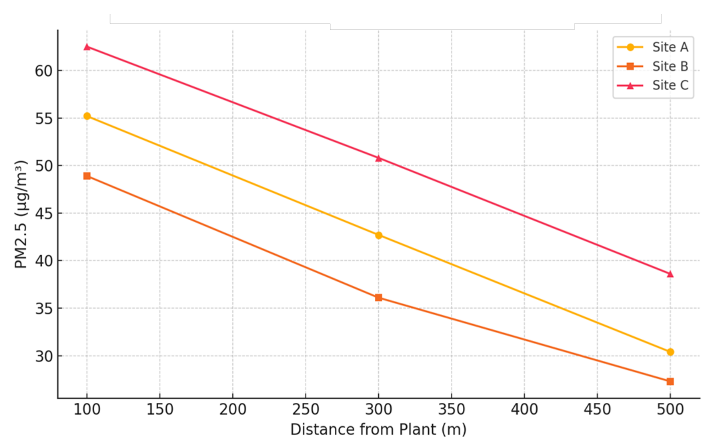

Fig. 4 $PM_{2.5}$ concentration by distance from asphalt plants

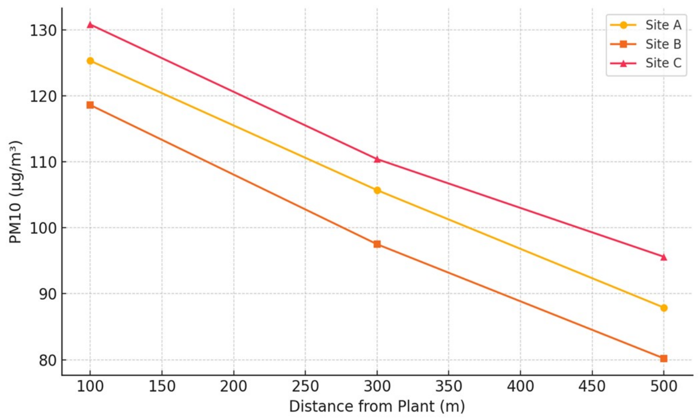

Fig. 5 PM_{10} concentration by distance from asphalt plants

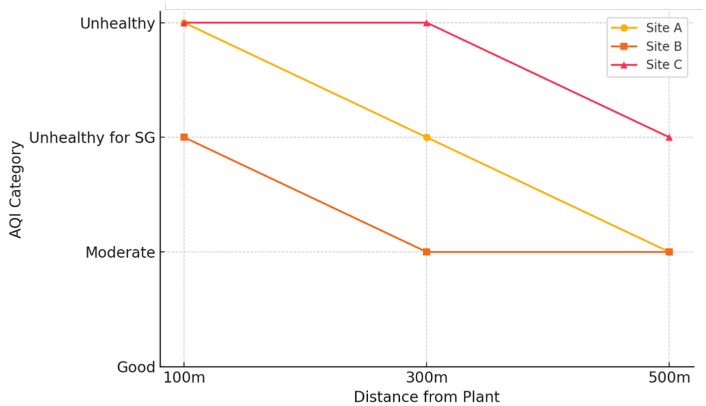

Fig. 6 AQI category based on $PM_{2.5}$ at different distances

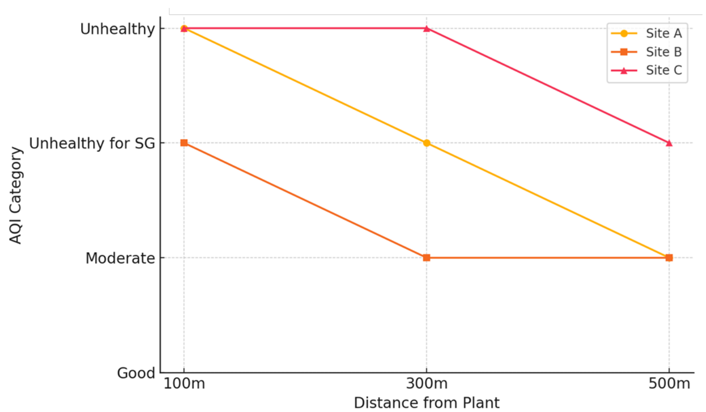

Fig. 7 AQI category based on PM_{10} at different distances

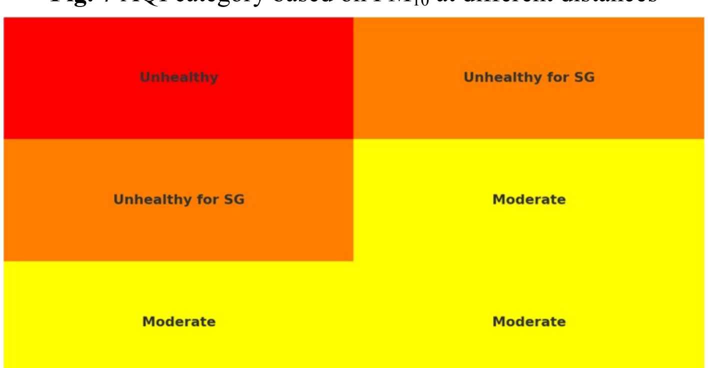

Fig. 8 AQI categories for $PM_{2.5}$ as comparative based on Iran and US classifications

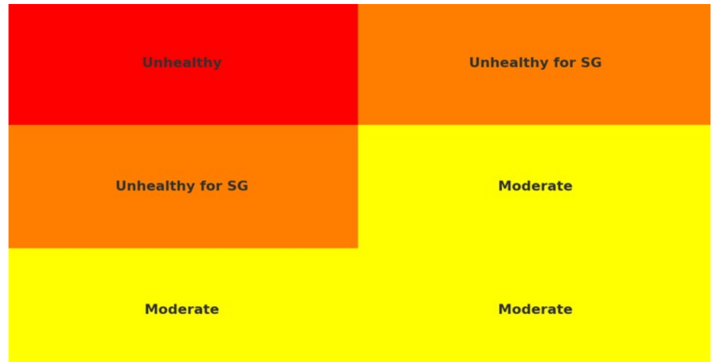

Fig. 9 AQI categories for PM_{10} as comparative based on Iran and U.S. classifications

Figure 8 displays a side-by-side comparison of AQI categories derived from $PM_{2.5}$ concentrations at 100m, 300m, and 500m from the asphalt plant, using both the U.S. EPA model and the Iranian DoE model. At 100 m, both models categorize the air quality as "Unhealthy," reflecting high levels of fine particulate matter near the emission source. This alignment between the models indicates a universally recognized high-risk exposure zone immediately around asphalt plants. At 300 m, the divergence between the two models becomes apparent. The U.S. model classifies this distance as "Unhealthy for Sensitive Groups," while the Iranian model maintains the same label, showing similar stringency at this threshold. However, these similar categorizations may still differ in practical implications due to underlying breakpoint values and health advisory interpretations in each country. By 500 m, the U.S. model places the air quality in the "Moderate" range, suggesting a significant improvement in air conditions. Meanwhile, the Iranian model also classifies this zone as "Moderate", highlighting a rare convergence in judgment at lower exposure levels. This indicates that both regulatory systems acknowledge diminishing health risk with increased distance from emission sources, although Iranian assessments may maintain caution slightly longer in real-world enforcement.

Figure 9 offers a comparison of AQI classifications for PM_{10} concentrations at the same distances. At 100m, both the U.S. and Iranian models agree on labeling the area as "Unhealthy", consistent with the elevated presence of coarse particles emitted during asphalt production. This suggests a universally unacceptable health risk close to the plant, necessitating strict controls and protective measures in surrounding communities. At 300 m, the U.S. model downgrades the category to "Unhealthy for Sensitive Groups", whereas the Iranian model maintains this same label. The agreement indicates that both frameworks identify this mid-range zone as hazardous for vulnerable populations, although Iran's slightly stricter thresholds may trigger precautionary measures earlier under marginal conditions. At 500 m, the U.S. model categorizes the site as "Moderate", while the Iranian model classifies it slightly more cautiously as "Unhealthy for Sensitive Groups." This contrast illustrates the Iranian model's more conservative stance, possibly influenced by local population sensitivity, climate, and cumulative exposure scenarios. These insights reinforce the value of using both models to evaluate short- and long-range impacts of PM pollution from asphalt operations.

V. Conclusion

The findings of this study clearly demonstrate that asphalt plants, particularly those operating on small and medium scales in Iran, are significant sources of particulate matter pollution. Measured concentrations of $PM_{2.5}$ and PM_{10} at distances of 100, 300, and 500 meters from selected asphalt facilities consistently exceeded recommended thresholds by WHO and national standards, especially at close proximity. These elevated values translated into AQI scores within the “Unhealthy” and “Unhealthy for Sensitive Groups” categories, indicating a substantial risk to public health in surrounding communities. By applying both U.S. EPA and Iranian DoE AQI models, the study offered a comparative lens through which pollution severity could be interpreted. While both models showed similar trends, the Iranian model tended to yield more conservative classifications, particularly in mid-range pollution zones. This reflects a stricter public health orientation and supports the argument for localized regulatory sensitivity. The comparative AQI approach strengthened the reliability of health impact interpretations and showed that existing levels of pollution cannot be dismissed under either system. Additionally, the results confirmed a direct relationship between filtration system quality and emission levels. Plants equipped with well-maintained baghouse filters exhibited noticeably lower PM readings compared to those using outdated or no filtration systems. Facilities lacking proper controls contributed to extended pollution zones, exacerbating exposure risks for residents, workers, and nearby agricultural lands. In conclusion, this research highlights a pressing environmental and public health concern tied to the asphalt industry in Iran. To mitigate these risks, regulatory enforcement must be paired with targeted investment in modern filtration technologies, operator training, and real-time air quality monitoring. Only through a multi-pronged strategy can the negative impacts of asphalt production be effectively reduced in line with sustainable development goals.

Acknowledgment

We extend our thanks to the reviewers for their meticulous attention to detail and constructive suggestions that greatly improved the quality of this manuscript. Your contributions have been instrumental in shaping this work.

Authors' contributions

Sanaz Ebrahimi and Tahere Vosogian conducted the main data analysis, contributed to the data collection, preprocessing, and interpretation, and were responsible for drafting the initial manuscript. Gholamreza Mosavi Lavasan performed supervision, conceptual guidance. Ali Fatemi conducted critical revision of the manuscript, overall project administration and final approval of the version to be published. All authors read and approved the final manuscript.

Conflict of interest

The authors have not disclosed any competing interests.

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