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A Review: Long term effect of PM2.5 on Cardiovascular system

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Abstract:

Thailand faces a pressing issue of hazardous air pollution driven by fine particulate matter (PM2.5), leading to severe health consequences. This review underscores the strong correlation between PM2.5 exposure and diseases, contributing to a staggering 4.2 million premature deaths globally each year. Economic and social activities, including construction, industry, and burning, fuel this problem. PM2.5's minuscule size enables it to infiltrate the respiratory system, causing multi-organ damage. Yet, many countries lack adequate air quality regulations. Long-term exposure to PM2.5 significantly elevates the risk of cardiovascular and respiratory disorders, including heart attacks and lung cancer. Research consistently reveals a link between PM2.5 and cardiovascular mortality, emphasizing the urgent need for air pollution regulation to safeguard public health. Scientists differentiate between direct effects, such as PM2.5's toxicity, and indirect effects stemming from atmospheric pollutant accumulation. PM2.5, present in sources like wildfire smoke and emissions, penetrates organs, inducing irritation and abnormal blood clotting. Notably, populations at risk, such as individuals with diabetes, face a heightened cardiovascular disease risk due to PM2.5 exposure. Numerous studies emphasize the detrimental effects of both short-term and long-term PM2.5 exposure, particularly in relation to cardiovascular disease. Thailand has adopted measures in line with WHO guidelines, encompassing six key areas to mitigate health risks and enhance overall quality of life. During periods of elevated PM2.5 pollution, precautions such as avoiding outdoor activities, wearing surgical masks or N95 respirators, and staying informed through government announcements play a pivotal role in protecting public health and mitigating PM2.5 pollution's impact. Addressing PM2.5 pollution is imperative to safeguard human well-being and the environment.

Keywords **—Fine particulate matter (PM2.5), Cardiovascular disease, Long-term exposure**

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INTRODUCTION

Thailand currently grapples with a critical issue: air pollution caused by harmful dust particles, posing grave risks to urban dwellers with both immediate and lasting health consequences [1]. Numerous studies have linked these minute particulates to diseases and fatalities in humans. The World Health

Organization's 2019 report estimated that fine dust particles, known as PM2.5, were responsible for 4.2 million premature deaths annually worldwide, resulting in cardiovascular, respiratory, and cancer-related ailments [2]. This pollution predicament primarily arises from growing economic and social activities like construction, industrial production, and open burning, all of which are escalating due to globalization. PM2.5 particles, being smaller than 2.5 micrometers and invisible to the naked eye, infiltrate our respiratory systems, enter our bloodstream, and disrupt various bodily functions, gravely impacting our health. Shockingly, many countries fail to establish adequate legal regulations for air quality control, with one-third of the world's nations lacking outdoor air quality standards, and those in place often not aligning with WHO guidelines [3].

The health repercussions of PM2.5 exposure depend on the level and duration of exposure. Short-term exposure (e.g., 8 or 24 hours) can result in irritations like eye and throat discomfort, coughing, sneezing, skin and eye irritation, and conjunctivitis [4]. Research, such as The Six Study, suggests that even a year of chronic exposure to PM2.5 is sufficient to capture its long-term health effects [5,6,7]. Continuous exposure to high levels of air pollution, typically above 100 µg/m3, or 35 µg/m3 over a 24-hour period, can lead to various health issues, including cardiovascular irregularities, increasing the risk of sudden cardiac arrest, heart attacks, ischemic strokes, high blood pressure, and respiratory ailments such as asthma, COPD, and lung cancer [2].

Thomas Bourdrel et al.'s study on the cardiovascular effects of air pollution reveals that a 10 µg/m3 increase in long-term PM2.5 exposure is associated with an 11% rise in cardiovascular mortality. Certain pollutants, especially PM2.5 from combustion and ultrafine particles, have significant cardiovascular impacts. Interestingly, some studies indicate that the adverse effects of PM2.5 are more pronounced among those with lower education levels, possibly due to reduced antioxidant intake associated with lower fruit consumption. Fine and ultrafine particles, especially those from combustion sources like road traffic, fossil fuels, and wood burning, have a greater cardiovascular impact compared to coarse particles. Additionally, the composition of PM, particularly carbon particles, plays a crucial role in cardiovascular toxicity [8]. Studies in the Asia-Pacific region also support the link between long-term PM2.5 exposure and increased cardiovascular mortality, as well as the incidence of cardiovascular diseases, type 2 diabetes, kidney diseases, and chronic obstructive pulmonary disease [9]. Moreover, research on PM2.5 concentration in Upper Northern Thailand reveals a higher mortality rate among lung cancer patients, with risk factors including gender (male), age, cancer stage, and duration of exposure to PM2.5 and PM10. Higher air pollutant concentrations are linked to a greater risk of death from lung cancer [10].

Air pollution stands as a significant contributor to cardiovascular diseases, demanding immediate attention. This review emphasizes the enduring impact of PM2.5 and its correlation with cardiovascular conditions, serving as a crucial resource for both the public and cardiovascular patients to understand the severity of PM2.5's effects. It underscores the urgent need for enhanced air pollution control measures and public health interventions.

PM2.5 Exposure and Cardiovascular Disease

The present study delves into the relationship between PM2.5 exposure and cardiovascular disease (CVD). PM2.5, comprising heavy metals, has been linked to heightened CVD risks due to molecular mechanisms. PM2.5's impact on the cardiovascular system involves metabolic activation, oxidative stress, genotoxicity, inflammation, disruptions in Ca2+ signaling, autophagy disturbances, and apoptosis induction, all culminating in cardiovascular events [11].

Heavy metals, such as lead (Pb), cadmium (Cd), arsenic (As), selenium (Se), antimony (Sb), nickel (Ni), thallium (Tl), aluminum (Al), iron (Fe), along with PM2.5, have shown cumulative effects on CVD mortality. Studies confirm the presence of these heavy metals in PM2.5, with some revealing organ damage caused by their accumulation. Meta-analyses suggest an association between urinary cadmium (Cd) levels and CVD risk, higher blood lead (Pb) levels with increased all-cause and CVD mortality, and urinary antimony (Sb) levels with overall and heart-disease-related mortality [12].

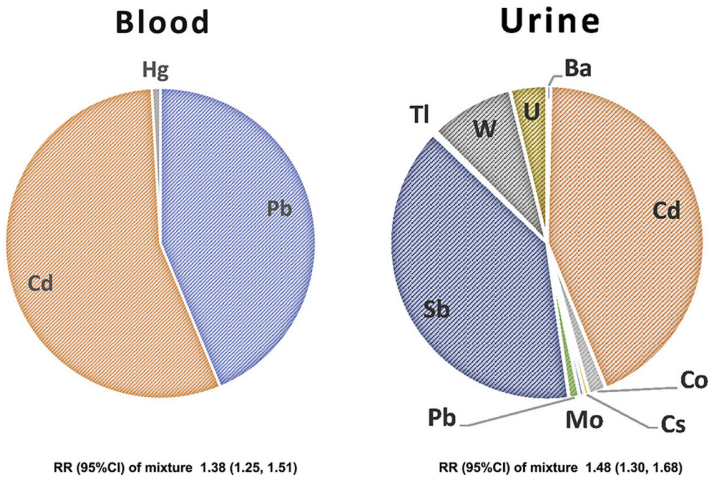

Figure 1: Contribution of heavy metals to mixture effect on all-cause mortality among U.S. adults, 1999-2014 [13]

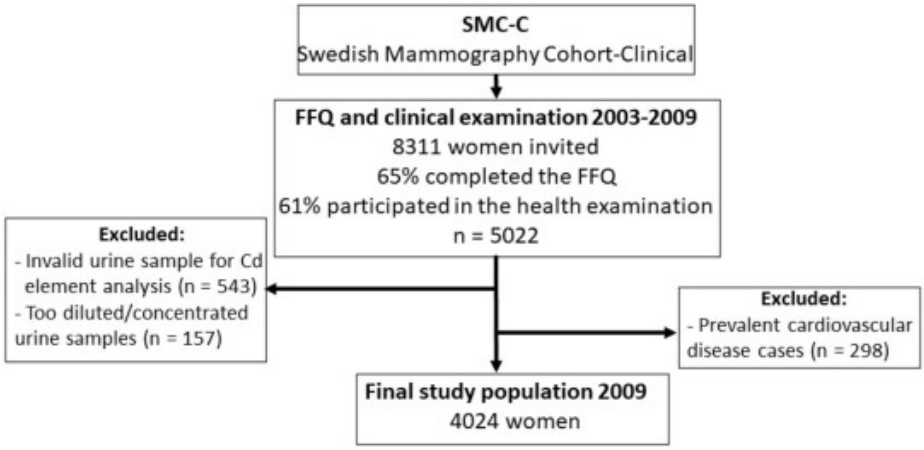

Figure 2: Flow-chart of recruitment and exclusion steps of the study population.[14]

Cadmium, a toxic metal, adversely affects various organs, including the cardiovascular system, leading to cell dysfunction. In clinical sub-cohorts like the Swedish Mammography Cohort-Clinical (SMC-C), associations between blood Pb levels and cardiovascular parameters have been established [15,16].

Antimony (Sb), widely used in industries, can lead to exposure through various routes. Studies indicate associations between increased urinary Sb levels and all-cause and heart disease mortalities. Notably, higher quartiles of Sb levels correspond to higher hazard ratios and odds ratios for heart diseases [17,18].

Copper (Cu), an essential element in biological functions, must maintain balance to prevent CVD. Studies have explored Cu exposure, revealing its presence in PM2.5 and higher concentrations in the liver and kidney in outdoor environments. Imbalances in Cu levels can result in inflammatory vascular diseases [19,20,21].

This study unveils the intricate connections between PM2.5 exposure and cardiovascular disease, underscoring the role of heavy metals, including lead, cadmium, antimony, and copper, in shaping the risks and mechanisms of CVD. Understanding these relationships can inform strategies for mitigating the cardiovascular impact of PM2.5 pollution.

PM2.5 and cardiovascular disease: A Brief Overview

Air pollution is a significant contributor to both human health problems and climate change, posing a dual public health threat [22,23]. Air pollution can be categorized into direct and indirect effects. Direct effects involve exposure to toxic pollutants, with PM2.5 being a notable example that causes various health issues [24]. These pollutants can lead to long-term health problems, emanating from sources like factories, vehicles, and construction sites. PM2.5, particularly present in smoke and emissions, can infiltrate our bodies, triggering inflammation in the lungs and circulation issues [25].

Studies have unveiled links between air pollution and cardiovascular disease (CVD). Long-term exposure to air pollution has been linked to cardiometabolic risk factors, which affect CVD outcomes, especially in individuals with preexisting conditions [26,27]. A study found that higher PM2.5 exposure is associated with increased death rates from heart disease and stroke, with risks escalating as PM2.5 levels rise [28]. PM2.5 poses a direct threat to our cardiovascular health by inducing oxidative stress and inflammation. Its small size allows it to enter our bloodstream and disrupt our autonomic nervous system, potentially leading to atherosclerosis, abnormal blood clotting, hypertension, structural heart changes, and various cardiovascular events [29,30].

A large-scale study involving 114,537 women examined the impact of PM exposure on CVD incidence, finding elevated risks among individuals with diabetes and potential risks for older and obese individuals [31,32]. The American Heart Association has long recognized the link between PM air pollution and CVD, with newer research reaffirming that short-term and long-term exposure increase cardiovascular mortality and reduce life expectancy, with reductions in PM levels yielding positive health effects [33,34,35,36,37].

Long-Term Impact of PM2.5 on Health in Northern Thailand and Beyond

Northern Thailand grapples with recurring air pollution issues due to open-air housing and agricultural practices [38]. Rural areas often lack awareness of dust and air pollution prevention, exposing residents to health risks, including respiratory and cardiovascular problems, and lung cancer as a leading cancer cause [39].

PM2.5, a significant air pollutant, poses kidney-related risks by reducing kidney function, elevating chronic kidney disease risk, and promoting kidney tumor development, likely driven by oxidative stress, inflammation, and cytotoxicity [40]. Prolonged PM2.5 exposure exacerbates pulmonary fibrosis and lung injury, impairing the body's ability to combat oxidative stress, potentially leading to fibrosis and increased susceptibility to bacterial infections [41].For those with diabetes, PM2.5 exposure increases cardiovascular

disease (CVD) risks, further emphasizing the connection between air pollution and CVD, especially among older individuals [42,43].

Research conducted in Karachi, Pakistan, reveals that PM2.5 constituents, particularly from fossil-fuel combustion and industrial emissions, increase cardiovascular hospital admissions, notably nickel's association [44]. Long-term PM2.5 exposure also worsens COVID-19 outcomes, with an annual increase of 1 μg/m3 in PM2.5 associated with an 18% increase in hospitalizations [45].

In rapidly expanding cities like those in China, agriculture and industry contribute to rising air pollution levels, with adverse effects on cardiovascular health and stroke risks [46]. In Beijing, long-term PM2.5 exposure is associated with increased mortality in CVD patients [47]. Elderly individuals, especially those over 65, face higher risks from air pollution. Increases in O3, NO2, SO2, PM10, and CO levels are linked to coronary intake and respiratory problems [48]. A study in Chiang Mai Province, Thailand, reveals fluctuating PM2.5 levels, with dangerous peaks during the winter, negatively impacting public health [49].

Guidelines for Reducing PM2.5 Exposure and Cardiovascular Disease Risk

Annually, approximately 2.4 million people worldwide succumb to the adverse health effects of air pollution [50]. Among these effects, PM2.5 pollution is particularly detrimental to cardiovascular health, especially in the elderly population. Plausible mechanisms behind these health risks involve inflammation, oxidative stress, abnormal hemostatic system activation, and disturbances in the autonomic nervous system.

To mitigate the risk and severity of PM2.5 exposure, certain prevention measures have been identified. 1) Avoiding Outdoor Activities: For the elderly population, refraining from outdoor exercise during high PM2.5 pollution episodes can reduce the risk of adverse cardiovascular effects. 2) Air Purifiers: Installing air purifiers within buildings can enhance indoor air quality and decrease the risk and severity of PM2.5 pollution exposure [51]. 3) Mask Usage: Surgical masks and N95 masks are effective in preventing PM2.5 exposure through the respiratory system. N95 masks provide a filtration efficiency of 95%, while surgical masks, despite lacking fiber filters, can still filter approximately 80% of PM2.5 dust, which is suitable for the weather conditions in Bangkok [52]. 4) Technological Advancements: Guidelines from the US Environmental Protection Agency suggest that advancements in diesel engine technology can help reduce air pollution, thereby positively impacting respiratory disease prevention and lowering premature mortality rates [50].

The impact of PM2.5 pollution on cardiovascular diseases is substantial. Short-term exposure can lead to acute coronary syndromes with risks of myocardial infarction, stroke, and acute heart failure, while long-term exposure results in an 11% increase in cardiovascular disease mortality [53]. Thailand has implemented measures in line with WHO guidelines, similar to countries such as China, Japan, and Vietnam, to mitigate health impacts and enhance the population's quality of life. These measures encompass various aspects of PM2.5 management.

Table 1:The measurement of PM 2.5 pollution in Thailand, China, Japan and Vietnam from 2017 to 2021 [1]

Areas	WHO	Thailand	China	Japan	Vietnam

Industry	Encourage citizens to use clean energy.	The long-term planning over a three-year period from 2022 to 2024 by increasing the efficiency of pollution management including controlling dust from construction, Industrial factories and establishments, open burning	Close the construction in Beijing, Controlling emissions from industrial factories, Suspend theconstruction of a project during winter season, Restructure the industry, Increasing gas-fired power plants instead of coal-fired power plant, Relocate a factory's production base outside of the city, Establishment a coal-free zone in some areas	Controlling emissions from industrial factories	Installing inspection equipment industrial gas emissions, standardization for the emission of inorganic substances and fine dust, restrictions on pollution-causing businesses. prescribe the penalty for establishments that violate the law.
Energy	Encouraged people to use clean energy within the household.	Become aware of the impact caused by cooking and grilling in open areas.	Directed citizens to refrain from using coal in their households to switch to clean energy from electricity and natural gas instead.	Increasing investment to find alternative energy from other sources for household	—
Transport	Encourages people to use clean modes of power, including cycling or traveling by train.	Measurement to control using of fuel with a sulfur value of not more than 10 ppm (Euro standard), development transportation service in public link all systems, encouraged citizen to use public transportation including air-condition, natural gas, electricity bus and hybrid bus, decrease taxes for electricity car, replace elderly government	Measurement to control emission ofsulfur dioxide, which requires emissions not to exceed 10 ppm. Moreover, supports and campaigns for people to turn to public transportation such as using high-speed trains instead.	Decrease and excepted taxes for the industry for eco-car and planning guidelines for using non-motorized transport and increase the number of cycling areas	—

		vehicles to electricity car, limit the number of cars entering the city during rush hour			
Urban planning	Encourages increasing green spaces and planning for people to systematically manage household energy.	Increasing green spaces in Bangkok's vicinity by government, private, and community sectors.	Increasing green spaces and public areas in Beijing.	—	—
Power Generation	Advocates for the use of energy that emits less fuel and recycles combustion.	Thailand's policy or guidelines on energy generation are ambiguous. Nevertheless, some government and private agencies that use solar energy and generate more electricity from renewable energy.	Encourage loans to companies investing in clean energy and using natural gas instead of using coal. It also increases investment in solar energy production.	Supported the production of electricity from energy sources, including the generation of electricity from wind turbines.	—
Municipal and agricultural waste management	Proposes guidelines for waste management, including biogas digestion and combustible waste that is unable to use emission-restricted technologies.	Standardization for controlling the emission of air pollution from rice mills and crematoriums.	Reduces the import of the garbage, development the electricity factory from garbage that underrated quality, penalty the illegal import of toxic waste, encourage about waste water treatment	Restrictions of burning area	Encourage the entrepreneur using clean manufacturing technology and participating in waste treatment, Establish a tax exemption policy on imports of equipment and raw materials for waste treatment, Encourage research for reuse and treatment of waste

Thailand's PM2.5 Policy and Environmental Strategy

Thailand has formulated a comprehensive approach to address PM2.5 dust pollution, stemming from its 20-year national strategic plan and the national climate change plan, known as the Health National Adaptation Plan (HNAP). This plan comprises four key components:

H: Health Literacy: This component aims to enhance the knowledge and skills of the population, enabling them to adapt to and protect themselves from climate change effects.

N: Networking for Capacity Building: It emphasizes the integration of various sectors' potential to collectively contribute to public health management in the context of climate change.

A: Advocacy for Commitment: Strengthening national preparedness for public health, driven by the recognition that it supports economic development, social well-being, and national security.

P: Public Health Preparedness: This component focuses on developing a national public health system aligned with international standards to cope with climate change [54].

Furthermore, Thailand's 20-year National Strategic Plan sets the course for long-term pollution management and outlines operational guidelines for each five-year period. The plan underscores the importance of building a growth strategy centered on improving the quality of life while being environmentally friendly. It encompasses the following aspects: 1) Green Economic Society: Promoting sustainable growth within a green economic society that emphasizes social and economic development while balancing natural resources and environmental quality, promoting a bio-based economy to reduce environmental risks and resource scarcity. 2) Marine Economy: Fostering sustainable growth in the marine economy while caring for marine and coastal resources to reduce social inequality. 3) Eco-Friendly Atmosphere: Emphasizing the reduction of greenhouse gas emissions, the development of a low-carbon society, enhanced disaster management, and citizen adaptability to reduce losses from natural disasters and climate change impacts, along with investments in climate-friendly infrastructure. 4) Urban and Rural Development: Developing urban, rural, agricultural, and eco-industrial areas with an emphasis on sustainable and environmentally friendly land use, promoting livable cities, stable rural areas, sustainable agriculture, and eco-industry [55].

PM2.5 pollution poses significant health risks due to its ability to penetrate the respiratory tract, bloodstream, and organs. Moreover, it carries other harmful substances like cadmium (Cd), mercury (Hg), and carcinogens into the body, primarily originating from car emissions, industrial processes, waste combustion, and atmospheric condensation, notably sulfur dioxide (SO2) and nitrogen oxides (NOx), as well as other toxic substances including mercury (Hg), cadmium (Cd), arsenic (As), and polycyclic aromatic hydrocarbons (PAHs) [56]. The impacts of PM2.5 pollution on health are substantial, leading to chronic cardiovascular diseases. Thailand has reported more than 50,000 deaths annually due to air pollution. Multiple government agencies, including the Ministry of Transport, Royal Thai Police, Ministry of Public Health, Ministry of Interior, Ministry of Agriculture and Cooperatives, Ministry of Digital Economy and Society, Ministry of Higher Education, Science Research and Innovation, Ministry of Industry, Ministry of Energy, Bangkok authorities, and the Prime Minister's Office, have taken concerted action to address this issue. Measures include reducing fuel usage in factories and limiting open burning practices, which have yielded reductions in PM2.5 dust levels [57].

Table 2: The significant measurement for controlling PM 2.5 pollution in regions of Thailand from 2017 to 2021.

Regions	**The significant measurement for control PM 2.5 pollution**
Northern	Transboundary Haze Pollution and Open-burning and agriculture area incinerator
Central	Transportation, Construction and Industry
Southern	Transboundary Haze Pollution

Eastern	Open-burning and agriculture area incinerator and Industry
Northeastern and Western	Open-burning and agriculture area incinerator

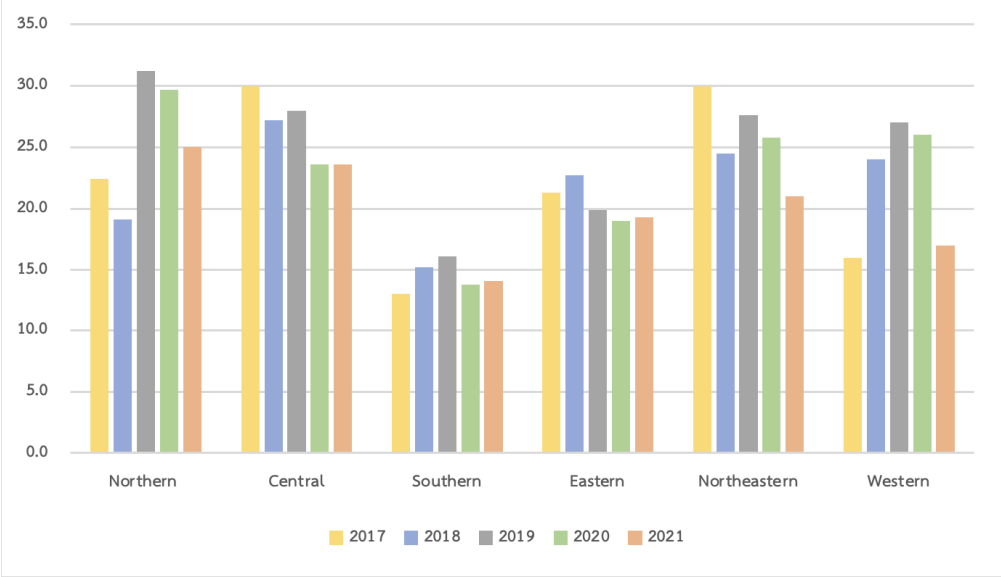

Figure 3: The proportion of PM 2.5 (µg./m) in regions of Thailand from 2017 to 2021.[58]

According to the research, it was found that releasing the impact of cardiovascular effects of air pollution by proposing long-term solutions for individuals. It can reduce the risk of cardiovascular disease associated with air pollution. Moreover, the method of using portable indoor air purifiers can reduce indoor PM 2.5 levels by >50% and has been prove to improve a growing list of surrogate endpoints, including blood pressure, insulin sensitivity, inflammation markers, stress hormones, and metabolic profiles.[59]

Conclusion

PM2.5 pollution poses a significant health threat, arising from various sources such as combustion, industrial processes, and vehicular emissions. A prior study reaffirms the significant association between PM2.5 exposure and cardiovascular mortality, particularly impacting individuals with lower education levels, potentially due to lower antioxidant intake. Research from the Asia-Pacific region also corroborates the link between prolonged PM2.5 exposure and persistent cardiovascular mortality, along with diseases such as type 2 diabetes and lung cancer. Residential PM2.5 levels in Upper Northern Thailand highlight an elevated risk of lung cancer mortality, especially within specific demographics. For individual to safeguard against PM2.5 pollution, it is essential to 1) Limit outdoor activities during periods of high PM2.5 levels. 2) Maintain a supply of surgical masks or N95 respirators. 3) Stay informed through government announcements. For industry to address the challenges posed by PM2.5 pollution requires a multifaceted approach 1) Strengthening emissions regulations for industries. 2) Promoting cleaner technologies. 3) Enhancing public transportation systems. 4) Raising public awareness about the health risks associated with PM2.5 exposure. 5) Fostering collaboration between government bodies, environmental agencies, healthcare institutions, and communities. 6) Effective monitoring, timely response, stringent enforcement

of pollution control measures, and the dissemination of real-time air quality information are essential steps to safeguard the well-being of the population.

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