Mitigating PM2.5 Pollution in Shijiazhuang: Strategies and Solutions

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Abstract. Air pollution, particularly PM2.5 pollution, has been a pressing issue in Shijiazhuang, a city in Hebei Province, China, characterized by high levels of PM2.5 concentration over the past years. This research paper delineates the historical trends and various factors influencing PM2.5 concentration in Shijiazhuang, including meteorological, geographical, and human factors. The paper further explores a range of strategies to mitigate PM2.5 pollution, focusing on policy interventions and technological solutions. Policy interventions encompass stricter emission standards for industries, promotion of green transportation, and sustainable agricultural practices. Technological solutions highlight the introduction of air purifiers in public spaces, development of cleaner industrial technologies, and the promotion of electric vehicles and public transportation systems. Grounded in recent research findings, the paper offers a comprehensive approach to reducing PM2.5 environmental pollution in Shijiazhuang, aiming to foster a healthier and more sustainable habitat for its residents.

Keywords: PM2.5 pollution; Air quality; Shijiazhuang; Policy interventions; Public health.

1. Introduction

Air pollution has emerged as a critical environmental issue, drawing considerable attention in public health debates. PM2.5, or fine particulate matter with a diameter less than 2.5 micrometers, has been a focal point due to its harmful impact on both human well-being and ecological systems. These tiny particles possess large surface areas despite their small size, enabling them to carry a range of toxic elements [1]. As a result, they can bypass the body's natural filtration mechanisms, such as nasal hairs, and penetrate deep into the respiratory tract. Once there, they can disperse throughout the body, causing a range of health issues, from respiratory conditions to cardiovascular diseases, and even premature death. For example, exposure to PM2.5 has been shown to reduce average life expectancy by approximately 8.6 months in countries within the European Union. Recognizing the gravity of the issue, the World Health Organization has classified PM2.5 exposure as a significant environmental health risk, attributing it to a high number of premature deaths globally.

Shijiazhuang, located in Hebei Province, epitomizes the cities in the North China Plain grappling with acute air pollution and elevated PM2.5 levels over recent years. Data from 2015 to 2017 revealed that the city's PM2.5 concentrations were 86.53, 94.51, and 81.82 μg/m^3, respectively—levels that significantly exceed the World Health Organization's annual guideline of 10 μg/m^3 [2]. Such elevated concentrations suggest a considerable health risk to the local population, particularly in terms of premature mortality and reduced life expectancy. Specifically, between 2015 and 2017, cerebrovascular diseases were the leading cause of premature deaths in the city, followed by ischemic heart diseases, lung cancer, and chronic obstructive pulmonary diseases. The total count of premature deaths attributed to PM2.5 exposure during these years were 4994, 5107, and 5088, respectively. Correspondingly, the years of life lost were 47,001, 47,880, and 47,381. The detrimental health impact of high PM2.5 levels in Shijiazhuang is staggering, and the contributing factors are multifaceted. Therefore, studying PM2.5 pollution in this city could significantly enhance our understanding and forecasting abilities in related scientific research.

This research paper aims to record recent trends and fluctuations in PM2.5 concentration through the brief history of PM2.5 levels in Shijiazhuang over the past years, analyze multiple factors that influence PM2.5 concentration in Shijiazhuang, and come up with coordinated strategies to reduce

PM2.5 environmental pollution in the city with the assistance of case studies that includes successful initiatives from other regions that reduced PM2.5 levels. To the end, this research paper aims to provide insights on the causes of high level of PM2.5 concentration, highlight the significance of PM2.5 pollution, emphasize on the collective responsibility to combat PM2.5 pollution, call for actions from policymakers, industries and the general public, and contribute to the pollution regulation in Shijiazhuang as well as other regions that are faced with similar problems.

2. Background: PM2.5 Concentration in Shijiazhuang

2.1. Historical Data and Trends

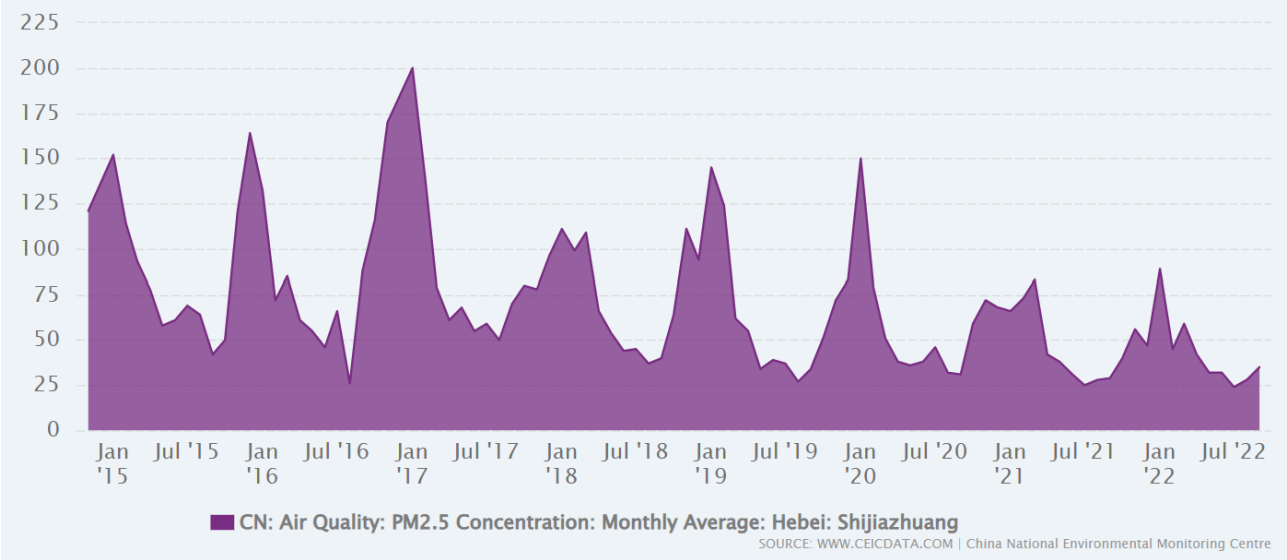

Fig. 1 Monthly average PM2.5 concentration in Shijiazhuang over 2015-2022

According to the data collected by China National Environmental Monitoring Centre, As shown in Fig. 1, the monthly average PM2.5 concentration in Shijiazhuang fluctuated over the past eight years with a general decreasing trend. The trend reflected that air pollution control in Shijiazhuang has become relatively effective in recent years, especially in 2021 and 2022 with the largest monthly average PM2.5 concentration less than 100 μg/m^3 [3]. However, though generally decreasing, the monthly average PM2.5 concentration is still well above 10 μg/m^3, this is the World Health Organization's recommended yearly value recommendation., suggesting that the air pollution in Shijiazhuang is still in a serious condition [2,3]. In addition, the pattern shows a risk of rebound to the original pollution levels, as could been from the data that the PM2.5 concentration dropped abruptly from 2017 to 2018 and then bounced back to a higher value from 2018 to 2019. The data also shows that the monthly average PM2.5 concentration is larger in January than in July, demonstrating that Shijiazhuang is more polluted in the winter than in the summer.

2.2. Meteorological Factors

Meteorological factors, which include air temperature, precipitation and wind, are an important series of elements that influence the PM2.5 concentration in Shijiazhuang. According to the data collected in 2013, the concentration of PM2.5 has a negative relationship with air temperature [4]. During summer time, the intense radiation heats the city's underlying surface, causing the lower atmosphere unstable and turbulent, which makes the diffusion of pollutants easier and mitigates the degree of pollution [4]. The situation would be contrary when the surface temperature is low in Shijiazhuang's winter [4]. In addition, the increase in precipitation would cause a slightly decrease in the level of PM2.5. Though not as much as the decline of PM10 concentration, the concentration of PM2.5 still declines in Shijiazhuang with large precipitations caused by the humid ocean currents in summer [4,5]. However, in winter especially in January, affected by the Mongolia and Siberian high

pressure. the dry climate results in the high concentration of PM2.5 in Shijiazhuang within the Jing-Jin-Ji region [5,6]. The speed and direction of wind affect the PM2.5 condition as well. In summer, the wind of Shijiazhuang mainly blows from the southeast, where industrial factories such as power plants, pharmaceutical factors, sewage treatment plants are accumulated, bringing pollutants to the city that increases the concentration of PM2.5 [4]. In winter, the wind speed is low with the general value less than 2m/s, which is even less than that in summer (2.1 m/s) [4,6]. Since the concentration of PM2.5 is more sensitive to wind speed compared to PM10, the low wind speed in winter leads to harder diffusion of those small particles and contribute to the high level of PM2.5 concentration [4].

2.3. Geographic Factors

The city area of Shijiazhuang stretches over two significant geomorphic units, namely the Taihang mountain areas and the north China Plain: the western part of the city lies in the middle of the Taihang mountains, comprising about 50% of the urban area, while moving towards the eastern side, the landscape transits into the alluvial plain of Hutuo River [5]. The overall terrain is high in the northwest and low in the southeast, with a large height difference and diverse, complex landforms [5]. Those geographical characteristics make it hard for the buildup of PM2.5 due to the dispersion of air pollutants [5]. In summer, due to the southeast wind, the particles above Shijiazhuang would move to the west and be blocked by the Taihang mountains, thus returning to the original place in the east. Similarly, in winter, due to the obstruction of Taihang and Yanshan mountains, northwest wind from Inner Mongolia could hardly enter Hebei Province aside from Zhangjiakou [7]. Therefore, particles such as PM2.5 in Shijiazhuang would be unlikely to be blown away and would mostly remain above the city.

2.4. Human Factors

In 2011, China was responsible for producing 45.5% of the world's steel and 60% of its coke. Within China, Hebei Province contributed to 24% of the steel and 14.5% of the coke production [8]. The Statistical Yearbook of China reveals that coal consumption per unit area in Hebei and neighboring regions was nearly five times the national average [6]. As Hebei's capital, Shijiazhuang is a quintessential industrial hub, renowned for its contributions to the energy sector, steel manufacturing, power generation, and cement industry [9]. The city's industrial activities and vehicular emissions are significant sources of primary pollutants, with an estimated 861.9 kilotons of primary PM2.5 emitted in 2012 alone [9]. Source apportionment studies suggest that manufacturing facilities in the border regions of Hebei, Henan, and Shandong Provinces, as well as central Shanxi Province, are also major contributors to Shijiazhuang's PM2.5 levels [9]. Additionally, the seasonal spike in coal consumption during winter months for heating purposes exacerbates the disparity in PM2.5 concentrations between summer and winter [5].

Three primary elements contribute to elevated PM2.5 levels in Shijiazhuang: meteorological conditions, geographical features, and human activities. The first two are natural determinants and, while they offer valuable insights into the worsening air quality in Shijiazhuang, they cannot be considered the root causes of the existing problem. In terms of human-induced factors, it has been found that vehicular emissions are not the primary source of PM2.5 in urban areas of China [10]. In the specific case of Shijiazhuang, industrial activities involving the combustion of fossil fuels emerge as the leading contributor. It's also noteworthy that although industrial facilities are generally located on the outskirts of the city, higher pollution levels are often observed in densely populated urban zones. This is likely due to the limited capacity for air pollutants to disperse and dilute in such areas [11].

3. Strategies to Reduce PM2.5 Environmental Pollution in Shijiazhuang

3.1. Policy Interventions

In recent years, the necessity for stricter emission standards for industries has been underscored to mitigate the adverse effects of PM2.5 pollution. Implementing stringent regulations can significantly reduce the concentration of harmful particles in the air, thereby fostering a healthier environment. A dynamic predictive model developed by Tong et al. offers a pathway to explore future anthropogenic emission trajectories in China, integrating energy system models, emission inventory models, and dynamic predictive models with parameterized schemes of Chinese policies. This model offers a powerful tool for policy-makers to develop informed strategies by correctly tracking the evolution of combustion and production technologies and control measures under various environmental policies in the future [12].

Furthermore, a study by Ou et al. delineated the most cost-effective control measures, sectors, and locations to reduce PM2.5 mortality through a representation of the entire human-Earth system. The study highlighted the significant health advantages of electrifying sources, such as industrial coal, industrial liquids, and home biomass, that have high PM2.5 emission intensities [13].

Moreover, sustainable mitigation of industrial air emission pollution can be achieved through various strategies such as upgrading industrial processes, improving energy efficiency, limiting the burning of agricultural waste, and switching to other fuels, as mentioned by Munsif et al. These tactics encourage both sustainable industrial development and PM2.5 emission reduction [14].

The advancement of eco-friendly and sustainable modes of transport is a key approach to alleviating the negative impact of PM2.5 emissions. Homayouni et al. underscored the importance of implementing carbon control measures to encourage environmentally responsible supply chains. Their research introduced a logistics model that takes into account various vehicle categories and their corresponding emissions during goods transport. The study advocates for government-backed cap-and-trade policies as a more effective means of curbing pollution through investment in cleaner technologies and the adoption of eco-friendly practices [15]. Research carried out in major Chinese cities like Beijing and Shanghai demonstrated that increasing public awareness about the advantages of sustainable transport options, such as cycling and eco-friendly public transit, significantly impacts their willingness to adopt these methods. The study recommends that municipal authorities and urban planners implement strategies to encourage sustainable transport habits among the populace [16]. Initiatives in green financing that target sustainable projects, including those aimed at controlling transport-related pollution, have been recognized as crucial for environmental sustainability. Such programs stimulate the growth of renewable energy and the use of electric vehicles, which are key to lowering carbon emissions and advancing sustainable transport [17].

Agricultural residue burning is a significant contributor to PM2.5 pollution. Implementing stringent regulations on agricultural practices can play a significant part in lowering Shijiazhuang's environmental pollution. This section outlines several strategies grounded in recent research findings. Research conducted by Zhang et al. highlighted the effectiveness of no-burn policies in reducing PM2.5 concentrations. The study emphasized the need for strict enforcement of regulations that prohibit open burning of agricultural residues, coupled with awareness programs to educate farmers on the adverse effects of burning practices on the environment [18]. A study by Li et al. underscored the importance of promoting sustainable agricultural practices, including conservation tillage and crop rotation, to reduce the need for residue burning. These practices not only help in reducing pollution but also enhance soil health and agricultural productivity [19]. Government incentives to encourage the use of agricultural residues for bioenergy production or as a raw material in various industries can be a viable strategy. This approach not only mitigates pollution but also adds economic value to agricultural residues, as highlighted in a study by Wang et al. [20].

3.2. Technological Solutions

A key tactic in reducing the negative impacts of PM2.5 pollution in Shijiazhuang is the installation of air purifiers in public areas. Utilizing air filtration technology developments can promote a better atmosphere for the inhabitants. Studies investigating various technology ways to improve air quality have recently been conducted. For instance, Lin et al.'s study focused on the potential of improving indoor air quality through photosynthesis by indoor plants integrated with smart home solutions, which can successfully reduce carbon dioxide concentrations by up to 53% and maintain oxygen concentrations between 18% and 21%, thereby significantly enhancing indoor air quality [21].

Moreover, research by Thomas et al. highlighted the necessity of facilitated air movement through plant media to improve the phytoremediation rates, indicating that static potted plants in buildings might not suffice to enhance indoor air quality significantly. The study suggests exploring advanced physical and chemical methods for VOC removal to address the serious health hazards posed by VOCs prevalent in indoor environments [22]. Implementing air purifiers equipped with advanced technologies can potentially work in tandem with green initiatives, such as the development of green roofs, to ameliorate environmental problems and enhance the urban microclimate, as discussed in a study by Kokkinou et al. [23].

The development and promotion of cleaner industrial technologies are essential in lowering Shijiazhuang's PM2.5 pollution levels. This involves the adoption of technologies that minimize emissions and the implementation of strategies that encourage industries to adopt cleaner production methods. A study by Wang et al. highlighted the significance of adopting cleaner production technologies in industries, emphasizing that it not only aids in reducing environmental pollution but also enhances the economic benefits for the industries themselves. The study illustrated that cleaner production technologies could reduce waste generation and resource consumption, thereby promoting sustainable development [24].

Additionally, a study by Zhang et al. emphasized the critical need for advancing clean coal technologies as a strategy to mitigate air pollution. The research recommended the utilization of innovative methods like fluidized bed combustion and integrated gasification combined cycle to minimize pollutant emissions, including PM2.5, from coal-burning power stations [25]. Furthermore, the encouragement of alternative energy sources like wind and solar power can substantially decrease dependency on fossil fuels, consequently lowering emissions. Research conducted by Li et al. showcased the effectiveness of wind power in diminishing greenhouse gas emissions and fostering a cleaner ecological landscape [26].

The transition to electric vehicles (EVs) is seen as a pivotal strategy in reducing PM2.5 environmental pollution in urban areas, including Shijiazhuang. This section explores the potential impacts and benefits of promoting electric vehicles and enhancing public transportation systems. A study conducted by Tran et al. investigated the environmental and economic benefits of a dual-battery powertrain for electric vehicles, which incorporates a zinc–air battery pack as a range extender to a smaller lithium-ion pack, thereby reducing costs. The study found that this innovative powertrain design could significantly reduce emissions and pollution caused by transportation, especially when compared to conventional internal combustion engine vehicles. Moreover, the research developed an air pollution model to assess the total amount of pollution released by the transportation sector, demonstrating the substantial pollution reduction potential with a mass rollout of passenger EVs [27]. In Shanghai, the local government has set an ambitious goal: by 2020, all new vehicles in sectors like public transport, rentals, sanitation, postal services, and intra-city freight should be fully electric. Research by Hu et al. scrutinized vehicular emissions in Shanghai over a five-year period and assessed the potential drop in road traffic-related emissions due to the increased use of electric vehicles. The findings suggest that the adoption of electric vehicles is a viable strategy for controlling road traffic emissions and enhancing urban air quality, thereby offering a solid foundation for policy development and electric vehicle management [28]. However, the shift to electric vehicles is not without its hurdles. Morgan pointed out that the actual reduction in emissions per vehicle might be less than initially estimated, given that the lifecycle of battery electric vehicles (BEVs) is not entirely emission-free.

Moreover, the transition to BEVs needs to be synchronized with a broader transformation in current transportation habits, requiring a substantial decrease in reliance on and ownership of powered vehicles, as well as a fundamental rethinking of private and public transportation systems [29].

4. Conclusion

The escalating issue of PM2.5 pollution in Shijiazhuang necessitates urgent and multifaceted interventions grounded in scientific research and predictive modeling. Firstly, it is imperative to adopt stricter emission standards for industries, a move that promises to significantly curb PM2.5 pollution and foster a healthier environment for the residents of Shijiazhuang. Moreover, the promotion of green and sustainable transportation emerges as a pivotal strategy in this endeavor. By adopting carbon regulation mechanisms, encouraging sustainable transportation behavior, and leveraging green finance initiatives, Shijiazhuang can significantly reduce environmental pollution, paving the way for a more sustainable future.

Addressing the agricultural sector's contribution to PM2.5 pollution is crucial. Strict implementation of no-burn policies, the promotion of sustainable agricultural practices, and incentivizing the utilization of agricultural residues in various industries stand as viable strategies to mitigate pollution. In terms of technological solutions, introducing air purifiers in public spaces emerges as a viable strategy, backed by scientific research, to curb PM2.5 pollution effectively in Shijiazhuang. Furthermore, fostering the development and promotion of cleaner industrial technologies emerges as a crucial strategy in mitigating PM2.5 pollution in Shijiazhuang, backed by substantial research evidence. Promoting the use of electric vehicles and enhancing public transportation systems are crucial strategies in reducing PM2.5 environmental pollution in Shijiazhuang. Supported by various studies, these strategies not only help in reducing emissions but also foster economic benefits and improve the quality of life for the residents. However, a successful transition requires a well-thought-out approach that considers the lifecycle emissions of electric vehicles and promotes a transformative shift in transportation trends.

In conclusion, through a concerted effort encompassing stringent industrial regulations, the promotion of green transportation, and sustainable agricultural practices, Shijiazhuang can forge a path towards a cleaner, healthier, and more sustainable environment for its residents. The strategies outlined in this paper, grounded in recent research findings, offer a blueprint for a comprehensive approach to reducing PM2.5 environmental pollution in Shijiazhuang, fostering a habitat that is not only healthier but also conducive to the well-being of its residents.

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