

Research Article

Portable and Low-Cost PM Dust Concentration Sensor Device for Vietnamese Asthma Patients

Khoa Nguyen Gia^{1,*} , Hung Nguyen Duy¹, Dung Nguyen Tien^{2,3} 

¹Hanoi-Amsterdam High School for the Gifted, Hanoi, Vietnam

²Bach Mai Hospital, Hanoi, Vietnam

³Faculty of Health Sciences, Thang Long University, Hanoi, Vietnam

Abstract

Air quality has plummeted to alarming levels worldwide, especially in Vietnam where recently have been recorded to have cities with the lowest air quality. About the pollution situation in Vietnam, PM (particulate matter) has always been one of the most hazardous factors along side NO_x and CO. This negative trend has increased the number of patients suffering from respiratory-related diseases and the severity of their conditions through inflammation. However, most Vietnamese asthma patients don't have access to high-quality air quality monitors due to their high prices. As a result, this project focuses on providing those with asthma with a low-cost and portable dust sensor. Through monitoring the concentration of PM_{2.5}, PM_{1.0}, and PM_{10.0}, our project aims to mitigate the impact of PM_{2.5} on Vietnamese asthma patients. The device was tested by comparison with IQAir's air monitoring device as well as We integrated a dust sensor with a timer, a storage compartment for an inhaler, and a microcontroller for serial communication between components, creating a sensor that assists in dust concentration management and the patient's asthma condition. In the final steps, we did surveys to confirm the need for our device on 300 asthma patients and we expect the developed sensor to be a great assistance for about 50% of Vietnamese asthma patients if mass produced. Ultimately, our sensor was built with a much lower cost, and a smaller size while exhibiting a positive correlation with the IQAir Pro air monitor. It shows little deviation and, thus can produce accurate real-time measurements as well as perform the additional timer task specifically for daily medication reminders of asthma patients.

Keywords

Low-Cost Particulate Matter Sensors, Transdisciplinary Research, Air Quality Monitoring, Particulate Matter, Air Pollution, Calibration, Air Quality and Health, Asthma Management

1. Introduction

With regards to air pollution, air quality has uncontrollably plummeted to alarming levels worldwide, especially in developing countries such as Vietnam, with particulate matter being one of the most hazardous factors [1-4]. They cause

damage to multiple human vital organs if inhaled [5-7] and contribute to about 8.34 million all-cause deaths per year, significantly raising the mortality rate [8, 9]. However it is well known in leading to an increase in the number of respir-

*Corresponding author: giakhoa200748@gmail.com (Khoa Nguyen Gia)

Received: 16 January 2025; **Accepted:** 27 February 2025; **Published:** 6 March 2025



Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

atory-related diseases patients [10, 11]. These particulate matter sizes range from 1.0 μm in diameter up to 10.0 μm in diameter, in addition, their sources can be one of the following: urban dust, gasoline-powered and diesel-powered motor vehicles, biomass combustion, marine aerosol, cooking operations, fuel oil combustion [12-15]. Based on data from IQAir, Vietnam has the 22nd worst air quality globally. In addition, Hanoi was ranked the 8th most polluted city in the world (March 22, 2024), and, on average, in 2023, Vietnam's PM_{2.5} readings were nearly six times the WHO (World Health Organisation) recommended levels. [16]. As for particulate matter, according to the World Air Quality Report in 2021, none of the 13 Vietnamese cities included in the report met the annual average WHO PM_{2.5} air quality guideline concentration of $5\mu\text{g}/\text{m}^3$. [17]. Regarding the asthma condition, people with asthma when in contact with air pollution at high concentrations may trigger asthma flares because it inflames and irritates the receptors in a person's airways, as well as aggravating negative respiratory health outcomes, evidently with pm_{2.5} causing inflammation and oxidative stress in the lungs. [18-22]. A 2017 study noted that coarse PM can deposit in the upper airways involved in obstructive lung diseases, and there is emerging evidence that short-term coarse PM exposure may be associated with cardiovascular and respiratory morbidity. [23-26] On the other hand, long-term exposure to PM is associated with poorly controlled asthma and decrements in lung function in children and adults. [27, 28]. On that note, the government of Vietnam passed a National Action Plan on Air Quality Management in 2016 with a vision toward 2025 to manage and minimize air pollution including stricter regulations [29, 30]. However, the policies that specify the monitoring of air quality through the promotion of sensory technology are nowhere to be seen and thus, we provided a product that is more affordable while still achieving a high level of accuracy.

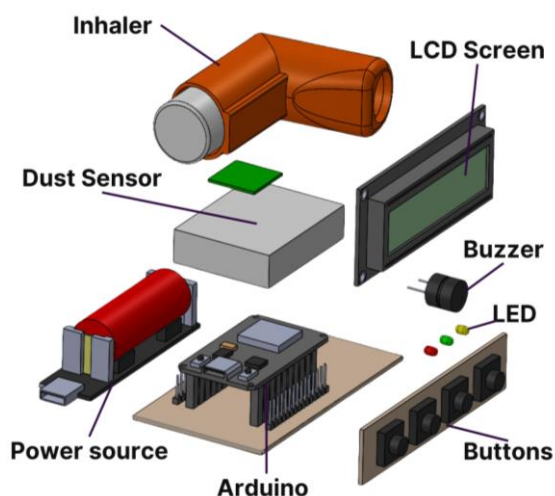


Figure 1. 3D visualization of the final sensor product.

2. Materials and Methods

2.1. Measurement Device - The Sensor Units

A low-cost, sensor-based measure device was developed which consists of a Plan tower PMS7003 PM_{2.5} Dust Sensor working under the light-scattering principle, connected to an ESP 32 Arduino through Serial UART (universal asynchronous receiver / transmitter) communication and an LCD (Liquid-crystal display) I2C (Inter-Integrated Circuit) screen for visual display. Figure 1 will help with the visualization of the product, which our project proceeded to carry out and replicated the exact design.

Table 1. Presents detailed specifications of each device and sensor type.

Model	PMS7003 Plantower	IQAir Visual Pro
Measurement Range	0~500 $\mu\text{g}/\text{m}^3$	0-1,000 $\mu\text{g}/\text{m}^3$
Temperature range	-10 to 60 $^{\circ}\text{C}$	-10 to 40 $^{\circ}\text{C}$
Humidity range	0 - 99%	0 - 95%
Physical size	48×37×12 mm	82×184×100 mm
Sensor manufacturer	Plantower	IQAir

2.2. Accuracy Testing Method

The two sensors (Plan tower PMS7003 and IQAir Visual Pro) were set up to simultaneously record PM_{2.5} dust concentrations at a 15s interval in a span of 225s in a ventilated chamber with humidity around 40% and temperature of 32 $^{\circ}\text{C}$.

With regards to the calibration of the device, this calibration would be applied to each individual recording of the Plan tower PMS7003 through the codes of the ESP 32, and the accuracy test would be carried out again. We had the two sensors recording PM_{2.5} dust concentration simultaneously at the same interval and time span as the first accuracy test, noting that the environment of the second accuracy test is the same chamber in the first accuracy test.

2.3. Dust Concentration Measurements in 3 Different Locations of Ha Noi

After testing the accuracy of the device, we developed, we proceeded to take real recordings and took three measurements of the PM dust concentration in a residence, on a high traffic density road, and next to a construction site which were all in the proximity of Giai Phong street, Dong Da district, Hanoi city. The recordings were made on June 17th,

2024, around noon, in sunny weather with temperatures ranging from 37-39 °C, and the humidity is at an average of 45-55%, in the given conditions, we believe it is fitting to carry out the measurements.

2.4. Customer Demand Campaign

The project also conducted a survey lasting 2 weeks, which aimed at the responders who are under the effect of asthma or related respiratory problems. The survey asked multiple questions however the two figures shown below are the key points that we wanted to point out. The Vietnamese asthma (or similar conditions) sufferers were asked two questions: 1. “How often do you forget to bring an inhaler, or forget to use the inhaler as prescribed by your doctor” with a scale from 1-5 (1: Always bring inhaler, 5: barely ever bring inhaler) and 2. “If there was a small, portable product that allowed you to use your asthma inhaler, reminded you to take the medication, measured dangerous dust levels in the air, and warned you to avoid areas with high levels of particulate matter, would you be interested?” with the scale from 1-5 (1: Not interested, 5: very interested).

3. Results

3.1. Measurement Device: The Sensor Units

We recorded the cost for each component into a list and although this cost does not consist of the user’s inhaler, as it is separate from the product, the final product does have a separate chamber to store the user’s inhaler. After listing out the costs of components, the total cost for our device came out to be about 1.239 million VND (Vietnam Dong) which is 49 USD (United States dollar). Furthermore, our product came out to have the dimensions of 110 x 90 x 90 mm while the IQAir Visual Pro has the dimensions of 82 x 184 x 100 mm.

3.2. Accuracy Testing Method

The first set of data was recorded into an accuracy test graph, which is [Figure 2](#).

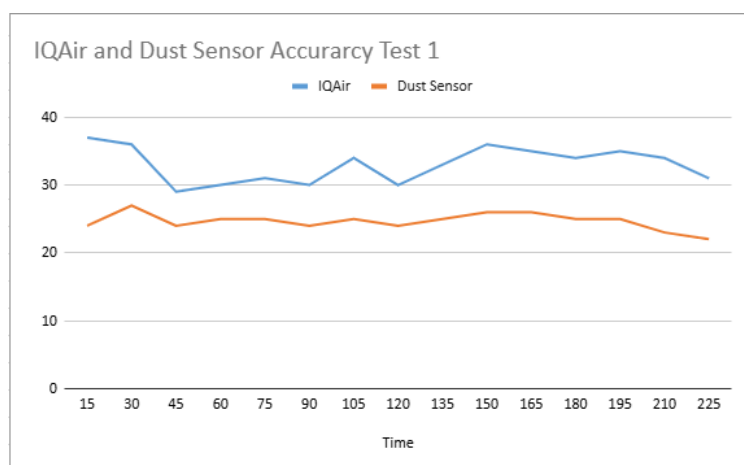


Figure 2. Comparison between the recordings of our PM Dust sensor and IQAir Pro in the same lab environment.

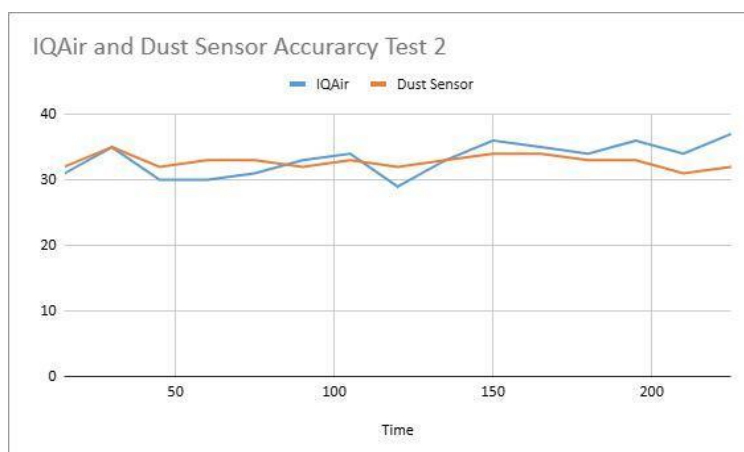


Figure 3. Repeated the recordings from accuracy test 1 after our device’s calibration.

The mean and standard deviation of the IQAir Visual Pro recordings were calculated to be $33.0\mu\text{g}/\text{m}^3$ and 2.618 and our sensor was $24.7\mu\text{g}/\text{m}^3$ and 1.234. After seeing the positive correlation between each pair of individual readings and the general trend of the graph of the two devices, a calibration was made to the output measurement of the Plan tower PMS7003 through a formula. The device was calibrated by adding the difference between the means of the two given data samples in the first accuracy test.

After this, the second accuracy test was conducted, producing the graph in Figure 3.

After the second accuracy test, we recalculated the means

and standard deviations. The IQAir Visual Pro's readings were $33.2\mu\text{g}/\text{m}^3$ and 2.484 and our device was $32.8\mu\text{g}/\text{m}^3$ and 1.014.

3.3. Dust Concentration Measurement in 3 Different Locations of Ha Noi

The following figures of PM_{2.5}, PM_{10.0}, and PM_{1.0} dust concentrations against time (seconds) were produced after the three measurements were carried out (Figures 4, 5, and 6 respectively).

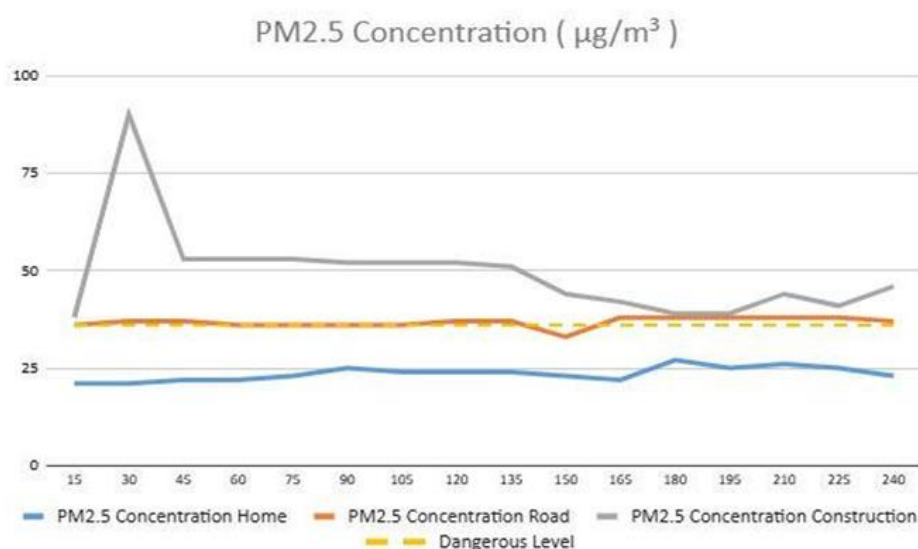


Figure 4. The measurement of PM_{2.5} concentration in an apartment, on a densely trafficked road and nearby a construction site

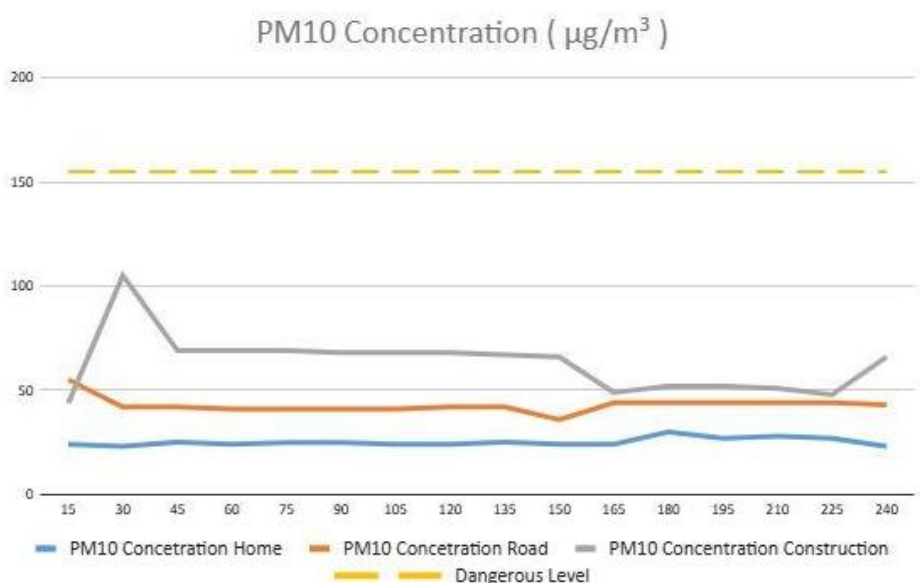


Figure 5. The measurement of PM_{10.0} concentration in an apartment, on a densely trafficked road and nearby a construction site.

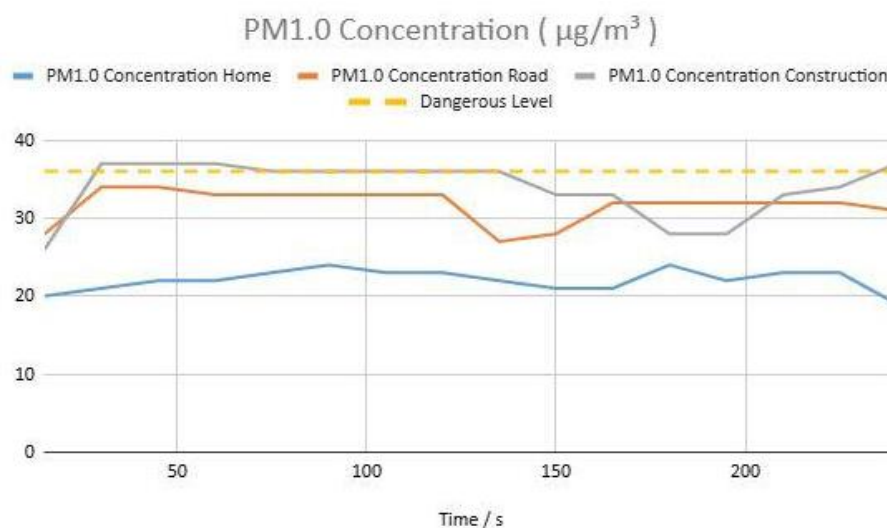


Figure 6. The measurement of PM1.0 concentration in an apartment, on a densely trafficked road and nearby a construction site.

3.4. Customer Demand Campaign

Among the two questions that were given in the survey,

320 Vietnamese Asthma patients responded. The first question asked about inhalers produced **Figure 7**, and the second question asked about their need for a multi-functional sensor device, produced the **Figure 8**.

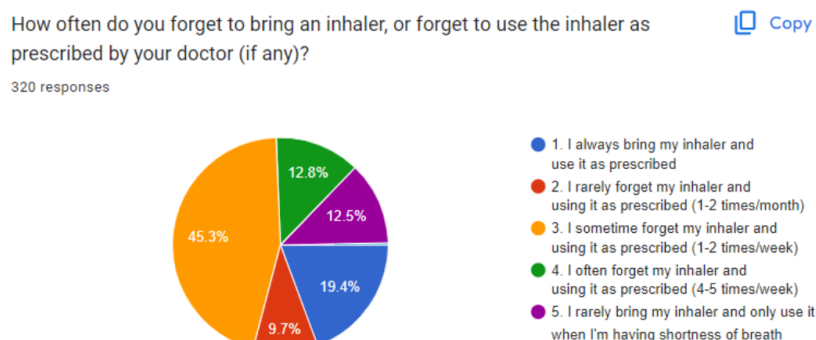


Figure 7. The sample survey of 300 Vietnamese asthma patients on the frequency of their inhaler medication usage.

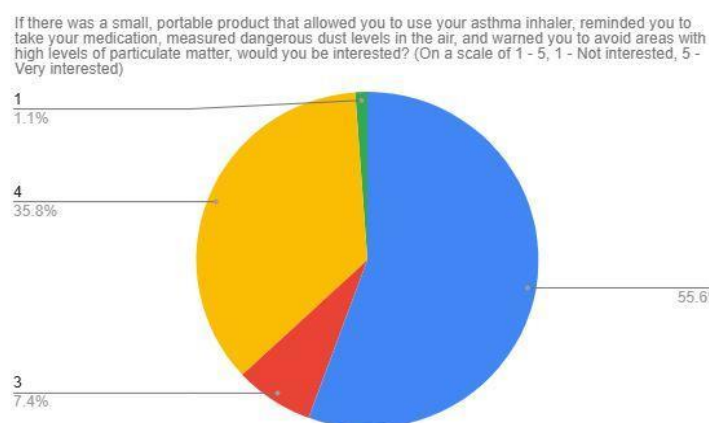


Figure 8. The sample survey of 300 Vietnamese asthma patients on their desire for an affordable and portable dust sensor.

4. Discussion

4.1. Measurement Device: The Sensor Units

As seen from the results, the total cost of the product is approximately 49 USD. It should be noted that this cost does not consist of the user's inhaler, as it is separate from the product, however, the final product does have a separate chamber to store the user's inhaler. With regards to the price, our product is much cheaper compared to the IQAir Visual Pro which cost currently 8,54 million VND on their website, which is about 337 USD. It should be noted that our project's sensor only covers 3 key statistics, which are the concentrations of particulate matter with sizes 1.0 μm , 2.5 μm , and 10.0 μm , having less functionality than the IQAir Visual Pro. Furthermore, as listed above, our product's dimensions are 110 x 90 x 90 mm while the IQAir Visual Pro's dimensions are 82 x 184 x 100 mm, which produces a volume that is 69.3% larger than ours, making ours much more portable.

4.2. Accuracy Testing Method

The second accuracy test (Figure 3) proved to show a much better correlation with the mean measurement of IQAir recordings being 33.2 $\mu\text{g}/\text{m}^3$ and ours being 32.8 $\mu\text{g}/\text{m}^3$, producing a much smaller percentage difference of 1.2% than previously, which is 35.2%, calculated from the two means 33.0 $\mu\text{g}/\text{m}^3$ and 24.4 $\mu\text{g}/\text{m}^3$ in the first accuracy graph (Figure 2). Because of that, it is evident that the accuracy of my product was becoming more reliable.

4.3. Customer Demand Campaign

Among the two questions that were given to 320 Vietnamese asthma patients in the survey, Figure 7 proposed the problem of asthma patients failing to take their medication, which can be seen from the 45.3% chance of them forgetting to take their inhalers. In addition, Figure 8 then solidifies the demand, which 55.6% of asthma patients in our survey had, for a multi-functional sensor that can alert the user not only to leave places with high concentrations of particulate matter in any size but also timing functions.

4.4. Dust Concentration Measurement in 3 Different Locations of Ha Noi

The produced figures show that for Ha Noi City specifically, the concentration of PM2.5 is always dangerous, which is above the 36 $\mu\text{g}/\text{m}^3$ unhealthy level (equivalent to 100 AQI (Air Quality Index)) for ordinary people in outdoor areas, while the concentration of PM1.0 only spikes into the harmful level (above the 36 $\mu\text{g}/\text{m}^3$ unhealthy level) when near expected dusty places such as construction sites. It is worth noting that the concentration of PM10.0 is nowhere near the

dangerous level, as well; in all of the three places where we measured the dust concentration. (Above the 150 $\mu\text{g}/\text{m}^3$ unhealthy level) [14].

5. Conclusion

The device is able to notify users of their medication when the set time is reached. More importantly, the device can successfully record the dust concentration within any given area, and compare the values with the known dangerous levels, thus displaying both the statistics and the alerts in real-time.

Due to the small size, the product is portable, it can store the user's inhaler and as seen from the listed costs of compartments, the product proves to be reliable while still being in an affordable price range.

The measurements of the three locations in Ha Noi proved that it's recommended that Vietnamese asthma patients who are going outdoors should wear face masks or equivalent protective devices as the concentration of PM2.5 is usually always above the unhealthy level, however, the concentrations of other particulate matters are normally not as concerning.

Overall, the project aims to contribute to the management of Vietnam's dust concentration, and to meet the demand of many asthma sufferers, assisting them in facing the severe air pollution situation in Vietnam.

Abbreviations

PM	Particulate Matter
WHO	World Health Organisation
VND	Vietnam Dong
USD	United States Dollar
UART	Universal Asynchronous Receiver / Transmitter
LCD	Liquid-Crystal Display
I2C	Inter-Integrated Circuit
AQI	Air Quality Index

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Makoto Enomoto, William J. Tierney, Kohsuke Nozaki, Risk of human health by particulate matter as a source of air pollution -Comparison with tobacco smoking-, The Journal of Toxicological Sciences, 2008, 33(3), 251-267. <https://doi.org/10.2131/jts.33.251>
- [2] Anderson, J. O., Thundiyil, J. G. & Stolbach, A. Clearing the Air: A Review of the Effects of Particulate Matter Air Pollution on Human Health. J. Med. Toxicol. 8, 166-175 (2012). <https://doi.org/10.1007/s13181-011-0203-1>

- [3] Bălă, GP, R ănovanu, RM., Tudorache, E. *et al.* Air pollution exposure—the (in) visible risk factor for respiratory diseases. *Environ Sci Pollut Res* 28, 19615–19628 (2021). <https://doi.org/10.1007/s11356-021-13208-x>
- [4] Park M, Joo HS, Lee K, Jang M, Kim SD, Kim I, et al. Differential toxicities of fine particulate matters from various sources. *Sci Rep.* (2018) 8: 17007. <https://doi.org/10.1038/s41598-018-35398-0>
- [5] Pryor, J. T., Cowley, L. O., & Simonds, S. E. (2022). The Physiological Effects of Air Pollution: Particulate Matter, Physiology and Disease. *Frontiers in Public Health*, 10, 882569. <https://doi.org/10.3389/fpubh.2022.882569>
- [6] Mutlu, E. A., Comba, I. Y., Cho, T., Engen, P. A., Yazıcı, C., Soberanes, S., Hamanaka, R. B., Niğdelioğlu, R., Meliton, A. Y., Ghio, A. J., Budinger, G. S., & Mutlu, G. M. (2018). Inhalational exposure to particulate matter air pollution alters the composition of the gut microbiome. *Environmental Pollution*, 240, 817–830, <https://doi.org/10.1016/j.envpol.2018.04.130>
- [7] Henning, R. J. (2023). Particulate Matter Air Pollution is a Significant Risk Factor for Cardiovascular Disease. *Current Problems in Cardiology*, 49(1), 102094. <https://doi.org/10.1016/j.cpcardiol.2023.102094>
- [8] Lelieveld J, Haines A, Burnett R, Tonne C, Klingmüller K, Münzel T et al. Air pollution deaths attributable to fossil fuels: observational and modelling study *BMJ* 2023; 383: e077784 <https://doi.org/10.1136/bmj-2023-077784>
- [9] Yazdi MD, Wang Y, Di Q, Requia WJ, Wei Y, Shi L, Sabath MB, Dominici F, Coull B, Evans JS, Koutrakis P, Schwartz JD. Long-term effect of exposure to lower concentrations of air pollution on mortality among US Medicare participants and vulnerable subgroups: a doubly-robust approach. *Lancet Planet Health.* 2021 Oct; 5(10): e689-e697. [https://doi.org/10.1016/S2542-5196\(21\)00204-7](https://doi.org/10.1016/S2542-5196(21)00204-7)
- [10] Winterbottom, C. J., Shah, R. J., Patterson, K. C., Kreider, M. E., Panettieri, R. A., Rivera-Lebron, B., Miller, W. T., Litzky, L. A., Penning, T. M., Heinlen, K., Jackson, T., Localio, A. R., & Christie, J. D. (2018). Exposure to Ambient Particulate Matter Is Associated With Accelerated Functional Decline in Idiopathic Pulmonary Fibrosis. *Chest*, 153(5), 1221–1228. <https://doi.org/10.1016/j.chest.2017.07.034>
- [11] Kyung SY, Jeong SH. Particulate-Matter Related Respiratory Diseases. *Tuberc Respir Dis (Seoul)*. 2020 Apr; 83(2): 116–121. <https://doi.org/10.4046/trd.2019.0025> Epub 2020 Mar 6.
- [12] Shandilya, K. K., & Khare, M. (2012). Particulate matter: sources, emission rates and health effects. *Advances in environmental research*, 23, 265–322.
- [13] Cheng, Y., Zou, S. C., Lee, S. C., Chow, J. C., Ho, K. F., Watson, J. G.,... & Wu, W. J. (2011). Characteristics and source apportionment of PM1 emissions at a roadside station. *Journal of Hazardous Materials*, 195, 82–91, <https://doi.org/10.1016/j.jhazmat.2011.08.005>
- [14] Hassan, M. S., Bhuiyan, M. A. H., & Rahman, M. T. (2023). Sources, pattern, and possible health impacts of PM2.5 in the central region of Bangladesh using PMF, SOM, and machine learning techniques. *Case Studies in Chemical and Environmental Engineering*, 8, 100366. <https://doi.org/10.1016/j.cscee.2023.100366>
- [15] Tessum MW, Anenberg SC, Chafe ZA, Henze DK, Kleiman G, Kheirbek I, Marshall JD, Tessum CW. Sources of ambient PM_{2.5} exposure in 96 global cities. *Atmos Environ* (1994). 2022 Oct 1; 286: 119234. <https://doi.org/10.1016/j.atmosenv.2022.119234>
- [16] Pratt, A., Khalidi, R., Flowers, R. (2024, June 5). Viet Nam's heavy air pollution needs stronger action. UNICEF.
- [17] Anh, V. (2022, March 22). Vietnam's air quality improves but has not met WHO standard. VnExpress.
- [18] Guarneri M, Balmes JR. Outdoor air pollution and asthma. *Lancet*. 2014 May 3; 383(9928): 1581–92, [https://doi.org/10.1016/S0140-6736\(14\)60617-6](https://doi.org/10.1016/S0140-6736(14)60617-6)
- [19] Arias-Pérez, R. D., Taborda, N. A., Gómez, D. M. *et al.* Inflammatory effects of particulate matter air pollution. *Environ Sci Pollut Res* 27, 42390–42404 (2020). <https://doi.org/10.1007/s11356-020-10574-w>
- [20] Shamsollahi H. R., Jahanbin, B., Rafieian, S. *et al.* Particulates induced lung inflammation and its consequences in the development of restrictive and obstructive lung diseases: a systematic review. *Environ Sci Pollut Res* 28, 25035–25050 (2021), <https://doi.org/10.1007/s11356-021-13559-5>
- [21] Amma, C., Inomata, Y., Kohno, R. *et al.* Copper in airborne fine particulate matter (PM_{2.5}) from urban sites causes the up-regulation of pro-inflammatory cytokine IL-8 in human lung epithelial A549 cells. *Environ Geochem Health* 45, 5879–5891 (2023). <https://doi.org/10.1007/s10653-023-01599-4>
- [22] Li, R., Wang, Y., Qiu, X. *et al.* Difference on oxidative stress in lung epithelial cells and macrophages induced by ambient fine particulate matter (PM_{2.5}). *Air Qual Atmos Health* 13, 789–796 (2020). <https://doi.org/10.1007/s11869-020-00835-5>
- [23] Peng RD, Chang HH, Bell ML, et al. Coarse Particulate Matter Air Pollution and Hospital Admissions for Cardiovascular and Respiratory Diseases Among Medicare Patients. *JAMA*. 2008; 299(18): 2172–2179, <https://doi.org/10.1001/jama.299.18.2172>
- [24] Zhao Y, Wang S, Lang L, Huang C, Ma W, Lin H. Ambient fine and coarse particulate matter pollution and respiratory morbidity in Dongguan, China. *Environ Pollute* 2017; 222: 126–131, <https://doi.org/10.1016/j.envpol.2016.12.070>
- [25] Martinelli, N., Olivieri, O., & Girelli, D. (2013). Air particulate matter and cardiovascular disease: A narrative review. *European Journal of Internal Medicine*, 24(4), 295–302. <https://doi.org/10.1016/j.ejim.2013.04.001>
- [26] Praznikar, Z., & Praznikar, J. (2012). The effects of particulate matter air pollution on respiratory health and on the cardiovascular system. *Zdravstveno Varstvo*, 51(3), 190, <https://doi.org/10.2478/v10152-012-0022-z>

- [27] Liu, L., Poon, R., Chen, L., Frescura, A. M., Montuschi, P., Ciabattini, G,... & Dales, R. (2009). Acute effects of air pollution on pulmonary function, airway inflammation, and oxidative stress in asthmatic children. *Environmental health perspectives*, 117(4), 668-674, <https://doi.org/10.1289/ehp11813>
- [28] Jacquemin, B., Kauffmann, F., Pin, I., Le Moual, N., Bousquet, J., Gormand, F., ... & Siroux, V. (2012). Air pollution and asthma control in the Epidemiological study on the Genetics and Environment of Asthma. *J Epidemiol Community Health*, 66(9), 796-802, <https://doi.org/10.1136/jech.2010.130229>
- [29] EPA (2012) Revised Air Quality Standards for Particle Pollution and Updates to the Air Quality Index (AQI).
- [30] Kim, S. E., Harish, S. P., Kennedy, R., Jin, X., & Urpelainen, J. (2020). Environmental Degradation and Public Opinion: The Case of Air Pollution in Vietnam. *The Journal of Environment & Development*, 29(2), 196-222. <https://doi.org/10.1177/1070496519888252>