REVIEW PAPER

J Health Inequal 2022; 8 (1): 75–81

Submitted: 01.07.2021; accepted: 22.04.2022

DOI: https://doi.org/10.5114/jhi.2022.116059

JOURNAL
of Health Inequalities

Impact of air pollution on health, including the role of the COVID-19 pandemic

Irena A. Wolińska[1], Karol Dykiert[2], Paweł Gać[3], Małgorzata Poręba[4]

[1]Department of Physiology and Pathophysiology, Divison of Pathophysiology, Wroclaw Medical University Wrocław, Poland
[2]Wrocław University of Science and Technology, Wrocław, Poland
[3]Department of Population Health, Division of Environmental Health and Occupational Medicine, Wroclaw Medical University, Poland
[4]Department of Paralympic Sport, Wroclaw University of Health and Sport Sciences, Wrocław, Poland

ABSTRACT

Environmental pollution is a global problem, temporarily obscured by the COVID-19 pandemic. This paper analyses the epidemiological and geographical differentiation of air pollution and provides an overview of types of pollution, their sources, and their effects on the human body. The paper characterises the effects of air pollution on the respiratory system, cardiovascular system, and other systems, including the impact of exposure to air pollution on children, pregnant women and the fetus. In addition, the paper discusses the legal basis for governing the emission of pollutants, as well as individual protective measures for preventing or removing pollution. However, it should not be forgotten that success may only be achieved when individual countries and organisations, such as the European Union, create and implement global policies to address air pollution.

KEY WORDS: air pollution; environmental health; COVID-19.

ADDRESS FOR CORRESPONDENCE: Dr hab. Paweł Gać, prof. UMW, Department of Population Health, Division of Environmental Health and Occupational Medicine, Wroclaw Medical University, Mikulicza-Radeckiego 7, 50-345 Wroclaw, Poland, e-mail: pawelgac@interia.pl or pawel.gac@umw.edu.pl

INTRODUCTION

The environment influences every element of our life. Unpolluted water, air and soil are essential to our survival and development. Contact with nature is an important element of somatic and mental health, and is critical for healthy development of children and adolescents. Environmental pollution is currently one of the greatest threats facing the world. It affects all aspects of our lives, and each type of pollution can have a negative impact on health. In conjunction with other phenomena such as the production of carbon dioxide, or through deforestation and insufficient care for the protection of green areas, it can also contribute to climate change [1].

Climate change, together with air pollution, can have a particularly negative impact on the occurrence of respiratory allergies, which have a complex pathomechanism. It is conjectured that particulate matter (PM) and ozone may influence climate warming and air stagnation, which leads to degradation of air quality in some areas. The effect of this is an increase in temperature and CO_2, which can result in an increase in concentrations of pollen, mould and spores, escalating the risk of respiratory allergies [2].

Each year, publications from multiple scientific fields aim to explain how environmental pollution affects human health by contributing to the shortening of life expectancy, deterioration of quality of life, and development of many so-called diseases of civilization [3].

The aim of this study, based on collected scientific reports from recent years, is to describe what the types of air pollution are, what they consist of, how we can protect ourselves against them, and how they affect specific organ systems. Additionally, air pollution is discussed in the light of the ongoing COVID-19 pandemic.

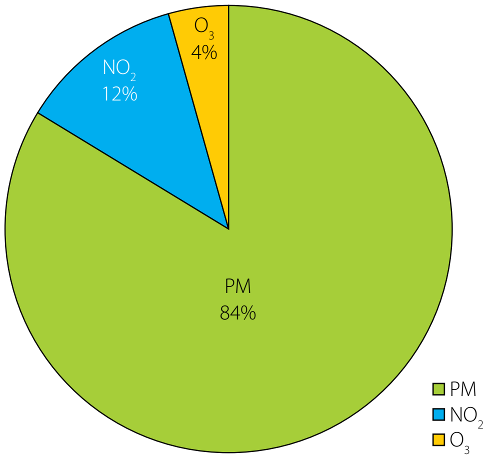

FIGURE 1. Deaths caused by different environmental pollutants in 2018 (based on European Environment Agency report) [3]

EPIDEMIOLOGY

According to the World Health Organization (WHO), in 2012 about 13% of all deaths in the European Union (EU) were caused by environmental pollution, and in 2018 environmental pollution contributed to 16% of all deaths worldwide [3]. In 2017, as many as 4,800,000 people died as a result of environmental pollution [4]. According to the latest report by the European Environment Agency (EEA), air pollution is the largest environmental factor influencing health in Europe, with 90% of environmentally related deaths connected to non-communicable diseases such as cancer, cardiovascular diseases, strokes, chronic obstructive pulmonary disease (COPD), diabetes, kidney disease, asthma, and mental and neurological disorders [3]. As shown at Figure 1, it is noticeable that PM is the main factor in increasing mortality due to air pollution [3].

Europe is geographically diverse in terms of exposure to pollution. The eastern and south-eastern parts of the continent are areas with a much higher $PM_{2.5}$ air fine inhalable particle count and have the highest rates of lost life years per 100,000 people. The south-east of Europe is also a leader in atmospheric NO_2 content [3]. Poorer countries are often more vulnerable to pollution. Poland is one of the most polluted regions in Europe. Norms defining limits of air pollution vary between EU limits/target values and strict 2021 WHO guidelines; see Table 1. Depending on which norms are taken into account, the percentage of the population living in an environment exposed to air pollution substantially varies; see Table 2. The WHO published its new Air Quality Guidelines in 2021 [4], but the newest report from the EEA still refers to the 2005 version [5].

TYPES OF AIR POLLUTION

Based on the definition and information from the EEA, air pollution can be defined as the presence in the atmosphere of a substance at concentrations hazardous to humans and the environment. The determination of such substances, their hazardous levels and health effects has been the subject of numerous studies. This work focuses on some of the most recognisable pollutants today, including:

- atmospheric aerosols – PM;
- sulphur dioxide (SO_2);
- nitrogen oxides (NO_x);
- polycyclic aromatic hydrocarbons (PAHs).

The sources of air pollution can be divided into natural and anthropogenic. In the case of the above-mentioned substances, the anthropogenic group plays a much greater role (see Diagram 1) [6].

ATMOSPHERIC AEROSOLS – PARTICULATE MATTER

Atmospheric aerosols, also known as PM, are liquid droplets or solid particles that have combined into aggregates of many particles. They are often composed of many different substances. Some of them react with the gases and vapours present in the air to form new substances. Particle aggregates tend to combine or agglomerate into larger clusters due to adhesion, thereby increasing their mass, which eventually leads to sedimentation – the fall of dust particles to the ground. These phenomena increase during rainfall, wind, or fog. These dust particles can also be removed from the air by adhering to buildings, plants, or the ground [7]. These processes are the natural mechanisms for removing PM from the air.

Concentrations of some of the other substances mentioned in this paper (in developed countries) are usually recorded at levels that do not threaten health, but they are also present in the form of solid particles suspended in

TABLE 1. Norms defining limits of air pollution according to EU limits/target values and WHO guidelines [4, 5]

Pollutant	Averaging period	EU limit/target value	WHO guidelines
$PM_{2.5}$	Annual	Limit value: 25 µg/m³	10 µg/m³
PM_{10}	Annual	Limit value: 40 µg/m³	20 µg/m³
O_3	Max. daily 8-hour mean	Target value: 120 µg/m³	100 µg/m³
NO_2	Annual	40 µg/m³	40 µg/m³
BaP	Annual	1 ng/m³	0,12 ng/m³
SO_2	Daily	Limit value: 125 µg/m³	20 µg/m³

gas [8], so in many scientific studies they are also mentioned in the group of atmospheric aerosols. The composition of suspended dust varies according to its origin and source. PM is a heterogeneous mixture often having variation in chemical composition depending on the source of its production. When particles have a diameter of 10 µm or less (≤ PM_{10}) they can penetrate deep inside the lungs. However, more health-damaging particles are those with a diameter of 2.5 microns or less (≤ $PM_{2.5}$), because they can penetrate the lung barrier and enter the blood system. $PM_{2.5}$ is therefore the principal type of particles associated with adverse health effects [8].

SULPHUR DIOXIDE

SO_2 enters the atmosphere primarily because of the combustion of fossil fuels, since virtually all fossil fuels contain 0.1% to 4.0% sulphur, depending on the type of material burned. Pure natural gas contains up to 40% hydrogen sulphide, but it is usually removed before combustion. SO_2 in the atmosphere is present as a gas or in the form of an acid aerosol. Due to its high solubility, SO_2 easily transforms into sulfuric acid (VI) after reacting with oxygen under the influence of ultraviolet radiation [6]. Sulphur oxide (IV) is much more common in the atmosphere than other sulphur oxides; therefore, its determined concentration is assumed to be equal to the concentration of all compounds included in SO_x [8].

NITROGEN OXIDES

NO_x, together with ammonia, play an important role in biological processes, participating in the decomposition and production of biomass, as well as in the ozone production cycle in the air. Unfortunately, they also pollute the air, contributing to the formation of free radicals and acid rain. Like sulphur oxides, nitrogen dioxide is used as an indicator for other NO_x compounds [6].

POLYCYCLIC AROMATIC HYDROCARBONS

Polycyclic aromatic hydrocarbons (PAHs) are a large group of organic compounds, the molecule of which consists of at least two interconnected benzene rings. These compounds occur both in the form of solid particles suspended in gas and in the gaseous state, and, due to their availability from many sources, easily become present in the air, both in the open air and inside buildings. PAHs can be divided according to molecular weight into light (two or three aromatic rings) and heavy (five or more rings), which occur in the form of gas and atmospheric aerosols, respectively. A common feature of PAHs is that they often undergo chemical changes after entering the atmosphere due to chemical reactions with ozone, nitrogen and sulphur oxides, and free radicals. They easily enter metabolic pathways, where they also undergo transformations. They often have a strong carcinogenic effect. The simplest measurements of PAH content in the air are modelled based on benzene content – the least complicated aromatic molecule. The properties of the aromatic system are enhanced in condensed systems, so the more complex the compound, the more carcinogenic it is [7].

TABLE 2. Percentages of the population living in an environment exposed to air pollution according to EU and WHO norms in 2016-2018 (based on European Environment Agency report) [5]

Pollutant	EU limit/ target values	WHO guidelines
$PM_{2.5}$	4–8%	74–78%
PM_{10}	13–17%	43–48%
O_3	12–34%	96–99%
NO_2	4–7%	4–7%
BaP	15–20%	75–90%
SO_2	< 1%	19–31%

PM	• Multiple sources, like fuel combustion, industrial processes, solid waste treatment, agriculture and traffic.
SO_2	• Combustion of fossil fuel: coal, gas and oil.
NO_x	• A product of burning/oxidizing a nitrogen-containing substance. The most important sources include traffic, electrical energy and heat production and fertilizers.
WWA	• Incomplete combustion of organic substances contained in coal, oil, wood, residues and tobacco.

DIAGRAM 1. Anthropogenic sources of air pollution (based on [6])

POLLUTION IN THE TIME OF THE COVID-19 PANDEMIC

Some studies have attempted to assess the relationship between air pollution and SARS-CoV-2 infection. For example, $PM_{2.5}$ and other small particles have been observed to be carriers of a live virus in the air and it could theoretically increase its dissemination, as in the case of measles or the coronavirus that causes SARS [9]. It has been suggested that SARS-CoV-2 transmission might be accelerated by air pollution. Additionally, attention has been drawn to the confirmed role of lockdown in reducing $PM_{2.5}$ levels in the ambient air, which may contribute to lowering SARS-CoV-2 transmission [10]. High levels of $PM_{2.5}$ were likely to result in higher mortality in people infected with the virus with contamination-dependent comorbidities [11]. Even a slight rise in $PM_{2.5}$ concentration led to increased fatality rates [9, 12-14]. An example of that is Italy, where there was a trend of fast-spreading infections at the beginning of the pandemic in a northern region with very high levels of air pollutants. Italian authors analysed weather changes in areas of epidemic intensity, associated with conditions such as higher temperature, low relative humidity and low rainfall [15, 16]. There are preliminary reports which indicate that PM increases the risk of death and severe COVID-19 based on studies from France [17], Canada [18] and Italy [12]. Exposure to NO is predicted to be a major contributor to poor prognosis in patients with COVID-19 infections [19].

It is conjectured that a renewed relaxation of regulations and the end of lockdowns will again increase the number of harmful particles in the air and accelerate the spread of COVID-19 and may increase morbidity and mortality [9].

The "spike protein" binds to the ACE-2 receptor, predominantly expressed in epithelial cells of the respiratory system. It increases the chance of infection and the severity of the disease. ACE-2 is overexpressed under chronic exposure to air pollution such as NO_2 and $PM_{2.5}$. High ACE-2 explains the positive correlation between the disease severity in COVID-19 patients and elevated air pollution [20].

LEGAL BASIS AND POLLUTION STANDARDS

The basic legal acts defining the limits of pollutant emissions in Europe concern substances such as PM, NO_x, SO_2,O_3, Pb and others; they are:

- the 2008 Directive on ambient air quality and cleaner air for Europe (2008/50/EC);
- the 1996 Framework Directive on ambient air quality assessment and management (96/62/EC).

In Poland, the basic legal document regulating air quality issues is the Act of April 27, 2001, Environmental Protection Law (Journal of Laws of 2001, No. 62, item 627). Since its introduction, it has been regularly amended to provide various state and local government bodies with the legal basis to fight air pollution.

INDIVIDUAL AND SIMPLE PROTECTION MEASURES

In addition to natural means of air purification, it is also possible to implement individual measures to limit exposure to PM, thus reducing their impact on human health. The United States Environmental Protection Agency (EPA) lists the following ways to limit exposure to atmospheric aerosols:

- limiting physical activity outdoors, especially during days with increased levels of PM and in places where their concentration is high, such as roads with heavy traffic;
- by using appropriate filters and air purifiers, the concentration of atmospheric aerosols in the air inside buildings can be reduced;
- limiting minor sources of atmospheric aerosols inside the building: not using a fireplace, wood-burning stoves, or candles;
- not smoking tobacco products inside buildings;
- purchase of dedicated dust masks for use on days when air quality is poorer.

When it comes to adjusting individual activity to air pollution levels, in Poland air quality can be checked, among other places, on the website of the Chief Inspectorate for Environmental Protection, which collects data from several hundred measuring stations throughout Poland. Unfortunately, they do not provide full information because a significant number of the stations monitor only selected components of air pollution, and there are fewer stations that conduct cross-sectional monitoring. In addition, their location is often selective, i.e. they record the most important air pollution indicators: levels of $PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3 and benzene, which are typical smog components. For example, in the Polish city of Wrocław, with an area of almost 300 km^2, there is only one station that conducts cross-sectional monitoring. Using only the data it provides will not give an accurate picture of the air quality across the entire city and its outskirts.

An important measure for the protection and purification of the atmospheric air, from the point of view of municipal and local programmes, is the cultivation of specific plant species. Numerous studies on this subject have shown that certain plant species have a great ability to trap PM from the air and bind them. In 2012, a study was published in which scientists collected samples over two years from 47 species of trees and shrubs growing in urban areas along roads and highways in Poland and Norway. During the research, it was found that the key parameters for the ability to bind PMs are the composition of the wax covering the leaves, its density, and the ratio of its dry leaf mass to the surface area [21]. Scots pine (*Pinus sylvestris*), intermediate yew (*Taxus media*), common yew (*Taxus baccata*) and silver birch (*Betula pendula*) turned out to be the best at trapping atmospheric aerosols. Research was also carried out to create artificial material that replicates the ability of plants to bind atmospheric aerosols. In this study, a modified silica dust called SUNSPACE (acronym – SUstaiNable materials Synthesized from by-Products and Alginates for Clean air and better Environment), which is a by-product of many industrial processes, was compared with common ivy (*Hedera helix* L.), and it was found that in laboratory conditions the material exhibits similar sorptive properties [22].

Indoor air pollution is another issue. Apart from atmospheric substances that can infiltrate buildings, there are also sources of pollution found inside the structures themselves. In addition to the previously mentioned pollutants, the premises may contain substances such as fungi and bacteria (including moulds and various spores), pesticides, asbestos and other chemicals from building materials. The values of concentrations of air pollutants inside buildings can be even higher than outside, potentially leading to so-called "sick building syndrome", meaning a building in which a prolonged stay may cause cardiovascular and respiratory diseases [23]. Such buildings do not necessarily have to be factories or be adjacent to them. Therefore, it is important to know how to protect the air in the home. One of the simpler and cheaper methods is the cultivation of specific plant species showing sorptive capacity [23]. They will not only help to reduce the amount of CO_2 and PM in the air but can also reduce the amount of some PAHs in the air. Some of the best species for air purification in this respect are Sternberg's herb (*Chlorophytum comosum*), crassula (*Crassula argentea*), scindapsus/golden pothos (*Scindapsus aureum*) and guzmania (*Guzmania lingulata*) [24].

Another method, according to the American Heart Association (AHA), is purchasing portable air cleaners. They seem to be an effective method of lowering levels of $PM_{2.5}$ indoors up to 50-60%. Not only do they decrease the occurrence of respiratory symptoms, but they also affect cardiovascular symptoms, for example reducing both systolic and diastolic blood pressure [25, 26]. However, a meta-analysis of available studies showed that in real-world exposure, the overall reduction of $PM_{2.5}$ is low. That is why reduction of air polluting sources is the most effective way to protect the environment and human health [27].

HEALTH IMPACT

PM is the best studied group of molecules, and their negative impact on the human body is well documented [28-40]. Air pollution increases the risk of respiratory allergies, asthma, and COPD exacerbations, and reduces lung function.

AIR POLLUTANTS AND THEIR IMPACT ON THE CARDIOVASCULAR SYSTEM

The effect of air pollution on the cardiovascular system is documented. It is worth mentioning, among other literature, the statements by the American Heart Association (AHA) [25, 26]. Air pollution causes a generalized inflammatory response [41], increases oxidative stress and increases blood clotting [42]. It has also been proven to have an adverse effect on hypertension [33] – a significant increase in pressure after exposure to PM, and a decrease in pressure after wearing a filter mask. Researchers link the increase in pressure with activation of the autonomic system as well as a change in the genome in the form of epigenetic changes and gene expression [43]. In addition, such contaminants aggravate endothelial dysfunction and atherosclerosis, as well as myocardial fibrosis, inducing myocardial remodelling and, as a result, possibly leading to heart failure [44]. PMs increase hospitalizations for heart failure and increase the risk of death. Environmental pollution has a negative impact on the development of atherosclerosis, calcification of the walls of the coronary arteries and the development of coronary artery disease. Exposure to PM, even short-term, significantly increases the risk of heart attack and stroke. Air pollution from nitric oxide (NO) has been described as a factor in the development of ventricular arrhythmia. Contact with air pollutants can also affect the development of a faster heart rate, and the development of atrial fibrillation or other supraventricular arrhythmias [34]. The 2021 ESC CVD guidelines list environmental pollution as one of the risk factors for the development of cardiovascular disease. The authors note that studying individual exposure to pollution is complex, affecting their formal risk classification. Recommendations were presented to consider risk screening programmes and for patients at very high risk of CVD to avoid highly polluted areas. Evidence for those is at level C – a consensus of the experts and/or small studies [45].

CHILDREN, PREGNANCY, FETAL STAGE

Children are particularly vulnerable to the harmful effects of environmental pollutants as they breathe more air per kilogram of body weight than adults. The response of the child's organism to exposure is different from that of the adult organism. Children also spend more time outdoors than adults, increasing their exposure [46]. Children's lungs continue to develop and are therefore more susceptible to the harmful effects of pollution. Environmental pollution negatively affects neuronal development and cognitive abilities, as well as depression and neuroses [47]. Infants exposed to traffic-related air pollution are more likely to be diagnosed with reduced lung function in adulthood [48], and obesity is more common in these children [49]. One percent of deaths associated with acute respiratory infection can be attributed to air pollution [50].

NO_2 and PM can also cause sleep disorders by inducing apnoea through inducing an inflammatory state of the upper respiratory tract [51]. They also worsen asthma, COPD and other chronic respiratory diseases.

Changes in DNA methylation (an element of epigenetic expression) caused by environmental pollutants influencing gene expression may cause serious respiratory diseases in adulthood [52].

A limitation of the present overview is that many studies, especially those evaluating relations of pollution and cardiovascular diseases, do not present the high level of credibility that is level C, based mainly on experts' opinions. From this point of view, more modern reports and research on pollution in this area are necessary.

CONCLUSIONS

Environmental pollution is currently one of the most serious political, economic, and medical challenges. Modern medicine must be prepared to diagnose and treat all diseases that are caused by pollutants. Physicians, especially those working in areas with high levels of pollution, should be aware of the risk and should be active participants in preventive actions. We need to continue research into COVID-19, so we can be able to observe a correlation between the severity of the disease course and environmental pollution.

DISCLOSURE

The authors report no conflicts of interest.

References

1. Rosario NA, D'Amato G, Ansotegui IJ. Global warming and warning. Clinics (Sao Paulo) 2019; 74(1): 3e1219.
2. Deng SZ, Jalaludin BB, Antó JM, et al. Climate change, air pollution, and allergic respiratory diseases: a call to action for health professionals. Chin Med J (Engl) 2020; 133(13): 1552-1560.
3. EEA Report. Healthy environment, healthy lives: how the environment influences health and well-being in Europe 2019. Available from: https://www.eea.europa.eu/publications/healthy-environment-healthy-lives (accessed: 24 June 2021).
4. EU Air Quality Directives (2008/50/EC, 2004/107/EC), WHO, 2006, Air quality guidelines: Global update 2005. Available from: https://www.eea.europa.eu/themes/air/air-quality-concentrations/air-quality-standards (accessed: 11 December 2021).
5. World Health Organization. WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Available from: https://www.who.int/publications/i/item/9789240034228 (accessed: 24 June 2021).
6. Popescu F, Ionel I. Anthropogenic air pollution sources. Available from: https://www.intechopen.com/books/air-quality/anthropogenic-air-pollution-sources (accessed: 24 June 2021).
7. Vallero DA. Air quality. In: Fundamentals of Air Pollution. Valero DA (ed.). 4th ed. Academic Press, Amsterdam 2008: 263-295.
8. Elder A, Schwartz J, Oberdörster G. Particulate air pollution and CNS health. In: Air Pollution and Health Effects. Molecular and Integrative Toxicology. Nadadur S, Hollingsworth J (eds.). Springer, London 2015: 269-288.
9. Sharma, AK, Balyan P. Air pollution and COVID-19: is the connect worth its weight? Indian J Public Health 2020; 64 (Suppl): S132-S134.
10. Zhu Y, Xie J, Huang F, Cao L. Association between short-term exposure to air pollution and COVID-19 infection: evidence from China. Sci Total Environ 2020; 727: 138704.
11. Yang J, Zheng Y, Gou X, et al. Prevalence of comorbidities and its effects in patients infected with SARS-CoV-2: a systematic review and meta-analysis. Int J Infect Dis 2020; 94: 91-95.
12. Conticini E, Frediani B, Caro D. Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy? Environ Pollut 2020; 261: 114465.
13. Fattorini D, Regoli F. Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy. Environ Pollut 2020; 264: 114732.
14. Wu X, Nethery RC, Sabath BM, et al. Exposure to air pollution and COVID-19 mortality in the United States: a nationwide cross-sectional study. medRxiv 2020; doi: 10.1101/2020.04.05.20054502. Preprint.
15. Magazzino C, Mele M, Schneider N. The relationship between air pollution and COVID-19-related deaths: an application to three French cities. Appl Energy 2020; 279: 115835.
16. Stieb D, Evans G, To TM, et al. An ecological analysis of long-term exposure to $PM_{2.5}$ and incidence of COVID-19 in Canadian health regions. Environ Res 2020; 191: 110052.
17. Ogen Y. Assessing nitrogen dioxide (NO_2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci Total Environ 2020; 726: 138605.
18. Zoran MA, Savastru RS, Savastru DM, Tautan MN. Assessing the relationship between surface levels of $PM_{2.5}$ and PM_{10} particulate matter impact on COVID-19 in Milan, Italy. Sci Total Environ 2020; 738: 139825.
19. Zoran MA, Savastru RS, Savastru DM, Tautan MN. Assessing the relationship between ground levels of ozone (O_3) and nitrogen dioxide (NO_2) with coronavirus (COVID-19) in Milan, Italy. Sci Total Environ 2020; 740: 140005.
20. Paital B, Agrawal PK. Air pollution by NO_2 and $PM_{2.5}$ explains COVID-19 infection severity by overexpression of angiotensin-converting enzyme 2 in respiratory cells: a review. Environ Chem Lett 2021; 19(1): 25-42.
21. Sæbø A, Popek R, Nawrot B, et al. Plant species differences in particulate matter accumulation on leaf surfaces. Sci Total Environ 2012; 427-428: 347-354.
22. Zanoletti A, Bilo F, Borgese L, et al. SUNSPACE, a porous material to reduce air particulate matter (PM). Front Chem 2018; 6: 534.
23. Brilli F, Fares S, Ghirardo A, et al. Plants for sustainable improvement of indoor air quality. Trends Plant Sci 2018; 23(6): 507-512.
24. Janelle P. Air purifying indoor plants: the best office plants for indoor air quality. Buildings 2018; 112: 17.
25. Rajagopalan S, Brauer M, Bhatnager A, et al. Personal-level protective actions against particulate matter air pollution exposure: a scientific statement from the American Heart Association. Circulation 2020; 142(23): e411-e431.
26. Kaufman JD, Elkind MSV, Bhatnagar A, et al. Guidance to reduce the cardiovascular burden of ambient air pollutants: a policy statement from the American Heart Association. Circulation 2020; 142(23): e432-e447.
27. Zhu, Y, Song X, Wu R, et al. A review on reducing indoor particulate matter concentrations from personal-level air filtration intervention under real-world exposure situations. Indoor Air 2021; 31(6): 1707-1721.
28. Heusinkveld HJ, Wahle T, Campbell A, et al. Neurodegenerative and neurological disorders by small inhaled particles. Neurotoxicology 2016; 56: 94-106.
29. Chen H, Kwong JC, Copes R, et al. Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study. Lancet 2017; 389(10070): 718-726.
30. Schraufnagel DE, Balmes JR, Clayton TC, et al. Air pollution and noncommunicable diseases: a review by the Forum of International Respiratory Societies' Environmental Committee, part 2: air pollution and organ systems. Chest 2019; 155(2): 417-426.
31. Brook RD, Franklin B, Cascio W. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation 2004; 109(21): 2655-2671.
32. Claeys M, Rajagopalan S, Nawrot TS, Brook RD. Climate and environmental triggers of acute myocardial infarction. Eur Heart J 2017; 38(13): 955-960.

33. Brook RD, Rajagopalan S, Pope A, et al. Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. Circulation 2010; 121(21): 2331-2378.
34. Link MS, Dockery DW. Air pollution and the triggering of cardiac arrhythmias. Curr Opin Cardiol 2010; 25(1): 16-22.
35. GBD 2015 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 79 behavioral, environmental and occupational, and metabolic risks or clusters of risks, 1990-2015: a systematic analysis for the Global Burden of Disease Study. Lancet 2016; 388(10053): 1659-1724.
36. Hamra GB, Guha N, Cohen A, et al. Outdoor particulate matter exposure and lung cancer: a systematic review and meta-analysis. Environ Health Perspect 2014; 122(9): 906-911.
37. Stafoggia M, Cesaroni G, Peters A, et al. Long-term exposure to ambient air pollution and incidence of cerebrovascular events: results from 11 European cohorts within the ESCAPE project. Environ Health Perspect 2014; 122(9): 919-925.
38. Meo SA, Memon AN, Sheikh SA. Effect of environmental air pollution on type 2 diabetes mellitus. Eur Rev Med Pharmacol Sci 2015; 19(1): 123-128.
39. Volk HE, Lurmann F, Penfold B, et al. Traffic-related air pollution, particulate matter, and autism. JAMA Psychiatry 2013; 70(1): 71-77.
40. Ha S, Hui H, Roussos-Ross, et al. The effects of air pollution on adverse birth outcomes. Environ Res 2014; 134: 198-204.
41. Kampfrath T, Maiseyeu A, Ying Z, et al. Chronic fine particulate matter exposure induces systemic vascular dysfunction via NADPH oxidase and TLR4 pathways. Circ Res 2011; 108(6): 716-726.
42. Lucking AJ, Lundback M, Mills NL, et al. Diesel exhaust inhalation increases thrombus formation in man. Eur Heart J 2008; 29(24): 3043-3051.
43. Bellavia A, Urch B, Speck M, et al. DNA hypomethylation, ambient particulate matter, and increased blood pressure: findings from controlled human exposure experiments. J Am Heart Assoc 2015; 4(10): e001981.
44. Wold LE, Ying Z, Hutchinson KR, et al. Cardiovascular remodeling in response to long-term exposure to fine particulate matter air pollution. Circ Heart Fail 2012; 5(4): 452-461.
45. Visseren FLJ, Mach F, Smulders YM, et al. 2021 ESC Guidelines on cardiovascular disease prevention in clinical practice. Eur Heart J 2021; 42(34): 3227-3337.
46. Kleinman MT. The health effects of air pollution on children. Available from: http://www.aqmd.gov/docs/default-source/students/health-effects.pdf (accessed: 24 June 2021).
47. Yolton K, Khoury JC, Burkle J, et al. Lifetime exposure to traffic-related air pollution and symptoms of depression and anxiety at age 12 years. Environ Res 2019; 173: 199-206.
48. Schultz ES, Hallberg J, Bellander T, et al. Early-life exposure to traffic-related air pollution and lung function in adolescence. Am J Respir Crit Care Med 2016; 193(2): 171-177.
49. Bloemsma LD, Wijga AH, Klompmarker JO, et al. The associations of air pollution, traffic noise and green space with overweight throughout childhood: the PIAMA birth cohort study. Environ Res 2019; 169: 348-356.
50. Ortega-García JA, Sánchez-Solís M, Ferris-Tortajada J, et al. Air pollution and children's health. An Pediatr (Engl Ed) 2018; 89(2): 77-79 [Article in Spanish].
51. Fang SC, Schwartz J, Yang M, et al. Traffic-related air pollution and sleep in the Boston Area Community Health Survey. J Expo Sci Environ Epidemiol 2015; 25(5): 451-456.
52. Gruzieva O, Xu CJ, Yousefi P, et al. Prenatal particulate air pollution and DNA methylation in newborns: an epigenome-wide meta-analysis. Environ Health Perspect 2019; 127(5): 57012.

AUTHORS' CONTRIBUTIONS

IAW, PG and MP prepared the concept of the paper. IAW and KD collected data and wrote the article. All authors have given their approval to the final version of the paper.