

Climate Change, Air Pollution, and Biodiversity in Asia Pacific and Impact on Respiratory Allergies



Ruby Pawankar, MD, PhD^{a,*}, Jiu-Yao Wang, MD, PhD^b

KEYWORDS

• Climate change • Air pollution • Allergic disease • Asia-Pacific

KEY POINTS

- Epidemiologic studies show that climate change, and indoor and outdoor air pollution affect respiratory health, including increase in the prevalence of asthma and allergic diseases.
- Asia-Pacific is the most populated region in the world, with a huge burden of both outdoor and indoor pollutants and household pollutants.
- Risk factors for the epidemic increase in allergic diseases in the Asia Pacific region are due to increased urbanization and environmental factors of air pollution and climate changes.
- Abatement of the main risk factors for respiratory diseases, in particular, indoor and outdoor air pollution, are needed to reduce the burden of respiratory allergies.

INTRODUCTION

Globally, there is an increase in allergic diseases with about 300 million people who suffer from asthma and 400 million from rhinitis.¹ Air pollution, climate change, and decreased biodiversity are major threats to human health with detrimental effects on a variety of chronic diseases in particular respiratory and cardiovascular diseases.^{1,2} According to the World Health Organization, every year 3 million people die prematurely owing to outdoor air pollution; the heaviest burden occurs in the major cities of Asia, Africa, and Latin America.

Climate change is a result of global warming, and is often defined as the change of temperature and weather patterns over a long period of time. Epidemiologic and experimental studies have demonstrated the relationship between various

^a Department of Pediatrics, Nippon Medical School, 1-1-5, Sendagi, Bunkyo-ku, Tokyo 113-8603, Japan; ^b Department of Pediatrics, Center for Allergy and Clinical Immunology Research (ACIR), College of Medicine, National Cheng Kung University Hospital, Tainan, Taiwan

* Corresponding author.

E-mail address: pawankar.ruby@gmail.com

environmental factors and climate change on respiratory allergies.^{1–10} However, the precise molecular mechanisms by which air pollutants and climatic change impacts allergic diseases are complex and not fully well defined.

Outdoor pollutants like carbon dioxide (CO₂), sulfur dioxide, ozone (O₃), and indoor pollutants like tobacco smoke and chemicals lead to limited plant, animal, and microbial life. This situation can then lead to immune dysfunction and impaired tolerance in humans.^{7,8} Lifestyle changes such as a westernized life style, urbanization, and high levels of vehicular-induced pollution have been shown to correlate with the increased frequency of pollen-induced respiratory allergies in residents in urban areas versus with those in rural areas.¹¹ O₃ has been reported to cause respiratory symptoms by inducing increases in airway responsiveness, airway injury and inflammation, and systemic oxidative stress.¹² Pollen from high-traffic roads have a higher allergenicity and children living in closer proximity to heavy traffic roads have greater symptoms of respiratory allergies.

Weather changes, like wind patterns, precipitation timing and intensity, and global warming, may also have an effect on the intensity of air pollution. One of the effects of climate change and global warming that can threaten respiratory health is thunderstorms asthma, which can be fatal.^{4,13,14} In fact, air pollutants can interact with allergen-carrying submicronic and paucimicronic particles derived from pollen or other part of the plants and these allergens can enter the peripheral airways inducing asthma in sensitized subjects.

Furthermore, changes in the environment and human activities have caused an alteration in the biodiversity.^{1,15} Metagenomic and other studies of healthy and diseased individuals reveal that reduced biodiversity and alterations in the composition of the gut and skin microbiota are associated with various inflammatory conditions, including asthma and allergic diseases. Solid fuel derived from plant material (biomass) or coal for cooking, heating, or lighting are smoky, often used in an open fire or simple stove with incomplete combustion, and result in a large amount of indoor air pollution.

CLIMATE CHANGE AND ITS IMPACT ON POLLEN ALLERGENS

Climate change influences not only the levels and the type of air pollution, but also the levels of allergenic pollen. Global warming affects the onset, duration, and intensity of the pollen season, as well as the pollen allergen potency. Over the last decades, many studies have shown changes in the production, dispersion, and allergen content of pollen and spores, and that the nature of these changes may vary in different regions and species. Current knowledge on the worldwide effects of climate change on respiratory allergic diseases is provided by several studies on the relationship between asthma and environmental factors, like meteorologic variables, airborne allergens, and air pollution. Published data suggest an increasing effect of aeroallergens on allergic patients, leading to a greater likelihood of the development of an allergic respiratory disease in sensitized patients and an aggravation in patients who are symptomatic.^{4,5} Ragweed pollen production was 61% higher per plant owing to a doubling of the atmospheric CO₂ concentration.¹⁰ Furthermore, ragweed pollen from high-traffic roads had increased allergenicity owing to the pollutants. In Southeast Asia (eg, Taiwan), where perennial allergen exposure is most common the major sensitizing perennial allergen is house dust mite, cockroaches, and pollen in the context of a highly polluted environment¹⁶

CLIMATE CHANGE, AIR POLLUTION, AND RESPIRATORY ALLERGIES IN THE ASIA PACIFIC REGION

The global burden of ambient PM_{2.5}, O₃, and NO₂ on the incidence of asthma and asthma-related emergency room visits estimated in 2015 were 8% and 20% and 4% and 9% of the total annual global visits, respectively.¹⁷ Anthropogenic emissions were responsible for approximately 37% and 73% of O₃ and PM_{2.5} impacts, respectively.¹⁸ Of all countries globally, India and China had the most estimated asthma emergency room visits attributable to total air pollution concentrations, respectively contributing 23% and 10% of global asthma emergency room visits estimated to be associated with O₃, 30% and 12% for PM_{2.5}, and 15% and 17% for NO₂.

Furthermore, 16 million new pediatric asthma cases could occur globally each year owing to anthropogenic PM_{2.5} concentrations. The percentage of national pediatric asthma incidence attributable to anthropogenic PM_{2.5} was estimated to be 57% in India, 51% in China, and more than 70% in Bangladesh. The estimated asthma incidence attributable to NO₂ and PM_{2.5} translate to approximately 1:7 million disability-adjusted life-years among children (approximately 97% of these attributable to PM_{2.5}), adding approximately 8% to the most recently estimated disability-adjusted life-year burden from ambient air pollution across age groups. The atmospheric concentration of CO₂, the most important anthropogenic greenhouse gas, has increased from 280 ppm to 379 ppm in 2005.^{1,2} About 75% of the anthropogenic CO₂ emissions to the atmosphere during the past 50 years resulted from fossil fuel burning.¹⁸ The key determinants of greenhouse gas emissions are energy production, transportation, agriculture, food production, and waste management.⁶ Moreover, rising temperatures contribute to the elevation of the concentrations of O₃ and PM at ground level.^{9,10} Westernized diets and lifestyle and urbanization combined with increased vehicular emissions correlate with an increase in the incidence of respiratory allergies in people living in urban versus rural areas.^{8,9,15} In South-East Asia, air pollution is a result of a massive migration of rural population from farm to city in recent years.

O₃ has been reported to cause respiratory symptoms by inducing increased airway responsiveness, airway injury and inflammation and systemic oxidative stress.^{4,19} O₃ and fine PM 2.5 are associated with respiratory symptoms and increased use of rescue medication among asthmatic children using maintenance medication. A 50 parts per billion increase in 1-hour O₃ was associated with increased likelihood of wheeze (35%) and chest tightness (47%). The highest levels of O₃ (1-hour or 8-hour averages) were associated with increased shortness of breath and rescue medication use.

Particular PM and diesel exhaust particles, O₃, nitrogen dioxide, and sulfur dioxide can exacerbate airway inflammation in susceptible persons, causing increased permeability, easier penetration of allergens into the mucus membranes, and easier interaction with immune cells.⁴ There is also evidence that predisposed persons have increased airway reactivity induced by air pollution and increased bronchial responsiveness to inhaled allergens.

Regional weather changes, such as changes in wind patterns, precipitation timing and intensity, and increasing temperatures, also affect the severity and frequency of air pollution. Tropospheric O₃, which is formed in the presence of high temperatures owing to the interaction between volatile organic compounds (VOCs) and nitrogen oxides, are increasing in most regions. From the study of the burden of air pollution and weather condition on daily respiratory deaths among older adults in Jinan, China, from 2011 to 2017, outdoor air pollution was significantly related to mortality from all respiratory diseases, especially from chronic airway disease.²⁰ An increase of 10 mg/m³ or

10 parts per billion of PM_{2.5}, PM₁₀, sulfur dioxide, NO₂, and O₃ corresponds with increments in mortality caused by chronic airway disease of 0.243% at lag 1 day, 0.127% at lag 1 day, 0.603% at lag 3 day, 0.649% at lag 0 day and 0.944% at lag 1 day, respectively. The effects of air pollutants were usually greater in females. Sex, age, temperature, humidity, pressure, and wind speed were considered to modify the short-term effects of outdoor air pollution on mortality in Jinan. Compared with other pollutants, O₃ had a stronger effect on respiratory deaths among the elderly. In a study looking at the impact of air pollution on small airway dysfunction in China, a significant association was found between urbanization, cigarette smoking, passive smoking, biomass use, exposure to high concentrations of particulate matter (PM_{2.5}), a history of chronic cough in childhood, a history of childhood pneumonia or bronchitis, a parental history of respiratory diseases, and increase of body mass index by 5 kg/m², and small airways dysfunction.²¹

THUNDERSTORM ASTHMA

One of the effects of climate change and global warming is an increasing frequency and intensity of floods and cyclones.^{9,10} An example of how this effect can threaten respiratory health is "Thunderstorm related asthma."^{4,5,22,23} Actually, thunderstorms occurring during the pollen season have been observed to induce severe asthma attacks and also deaths in pollen-allergic patients.^{22–24} Thunderstorm asthma refers to an observed increase in acute bronchospasm cases after the occurrence of thunderstorms in the local vicinity. Evidence suggests that these thunderstorm asthma epidemics occurred only during the pollen season, with pollen-allergic patients at highest risk. Events have been reported from Europe, North America, the Middle East, and Australia.²² Previously, the largest documented outbreak occurred in June 1994, when 640 patients attended London Emergency Departments within a 30-hour period. This event has been greatly surpassed by a recent thunderstorm event in Melbourne, Australia, on November 21 to 22, 2016, when more than 9900 patients presented to hospitals with asthma attacks^{23–25} (Fig. 1). In excess of 2300 emergency calls were received, and despite valiant efforts of emergency services, 10 deaths have been attributed to this tragic crisis. A pilot questionnaire study of 344 patients who presented to the emergency departments in eastern Melbourne found that the majority of affected patients (57%) did not have a previous diagnosis of asthma, although most (51%) of these had symptoms suggestive of latent asthma; (ii) rhinitis was highly prevalent in 88% of subjects, with 71% of these being moderate to severe; (iii) 46% of cases were born outside Australia with a mean duration of 16.0 ± 11.9 years living in Australia; (iv) there was over-representation of non-Caucasian population, with 27% identifying ethnically as Asian (Chinese, Vietnamese, East or South-East Asian), and 16% as Indian (including subcontinental Sri Lankan, Pakistani, or Bangladeshi).²³ This over-representation of those born outside Australia (46%), and of Asian/Indian ethnicity (43%), is far in excess of that expected in the resident population. This finding has been confirmed in a subsequent analysis across the Melbourne population.²⁴

NOVEL CORONAVIRUS DISEASE 2019, ALLERGIES, AND AIR POLLUTION

Since its first report in Wuhan, China, in December 2019, the novel coronavirus disease 2019 (COVID-19) pandemic has become a global public health problem. Previous studies have found that air pollution is a risk factor for respiratory infection by carrying micro-organisms and affecting the body's immunity. In a study in China addressing the relationship between ambient air pollutants and the infection caused by the severe acute respiratory syndrome coronavirus 2 showed that short-term

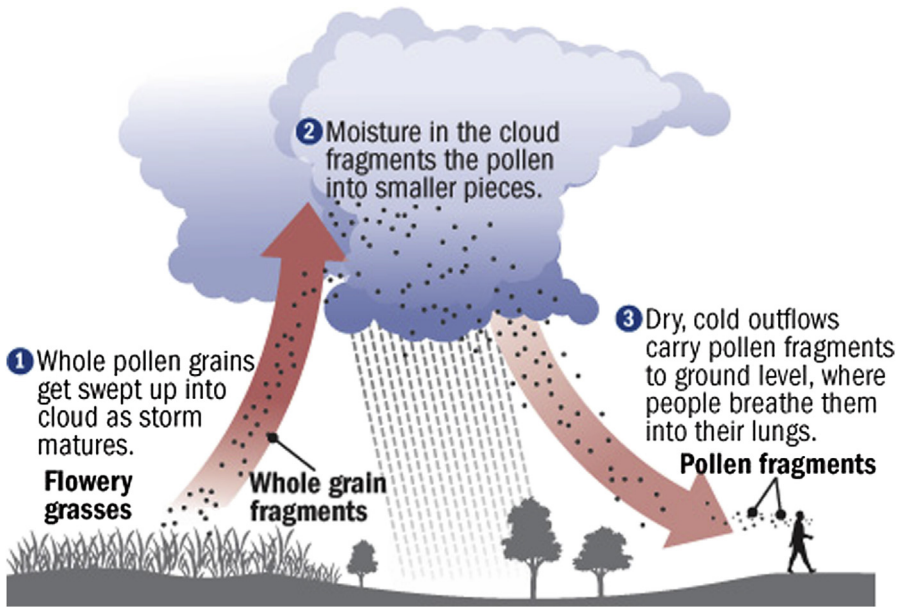


Fig. 1. Hypothesis for the mechanism of thunderstorm asthma. (Adapted from Department of Health and Human Services. Review of response to the thunderstorm asthma event of 21–22, 2016 Final Report. Victoria State Government 2017. Available at: <https://www2.health.vic.gov.au/about/publications/researchandreports/thunderstorm-asthma-igem-review-final-report-april-2017> © Copyright State Government of Victoria.)

exposure to higher concentrations of $PM_{2.5}$, PM_{10} , CO , NO_2 , and O_3 is associated with an increased risk of COVID-19 infection.²⁶ Patients with asthma and allergies are usually at greater risk of more severe outcomes with viral infections. However, recent reports have accumulated evidence that the prevalence of allergic diseases and asthma in patients with COVID-19 is lower than expected. Potentially, this finding is due to chronic and sustained type 2 immune inflammation in the lungs of asthmatic patients, or by the medications they use for asthma control, it seems asthma is not a major comorbidity and risk factors of the severe form of COVID-19.²⁷ Another potential factor could be the low levels of air pollution during the lockdown in many cities worldwide.

INDOOR AIR POLLUTION

Human activities, like the burning of fossil fuels like coal and oil, increase the amount of CO_2 that is emitted into the atmosphere, thus altering natural atmospheric greenhouse. One-third of the world's population uses solid fuel derived from plant material (biomass) or coal for cooking, heating, or lighting. These fuels are smoky, often used in an open fire or simple stove with incomplete combustion, and result in a large amount of household air pollution when smoke is poorly vented. Household air pollution accounts for about 3.5 to 4.0 million deaths every year. In Southeast Asia, many rural and even urban households use coal-based heating systems for cooking owing to financial reasons. Women and children living in severe poverty have the greatest exposures to household air pollution. Exposure to particulate emissions poses a variety of public health concerns worldwide, specifically in developing countries. One review

summarized the documented studies on indoor PM emissions and their major health concerns in South Asia.²⁸ Alarming levels of indoor air pollution are reported in India, Pakistan, Nepal, and Bangladesh; Sri Lanka and Bhutan are confronted with relatively lower levels, although they are not safe, either. The reported levels of PM with a diameter of PM₁₀ or less and PM_{2.5} in Nepal, Pakistan, Bangladesh, and India were 2- to 65-fold, 3- to 30-fold, 4- to 22-fold, 2- to 28-fold, and 1- to 139-fold, 2- to 180-fold, 3- to 77-fold, and 1- to 40-fold higher than World Health Organization standards for indoor PM₁₀ (50 µg/m³) and PM_{2.5} (25 µg/m³), respectively. Regarding indoor air pollution-mediated health concerns, mortality rates and incidences of respiratory and nonrespiratory diseases were increasing with alarming rates, specifically in India, Pakistan, Nepal, and Bangladesh. A major cause might be the reliance of approximately 80% population on conventional biomass burning in the region.

VOCs are a group of carbon-based chemicals that easily evaporate at room temperature. Many common household materials and products, such as paints and cleaning products, give off VOCs. Common VOCs include acetone, benzene, ethylene glycol, formaldehyde, methylene chloride, perchloroethylene, toluene, and xylene. Several studies suggest that exposure to VOCs may make symptoms worse in people who have asthma or are particularly sensitive to chemicals. From a cohort study in Hong Kong regarding the household incense burning and children's respiratory health, incense burning was associated with 48.6 mL/min lower maximum mid-expiratory flow in boys.²⁹ In follow-up, incense burning was associated with reduced peak expiratory flow growth in all participants. These researchers also found that incense burning was associated with increased prevalence of bronchitis and bronchiolitis,

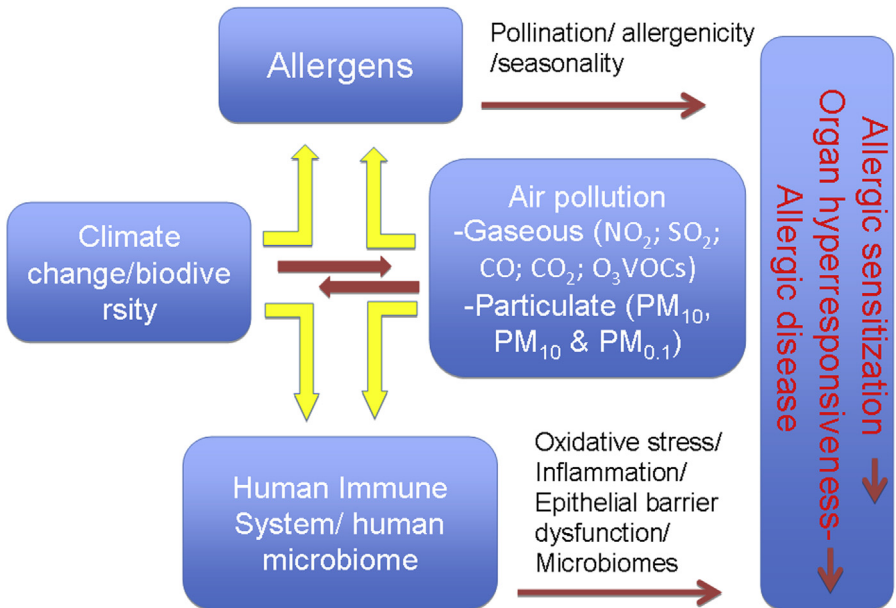


Fig. 2. Interactions of climate change and air pollution on respiratory allergies. (From Reinmuth-Selzle K, Kamp CJ, Kurt Lucas K, et al. Air Pollution and Climate Change Effects on Allergies in the Anthropocene: Abundance, Interaction, and Modification of Allergens and Adjuvants. *Environ Sci Technol* 2017; 51(8): 4119–4141 (<https://pubs.acs.org/doi/10.1021/acs.est.6b04908>); with permission.)

higher prevalence of pneumonia (odds ratio, 2.79) and wheezing (odds ratio, 1.49) in boys, but not in girls. The respiratory effects of secondhand smoke have been widely studied, supporting a causal relation between parental smoking and respiratory symptoms, including cough, phlegm, breathlessness, and wheeze, in children aged 5 to 16 years of age. From a cross-sectional study in Hong Kong on the relationship of exposure to secondhand smoke from neighbors and respiratory symptoms in never-smoking adolescents, they found in all study subjects that 33.2% were exposed to secondhand smoke at home, including 16.2% from inside the home only, 10.0% from neighbors only, and 7.0% from both. The prevalence of secondhand smoke exposure from neighbors was 17.1%, including 13.5% for 1 to 4 d/wk and 3.6% for 5 to 7 d/wk. In never-smokers ($n = 50,762$), respiratory symptoms were significantly associated with secondhand smoke exposure from neighbors with adjusted odds ratios of 1.29 for any exposure, 1.21 for 1 to 4 d/wk and 1.63 for 5 to 7 d/wk. Secondhand smoking exposure was associated with respiratory symptoms in never smokers. Country-wise data on the impact of air pollution on respiratory allergies in Asia-Pacific is summarized in the Asia Pacific Association of Allergy Asthma and Clinical Immunology White Paper on Climate Change and Air Pollution and impact on respiratory allergies of the.³⁰

SUMMARY

Climate change has major health effects, including an increase in the prevalence of allergic respiratory diseases, exacerbations of chronic obstructive lung disease and premature mortality. These adverse health effects are seen especially in the most vulnerable like the elderly, children, and those from poor socioeconomic conditions. According to the World Health Organization, nearly 1.0 million of the 3.7 million people who died from ambient air pollution in 2012 lived in South-East Asia.⁹ The Asia-Pacific has a huge burden of both outdoor and indoor pollutants, including PM_{2.5}, PM₁₀, suspended particulate matter, CO, O₃, NO₂, sulfur dioxide, NO, and household pollutants, including biomass and tobacco. Westernized diets and lifestyle, urbanization, air pollution, and climate change have contributed to through different interactions with the human immune system and allergens (Fig. 2)³¹ and contribute to the increase in the incidence of respiratory allergies in people living in urban versus rural areas in the Asia Pacific region.

CLINICS CARE POINTS

- Patient's respiratory allergies like asthma and AR are well controlled.
- Adherence to medications should be checked.
- Digital/Mobile technologies to report patient status or patient symptom and medications records can be used to report the clinical status of patients.
- Advise patients regarding avoidance of exposure to air pollutants.

DISCLOSURE

The authors have nothing to disclose.

REFERENCES

1. Pawankar R, Canonica GW, Holgate ST, et al. WAO White book on allergy: update 2013. Milwaukee (WI): World Allergy Organization; 2013.

2. Haahtela T, Holgate S, Pawankar R, et al. WAO Special Committee on Climate Change and Biodiversity. The biodiversity hypothesis and allergic disease: World Allergy Organization position statement. *World Allergy Organ J* 2013;6:3.
3. Hegerl GC, Zwiers FW, Braconnot P, et al. Understanding and attributing climate change. In: Solomon S, Qin D, Manning M, et al, editors. *Climate change 2007: the physical science basis. Contribution of the working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge, (United Kingdom): Cambridge University Press; 2007. p. 663–746.
4. D'Amato G, Holgate ST, Pawankar R, et al. Meteorological conditions, climate change, new emerging factors, and asthma and related allergic disorders. A statement of the world allergy organization. *World Allergy Organ J* 2015;8:25.
5. D'Amato G, Vitale C, Lanza M, et al. Climate change, air pollution, and allergic respiratory diseases: an update. *Curr Opin Allergy Clin Immunol* 2016;16:434–40.
6. D'Amato G, Vitale C, De Martino A, et al. Effects on asthma and respiratory allergy of Climate change and air pollution. *Multidiscip Respir Med* 2015;10:39.
7. Pielke RA, Cecchi L, D'Amato G, et al. Climate, urban air pollution and respiratory allergy. In: Pielke RA, editor. *Climate vulnerability: understanding and addressing threats to essential resources*. Waltham (MA): Academic Press; 2013. p. 105–13.
8. D'Amato G, Bergmann KC, Cecchi L, et al. Climate change and air pollution: effects on pollen allergy and other allergic respiratory diseases. *Allergo J Int* 2014; 23:17–23.
9. Singer BD, Ziska LH, Frenz DA, et al. Increasing Amb a 1 content in common ragweed (*Ambrosia artemisiifolia*) pollen as a function of rising atmospheric CO₂ concentration. *Funct Plant Biol* 2005;32:667–70.
10. Wayne P, Foster S, Connolly J, et al. Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) is increased in CO₂-enriched atmospheres. *Ann Allergy Asthma Immunol* 2002;88:279–82.
11. Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller foundation-lancet commission on planetary health. *Lancet* 2015;386:1973–2028.
12. Islam T, Gauderman WJ, Berhane K, et al. Relationship between air pollution, lung function and asthma in adolescents. *Thorax* 2007;62:957–63.
13. D'Amato G, Cecchi L, Bonini S, et al. Allergenic pollen and pollen allergy in Europe. *Allergy* 2007;62:976–90.
14. D'Amato G. Airborne paucimicronic allergen-carrying particles and seasonal respiratory allergy. *Allergy* 2001;56:1109–11.
15. Flandroy L, Poutahidis T, Berg G, et al. The impact of human activities and life-styles on the interlinked microbiota and health of humans and of ecosystems. *Sci Total Environ* 2018;627:1018–38.
16. Liang KL, Su MC, Shiao JY, et al. Role of pollen allergy in Taiwanese patients with allergic rhinitis. *J Formos Med Assoc* 2010;109:879–85.
17. Anenberg SC, Henze DK, Tinney V, et al. Estimates of the global burden of ambient PM_{2.5}, ozone, and NO₂ on asthma incidence and emergency room visits. *Environ Health Perspect* 2018;126:107004.
18. D'Amato G, Pawankar R, Vitale C, et al. Climate change and air pollution: effects of respiratory allergy. *Allergy Asthma Immunol Res* 2016;8(5):391–5.
19. Baulig A, Garlatti M, Bonvallot V, et al. Involvement of reactive oxygen species in the metabolic pathways triggered by diesel exhaust particles in human airway epithelial cells. *Am J Physiol Lung Cell Mol Physiol* 2003;285:L671–9.

20. Wang S, Li Y, Niu A, et al. The impact of outdoor air pollutants on outpatient visits for respiratory diseases during 2012–2016 in Jinan, China. *Respir Res* 2018; 19:246.
21. Xiao DW, Chen Z, Wu S, et al. Prevalence and risk factors of small airway dysfunction, and association with smoking, in China: findings from a national cross-sectional study. *Lancet Respir Med* 2020. [https://doi.org/10.1016/S2213-2600\(20\)30155-7](https://doi.org/10.1016/S2213-2600(20)30155-7).
22. Davies JM. Pollen allergens. In: Nriagu JO, editor. *Encyclopedia of environmental health*. 2nd edition. Amsterdam (Netherlands): Elsevier; 2019.
23. Thien F, Beggs PJ, Csutoros D, et al. The Melbourne epidemic thunderstorm asthma event 2016: an investigation of environmental triggers, effect on health services, and patient risk factors. *Lancet Planet Health* 2018;2:e255–63.
24. Thien F. Thunderstorm asthma: potential danger but a unique opportunity. *Asia Pac Allergy* 2017;7:55–6.
25. Inspector-General for Emergency Management. Review of response to the thunderstorm asthma event of 21–22, 2016 Final Report. Australia: Department of Justice and Regulation. Victoria State Government; 2017.
26. Jiang Y, Wu X-J, Guan Y-J. Effect of ambient air pollutants and meteorological variables on COVID-19 incidence. *Infect Control Hosp Epidemiol* 2020;1–5. <https://doi.org/10.1017/ice.2020.222>, 2020.
27. Wang JY, Pawankar R, Tsai HJ, et al. COVID-19 and asthma, the good or the bad? *Allergy* 2020;00:1–3. <https://doi.org/10.1111/all.14480>. Available at:.
28. Junaid M, Syed JH, Abbasi NA, et al. Status of indoor air pollution (IAP) through particulate matter (PM) emissions and associated health concerns in South Asia. *Chemosphere* 2018;191:651–63.
29. Zhang Z, Tan L, Huss A, et al. Household incense burning and children's respiratory health: a cohort study in Hong Kong. *Pediatr Pulmonol* 2019;5484: 399–404. <https://doi.org/10.1002/ppul.24251>.
30. Pawankar R, Wang JY, Wang IJ, et al. Asia pacific association of allergy asthma and clinical immunology white paper 2020 on climate change, air pollution, and biodiversity in Asia-Pacific and impact on allergic diseases. *Asia Pac Allergy* 2020;10(1):e11.
31. Reinmuth-Selzle K, Kamp CJ, Kurt Lucas K, et al. Air pollution and climate change effects on allergies in the Anthropocene: abundance, interaction, and modification of allergens and adjuvants. *Environ Sci Technol* 2017;51:4119–41.