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Review

Environmental and health impacts of air pollution: A mini-review

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Abstract:

Air pollution is one of the leading risk factors for death but also a significant contributor to the global disease burden, affecting quality of life. According to a World Health Organisation (WHO) report, seven million people die from air pollution every year, and 9 out of 10 people worldwide breathe polluted air. Any person can be affected by exposure to polluted air, especially the elderly, children, pregnant women, and people with comorbidities. Some studies indicate that the diseases most affected by air pollution are respiratory infections, chronic obstructive pulmonary disease (COPD), lung cancer, and cardiovascular diseases. The degree of effect on the body depends on the pollutant composition, source and dose, level and duration of exposure to polluted air. Particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2) could lead to air pollution. Long-term exposure to air pollution can affect every organ in the body and worsen existing health conditions. Short-term exposure to contaminants can include unpleasant sensations such as coughing, wheezing, shortness of breath, eye, nose, and throat irritation, headache, dizziness, and fatigue. Community and individual solutions such as using clean fuel, wearing personal masks, filtering indoor air, and ventilating need to be taken to reduce the impact of air pollution.

Keywords: **air pollution, environment, health, impacts.**

Classification number: **5.3**

1. Introduction

Air pollution is a global issue. According to World Health Organisation (WHO) statistics, over 92% of the population lives in polluted air [1]. This has significantly impacted human life and the natural environment. Notably, approximately 93% of children over 15 years old worldwide breathe polluted air, primarily due to indoor air pollution sources [2].

Air pollution entails a significant alteration in the composition of the air, caused by smoke, dust, vapours, or foreign gases being introduced into the atmosphere, leading to peculiar odours, reduced visibility, and climate change. These pollutants directly affect the health of humans, animals, and plants on Earth. PM, O_3, NO_2, and SO_2 are the main contributors to air pollution. In Vietnam, particulate matter (i.e. $PM_{2.5}$ and PM_{10}) was the most prominent concern among air pollutants from 2011 to 2020 [3]. Fine dust pollution remains a significant issue in major industrial centres of Vietnam such as Hanoi and Ho Chi Minh city. $PM_{2.5}$ and PM_{10} levels at continuous automatic monitoring stations in Hanoi during the period 2018-2020 exceeded the QCVN 05:2013/BTNMT (National technical regulation on ambient air quality) threshold by 1.1 to 2.2 times [4]. Research by N.T.K. Oanh, et al. (2018) [5] estimated $PM_{2.5}$ emissions in 2018 from human activities and forest fires in Vietnam at approximately 600 thousand tons (excluding road dust and other sources). Among these, $PM_{2.5}$ emissions from agricultural waste incineration accounted for the highest proportion (40%), followed by residential cooking (17%), road traffic (13%), forest fires (12.7%), industrial activities (11%), and thermal power plants (3.3%). The remaining sectors collectively contributed about 3% of

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the country's total $PM_{2.5}$ emissions. Particularly, Hanoi and Ho Chi Minh city had the highest emissions, ranging from 9.01 to 10.25 tons/km^2/year. Provinces in other regions, such as the northern midlands, mountains, and the central region, had lower $PM_{2.5}$ emissions, ranging from 0.35 to 3.0 tons/km^2/year. The total amount of sulphur oxide (SO_x) emissions for the entire country in 2018 was about 750 thousand tons/year, with emissions from thermal power plants and industrial activities contributing over 91%.

The disease burden associated with exposure to indoor and outdoor air pollution is significant and increasing. It poses a major threat to human health, resulting in approximately 7 million deaths annually. Air pollution increases morbidity and mortality from non-communicable cardiovascular and respiratory diseases. Furthermore, deteriorating air quality is the leading cause of increased disease burden from lower respiratory tract infections, premature births, and other causes of death in children.

Moreover, air pollution remains a significant cause of disease burden in low- and middle-income countries [6]. In 2019, the impact of indoor and outdoor air pollution on mortality surpassed common factors such as obesity, low birth weight, or an unhealthy diet [7]. Additionally, based on European data, a 1 μg/m^3 increase in $PM_{2.5}$ concentration (or a sample mean increase of 10%) results in a 0.8% decrease in real GDP in the same year [8]. Besides the associated health burden, air pollution imposes additional economic costs, such as its impact on crops or damage to buildings and infrastructure. Furthermore, there are costs associated with climate change resulting from air pollution and environmental degradation [6].

Various reports have presented the air quality in Vietnam. According to Yale University's Environmental Performance Index (EPI) 2020, Vietnam's air pollution exposure ranks 115th out of 180 countries. On the IQir/AirVisual ranking, Vietnam's average $PM_{2.5}$ concentration in 2020 ranked 21st among 106 countries [5]. According to new data from the WHO, over 60,000 people died in 2016 from heart disease, stroke, lung cancer, chronic obstructive pulmonary disease, and pneumonia in Vietnam [9]. Therefore, this review aims to provide general information on air pollution, along with implementing some policies and measures to reduce the impact of air pollution on personal health and the community.

2. Air pollution

2.1. Classification of air pollution

Air pollution can be defined as harmful chemicals or compounds, including those of biological origin, in the air at levels hazardous to health [10]. Additionally, air pollution refers to the presence of chemicals or compounds in the air that reduce air quality or cause harmful changes to the quality of life, such as destroying the ozone layer or causing global warming [11].

Air pollution is classified into outdoor and indoor air pollution. Outdoor air pollution mainly originates from vehicles and industrial plants such as thermal power plants, industrial boilers, garbage incinerators, and petrochemical plants. Indoor air can contain significant amounts of chemicals, irritants, carcinogenic chemicals, microbial agents, allergens, and fine indoor dust, termed indoor air pollution [12-15].

During the COVID-19 pandemic, governments imposed various restrictions to prevent the spread of the disease. People spent much of their time in indoor environments. Movement of people and transportation (road and air) was limited. Additionally, the suspension of international flights by airlines contributed to changes in air pollutant emissions. For example, $PM_{2.5}$ concentrations decreased by approximately 15% in the most polluted cities worldwide, with the most significant declines observed in capitals in the Americas, Asia, and Africa. Hence, it is considered that air pollution can directly result from economic growth and human activities. Various studies have shown that many indoor and outdoor pollutants are found in comparable concentrations. In some areas with limited ventilation, indoor pollution levels were higher. R. Xu, et al. (2020) [16] found that CO concentrations in indoor and outdoor environments were approximately the same at 396 and 386 ppb, respectively. Volatile organic compounds (VOC) and PM_{10} concentrations in Portuguese and UK homes were several times higher than in outdoor environments [17].

2.2. Main source and causes of air pollution

Air pollution consists of a mixture of dust, gases, fumes, particles, and biological materials in sufficient amounts to affect the environment and human health [11]. The primary sources of air pollution can be divided into natural and man-made sources. Natural activities such as volcanoes (emitting toxic gases like sulphur, chlorine, and particulate matter such as ash) and forest fires generate large amounts of CO_2 or radioactive decay. The second source originates from human activities [18]. With rapid population growth and a constantly developing economy, energy demand has significantly increased. Human production activities generate products to meet essential needs but are also the primary source of toxic substances with harmful effects on humans. Emissions of exhaust gases, tobacco smoke, pesticides, solvents, detergents, particles, dust, moulds, fibres, and allergens are deposited daily [18, 19]. The consumption of more fossil fuels is also concerning as they cause harm affecting the sustainable development of the environment [20, 21]. Combustion sources and cooking activities also contribute to the emission of CO_2, SO_2, CO, NO_2, and PM into the indoor atmosphere [22].

Besides, outdoor and indoor air pollution are related [23, 24]. Several air pollutants have been recognised to exist indoors, including NO_x, SO_2, O_3, CO, volatile and semi-volatile organic compounds (VOCs), PM, radon, and microorganisms. Some pollutants (e.g., NO_x, SO_2, O_3, PM) are common indoors and outdoors, and some may originate outdoors [25]. As concentrations of outdoor pollutants increase, they are transported from the outdoors into the indoor environment, e.g., through ventilation systems [24].

2.3. Recommended standards of air pollutants

Table 1. Guidance on short-term, long-term air quality and short-term goals, updated in 2021.

Agent	Average time	Short-term goal				AQG level
		1	*2*	*3*	*4*	
$PM_{2.5}$ (µg/m³)	Yearly	35	25	15	10	5
	24 hours[a]	75	50	37,5	25	15
PM_{10} (µg/m³)	Yearly	70	50	30	20	15
	24 hours[a]	150	100	75	50	45
O_3 (µg/m³)	Peak season[b]	100	70	-	-	60
	8 hours[a]	160	120	-	-	100
NO_2 (µg/m³)	Yearly	40	30	20	-	10
	24 hours[a]	120	50	-	-	25
SO_2 (µg/m³)	24 hours[a]	125	50	-	-	40
CO (mg/m³)	24 hours[a]	7	-	-	-	4

[a]: 99[th] quartile range (e.g., exceeding 3-4 days/year); [b]: the highest average O_3 concentration over 8 hours daily for six consecutive months.

According to Table 1 and the WHO global air quality guidelines, compared to the 2005 AQG level, the updated 2021 version of the WHO has the following significant changes:

- The annual $PM_{2.5}$ AQG level has been lowered from 10 to 5 µg/m³. This reflects new evidence on the impact of $PM_{2.5}$ on mortality occurring at concentrations below 10 µg/m³. The 24-hour AQG level for $PM_{2.5}$ changed from 25 to 15 µg/m³.

- The annual PM_{10} AQG level has been reduced from 20 g/m³ to 15 µg/m³. This reflects new evidence that the impact on mortality occurs at concentrations below 20 µg/m³. The 24-hour AQG for PM_{10} has changed from 50 to 45 µg/m³.

- New peak season (long-term) ozone AQG level has been determined. This is based on new evidence on the long-term effects of ozone on total mortality and respiratory mortality. The short-term AQG level of 100 µg/m³ is the same as the 2005 short-term level.

- The annual AQG level for NO_2 has changed from 40 to 10 µg/m³. This is primarily because this update of air quality guidance is based on the long-term impact of NO_2 on all-cause mortality and respiratory mortality. A new 24-hour AQG level of 25 µg/m³ is recommended.

- A 24-hour AQG level for carbon monoxide of 4 µg/m³ is recommended. This is based on a new assessment of the impact of short-term carbon monoxide levels on hospitalisation for myocardial infarction[6].

3. Some studies on the relationship between air pollution and health

3.1. Individual level exposure

When it comes to exposure to air pollution on an individual level, the level of exposure depends on the concentrations of pollutants in the air around them in which they reside, such as workplaces/schools or on the means of transport, etc., and the time people live/work in those spaces. Human activity time surveys show that people spend approximately 87% of their time in inadequately ventilated offices and 6% in closed vehicles. Thus, exposing themselves to air pollution on a personal level receives much attention [26, 27]. Several studies on individual monitors have found that indoor exposure to $PM_{2.5}$ contributes to 85.1% of the total exposure. The concentration of $PM_{2.5}$ inside the house increases the most at the entrance, followed by outdoor exposure (7.6%), bus (3.7%), subway (3.1%), and car (0.5%) [28].

Moreover, human activities within the home can increase an individual's exposure to $PM_{2.5}$. Three indoor practices that have been proven to raise the levels of fine dust within the home significantly are smoking cigarettes, burning incense, and cooking [29]. In 2020, WHO statistics revealed that approximately 2.4 billion individuals continue to cook using solid fuels, including wood, crop waste, charcoal, coal, and kerosene, in open-air furnaces and inefficient stoves [30]. This practice leads to an increase in the concentration of particles present in the household. In Vietnam, reports show an average individual $PM_{2.5}$ exposure of 64.28±33.18 µg/m^3. This exposure is higher than the concentration of $PM_{2.5}$ dust observed at two monitoring stations in district 2 and Zoo and Botanical Gardens, which is 38.49±18.45 µg/m^3 and 48.99±21.68 µg/m^3, respectively ($p<0.05$) [31]. Despite this, many remain unaware that indoor air pollution can increase exposure. The KAP Survey Model (Knowledge, Attitudes, and Practices) on indoor air pollution shows that most people do not have sufficient knowledge and correct behaviour about indoor air pollution [32-34].

3.2. Community level exposure

Controlling individual exposure sources is essential for reducing health risks. However, when outdoor pollutant concentrations rise, they can infiltrate homes through ventilation systems or windows/doors [28]. Research by H.L. Chen, et al. (2020) [35] in Taiwan revealed that outdoor fine dust significantly contributes to individual exposure, accounting for approximately 44% (range 33-55%) of $PM_{2.5}$ and 74% (range 57-88%) of NO_2 .

Community-level exposure is associated with increased adverse health outcomes in humans [36-38]. According to a study by T.N. Dang, et al. (2022) [38] in Vietnam, monitoring $PM_{2.5}$ concentration at 31 locations in Ho Chi Minh city estimated an average $PM_{2.5}$ concentration of 27.8±7.7 µg/m^3. High environmental $PM_{2.5}$ concentration increases the risk of low-birth-weight babies at term during pregnancy [39]. The reports identify areas such as residential areas near main roads, factories, and chimneys as sources of air pollution for the community [36]. Vehicle transportation in urban areas is considered a source of air pollution and is linked to the development of asthma and other respiratory diseases in children [40]. Asian housing estates are often built along roads, leading to higher exposure levels in residents near significant roads than those measured in monitoring stations in the surrounding environment [41]. Accordingly, the exposure concentration of $PM_{2.5}$ for cyclists (105 µg/m^3) is higher than that for motorcyclists (95 µg/m^3), with $PM_{2.5}$ concentration in the surrounding air at 34 µg/m^3. Exposure to $PM_{2.5}$ was found to be highest in the morning and during peak traffic hours, especially in the inner city compared to the suburbs [42]. Studies conducted in central Manhattan (New York city, USA) revealed that the traffic system in alleyways significantly increases particulate pollution concentration in community air. Ultra-fine particles (UFP) increased by 11%, and $PM_{2.5}$ increased by 8% compared to the measured urban background index. Additionally, central parks showed a 40% higher particle density than the general background of the central area [43]. Moreover, vehicle emissions increased PM_1 and $PM_{2.5}$ levels at points such as bus stops and intersections by 5 µg/m^3 [41].

Additionally, public places such as restaurants, temples, and construction sites also contribute to increased airborne particle concentrations [36]. Incense burning in temple areas leads to a density increase of $PM_{2.5}$ particles by 2.72 µg/m^3, along with an elevation in the concentration of substances in incense smoke, such as VOC, carbonyl compounds, CO, NO_x, and CH_4 [20]. In Asia, the density of particles in temples is higher due to the practice of worshiping and burning incense in these countries. Research in Taiwan indicated that particle density in temples and pagodas increased by 13.2, 15.1, and 17.2 µg/m^3 for PM_1, $PM_{2.5}$, and PM_{10} communities at all levels, respectively [17]. Another study by B. Wang found that particle density at two temples in Hong Kong increased from 4.2 to 18 in $PM_{2.5}$ [44].

4. Health effects of air pollution

Air pollution is considered a risk factor for several respiratory diseases. Most pollutants enter the body through the respiratory tract, making it the first gateway in the development and progression of air-polluted diseases [45]. Many pollutants are the leading cause of diseases in humans. In particular, particulate matter with tiny sizes, such as PM_{10} and $PM_{2.5}$, can penetrate the lungs and cardiovascular system, causing cardiovascular disease, stroke, respiratory infections, COPD, asthma, and lung cancer [46].

Outdoor air pollution and urbanisation are associated with increased asthma incidence and severity. According to a study in ten European cities, the incidence of asthma in children after exposure to pollutants from road vehicle exhaust was 14% and 15%, respectively. Those with asthma reported worsening conditions. Research has also shown a correlation between short-term exposure to $PM_{2.5}$ and PM_{10} in the air with asthma symptoms, especially in children with atopy [47].

In 2023, a study showed that a combination of $PM_{2.5}$ and O_3 in the air caused asthma-related changes in children's airways [48]. $PM_{2.5}$, PM_{10}, and O_3 contribute to oxidative stress, facilitating pneumonia and may be the first step in carcinogenesis [49]. NO_2 exposure was reported to have a link with an increased risk of hospitalisation in patients with chronic obstructive pulmonary disease and asthma [50]. A systematic review and meta-analysis in China also demonstrated a positive correlation between NO_2 exposure and lung diseases. Specifically, an increase in NO_2 concentration to 10 μg/m^3 was associated with increased mortality from respiratory diseases and hospitalisation by 1.4 and 1%, respectively [51]. Additionally, according to many studies worldwide, exposure to fine dust particles ($PM_{2.5}$) combined with CO and SO_2 in the surrounding environment will increase the risk of death from respiratory diseases and lung cancer, with a 1.9% increase in total deaths when CO concentrations increased by 1 mg/m^3 [52].

Daily exposure to polluted air is linked to oxidation and cell inflammation, risk factors for chronic diseases and cancer. WHO classified air pollution as a human carcinogen in 2013. Several studies have provided evidence of a correlation between the diameter of $PM_{2.5}$ and lung cancer morbidity and mortality. The AHSMOG-2 study found that for every 10 μg/m^3 increase in $PM_{2.5}$ in the air, the risk of lung cancer also increased, and this rate was higher among people who lived in their area for five years or more and spent more than 1 hour/day outdoors [53]. The incidence of lung cancer is expected to increase due to daily exposure to air pollution associated with large-scale industrialisation and smoking habits [54].

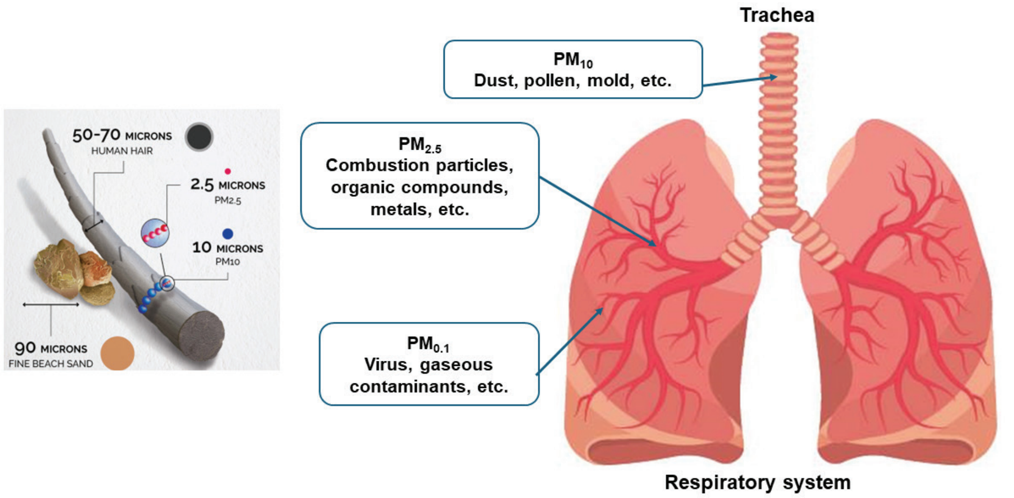

Fig. 1. Size, main composition, and deposition site of PM in the lung.

Many studies worldwide have identified a direct link between exposure to air pollution and cardiovascular diseases [55]. According to various studies, fine particulate matter can cause impaired blood vessel function and accelerate calcification in the arteries. In particular, the smaller the particles, the greater the ability to penetrate deep into the lower respiratory tract, thus having a more extraordinary ability to cause lung and heart diseases [45]. Together with particulate matter, CO is also known to be one of the most harmful substances to the central nervous system and cardiovascular systems. The affinity of CO for haemoglobin is 250 times greater than that of oxygen, leading to competition for the oxygen bond and the haeme nucleus of haemoglobin, resulting in oxygen loss and hypoxia [46]. Besides, high NO_2 exposure is thought to be associated with ventricular hypertrophy [56]. Additionally, scientific data from studies suggest an association between ambient air pollutants and blood pressure. To support this, a Korean study showed that exposure to pollutants such as O_3 and NO_2 in the short term increased systolic and diastolic blood pressure. Patients with hypertension are more susceptible to the effects of increased blood pressure than those with normal blood pressure. The mechanism by which O_3 exposure-induced hypertension is improved serotonin-induced vasoconstriction and decreased acetylcholine-induced vasodilation. Meanwhile, SO_2 and CO lower blood pressure within hours [57].

Besides the harmful effects of air pollution on the respiratory system, the impact on the eyes is also of great concern. The extent of the damage is variable and can range from asymptomatic to dry eye syndrome. Long-term exposure to air pollution can increase the likelihood of eye diseases [45]. If the concentration of toxins in the air is high, it can cause clinical manifestations within the day. The major reported air pollution-related eye health problems are eye discomfort, eye irritation, conjunctivitis, dry eye syndrome (DES), meibomian gland dysfunction (MGB), and blepharitis [58]. High concentrations of airborne pollutants narrow the retinal vessels, leading to microcirculation disorders. A study was conducted in China on 9737 patients who came for an eye examination for conjunctivitis. The study results showed an association when the concentration of CO, NO_2, SO_2, O_3, $PM_{2.5}$, and PM_{10} in the air increased to 10 μg/m^3 on the day of the visit and the previous day; the number of patients presenting for conjunctivitis also increased [59]. According to another study, $PM_{2.5}$ concentrations from 20 to 200 μg/ml were genotoxic, causing DNA damage and reducing the efficiency of corneal epithelial cells [60].

Air pollution not only affects adults but also has negative effects on children's health in their first years of life or exposure to air pollution by the mother during pregnancy. The cardiovascular, metabolic, respiratory, allergic, and neurodevelopmental systems have been reported to be affected by pollutants [61, 62]. Birth weight was reported to correlate with prenatal exposures to constituents sourced from industrial dust [63]. $PM_{2.5}$ and PM_{10} particles, SO_2, NO_2, or O_3 have been reported to be associated with reduced or low birth weight in newborns or, more seriously, can lead to premature birth [64].

5. Some recommended solutions to reduce the impact of air pollution

According to WHO statistics, outdoor air pollution contributes to about four million deaths annually, mainly from cardiovascular and respiratory diseases. Essential policies supporting air quality standards, such as energy-efficient housing and sustainable land use, should be implemented to reduce outdoor air pollution. Some major cities have introduced policies to reduce urban air pollution, such as bike-sharing in Paris, congestion charging in London, and an environmental police force in Beijing [65]. Additionally, protecting the integrity of ecosystems helps improve the health of communities worldwide. Therefore, expanding green land is necessary to prevent biodiversity loss, especially in highly urbanised and polluted countries [66].

Healthcare professionals need to connect with patients through an automated air pollution alert network, including alerts via text, email, or phone [67, 68]. Individuals are encouraged to plan their activities through their news feed, website, or mobile application to reduce their exposure to air pollution.

Using a mask is one way to reduce exposure to air pollution at the individual level. Some standard masks used worldwide include N95 in the United States, KN95 in China, and FFP2 in European countries. Unlike ordinary masks, these masks are equipped with filters (can remove more than 95% of impurities in the air and prevent dust particles as small as 0.3 microns) and are designed to fit the face [69].

Since air pollution is usually diffusive from outside into buildings, indoor air pollution could contain contaminants from itself and outdoor sources [70]. Therefore, reducing $PM_{2.5}$ indoors can also minimise the impact of particles produced from outdoor sources on human health. PM can be removed by using an air purifier, ventilation, and air conditioning system. Most studies have focused on mechanical filtration with a highly efficient particulate containment/air filter (HEPA), which removes at least 99.97% of 0.3 μm particles. Besides, eliminating burning solid fuels is an effective way to reduce indoor air pollution. Access to cleaner fuels, such as liquefied petroleum gas, natural gas pipelines, and electric stoves, is critical to public health. Several studies have shown a positive association between replacing solid fuels with improved stoves and significant improvements in health outcomes [70, 71].

6. Conclusions

Among various factors causing air pollution, $PM_{2.5}$ is the leading cause of adverse health effects. The main contributors to air pollution are traffic (especially bus stops), markets, temples, restaurants, gas stations, etc. Personal $PM_{2.5}$ exposure contributions have been shown to be higher when people are at home. Many studies have shown air pollution as a risk factor for death related to heart disease, stroke, lower respiratory tract infections, lung cancer, diabetes, and COPD. Additionally, air pollution causes adverse health-related economic impacts. Therefore, reducing emissions and adapting to the impact of the climate are necessary activities to reduce air pollution. Furthermore, individual measures to effectively reduce the health impact of air pollution include promoting personal mask-wearing, using air purifiers, ventilation, choosing low-exposure travel routes, and maintaining a proper diet.

CRediT author statement

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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