Influence of Climate Change on Respiratory Diseases

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Abstract: Global warming and the associated climate change is attributed mainly to the burning of fossil fuels. The resulting greenhouse gases and air pollutants cause or worsen disorders such as asthma, rhinosinusitis, chronic obstructive pulmonary disease, lung cancer, respiratory infections and pulmonary fibrosis. During the heat wave in the summer of 2003 approximately 22,000 to 55,000 people died in Europe and about 7,000 in Germany in addition to the normal mortality rate. Heat waves are often accompanied by elevated ozone and fine dust concentrations, which may be increased by occurring wildfires. Southern Europe will be burdened by sandstorms from the Sahara. According to present knowledge, short-term fine dust exposures cause an increase of pulmonary-related hospital admissions and an elevated mortality rate. Long-term fine dust exposures result in the deterioration of lung function in children with asthma. In Europe, the milder climate has extended the pollen season and has facilitated the distribution of Ambrosia so that allergic diseases continue to increase. Moreover flooding caused by extreme rainfall has resulted in a rise of allergies by molds and house dust mite. As a further global warming for the next few decades is predicted, an increase in pulmonary diseases can be expected.

Keywords: Air pollution, Allergen, Asthma, COPD, Heat waves, Greenhouse Gas, Particulate matter.

CAUSES OF CLIMATE CHANGE

According to historical records a cooling period known as the little ice age lasted from the 15th to the 19th century. In this period massive crop failures and hypothermia-related diseases occurred [1]. But since the beginning of industrialization the global air temperature has increased. In Germany between 1881 and 2009 the average air temperature has increased by 1.1°C [2]. The annual average air temperature in Germany was 9°C between 1991 and 2010 [3]. The years from 2000 to 2009 were the warmest measured so far.

For years the Intergovernmental Panel on Climate Change and the WHO have indicated that global warming is mainly anthropogenically caused by burning fossil fuels (coal, petroleum, natural gas), global deforestation, agriculture, livestock farming and uncontrolled waste disposal, which has a decisive influence on the health system (Figure 1) [4-6]. The so-called greenhouse gases (GHG) such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and air pollutants such as particulate matter (PM) with an aerodynamic diameter of less than 10 µm (PM₁₀), Sulphur dioxide (SO₂), nitrogen dioxide (NO₂) and carbon monoxide (CO) are enriched in the atmosphere [7-10].

This greenhouse effect has already been described in 1824. At that time, it was believed that the responsible gases were water vapor and CO₂ [11, 12]. In 1896, it was hypothesized that the anthropogenic caused enrichment of CO₂ in the atmosphere could elevate the Earth’s temperature [10, 13, 14].

Figure 1: Direct and indirect health effects by climate change [4, 5].

The continuous measurements of CO₂ on the volcano Mauna Loa in Hawaii since 1958 confirm that the atmospheric concentration of CO₂ has increased from approximately 316 parts per million (ppm) to now
387 ppm in 2008 in rural areas and more than 400 ppm in cities [10, 15-17].

Predicted CO₂ levels in 50 years are more than 600 ppm. Indoor CO₂ levels were supposed to be below 1000 ppm, but in response to rising outdoor levels the recommended level has been changed to 700 ppm above ambient levels [18]. Levels more than 1000 ppm often occur in crowded spaces such as classrooms and auditoriums [19, 20].

OZONE

The respiratory system is affected by extreme temperature, air pollutants such as ozone, fine dust and allergens with the result, that asthma, rhinosinusitis, chronic obstructive pulmonary disease (COPD), lung cancer, respiratory infections, and probably also the idiopathic pulmonary fibrosis will further increase [6, 21-23].

Tropospheric ozone is formed by air pollutants such as methane, nitrous oxide and volatile organic compounds under sunlight mainly by photochemical reaction [24, 25]. High temperatures are often associated with dry weather, which causes the increase of ozone levels, especially during hot weather periods. Forest fires, which occur mainly in southern regions of Europe, also generate high amounts of ozone.

Ozone causes a deterioration of lung function [25, 26]. Elevated ozone concentrations may lead to exacerbation of chronic lung diseases, increase in hospital admissions and raised mortality [27-31]. A positive association between ozone and hospitalization of asthma in children was demonstrated during summer months [32]. The combination of ozone and high temperatures, as well as high PM concentrations strengthened the effects on the respiratory system [28, 33-35]. In the future a further increase in ozone is predicted due to global warming [30, 36].

Although by some measures air quality in the United States has improved over recent decades, ozone remains a problem that is related to increasing emissions of methane, carbon monoxide, and nitrogen oxides produced chiefly by transportation-related activities. Numerous studies have linked increased respiratory-related emergency department visits and increased hospital admissions to elevated levels of outdoor ozone [37].

A moderately high annual mean maximum ozone concentration of 60 parts per billion (ppb) is typically seen in large cities of the developed world [37]. This is of great concern, because young children with asthma can begin having symptoms at approximately 60 ppb [37]. Healthy young adults experience significant decrements in lung function and increased inflammation in the airways when experimentally exposed to ozone at 60 ppb [38].

In most US cities, warnings are issued when monitors for ozone reach or exceed 125 ppb, averaged over 1 hour. The warnings are according to the EPA color codes for ozone. An orange warning is issued if 1-hour ozone levels are between 125 and 164 ppb, a red warning between 165 and 204 ppb, and a purple warning between 205 and 404 ppb. Efforts by the EPA to control airborne volatile organic carbon and particle pollution have reduced ground level ozone in the United States for the past 20 years [39].

Currently most large cities in the United States have 10 to 20 orange days a year and 1 to 2 red days a year. Estimates are that by 2030 a much larger area of the globe will experience a background of 60 ppb and that by 2060 most populated areas will have typical ozone concentrations of at least 60 ppb [37]. Despite successful programs aimed at reducing ozone in the United States, ozone is expected to increase worldwide over the next 50 years [37]. However, if large cities around the world succeed in reducing vehicle-based emissions, urban concentrations of ozone may decrease or rise less rapidly [40].

FINE DUST

Climatic factors influence the formation of particulate matters (PM₂.₅-₁₀ and PM₁₀). Although local measures in urban centers are carried out to reduce PM concentrations, the fine dust created by forest fires can be transported over greater distances during heat periods [41, 42]. Short-term fine dust exposure causes an increase of hospital admissions due to respiratory diseases and elevates the mortality rate [43-46]. The exposure of PM over a period of time in children with asthma leads to the deterioration of lung function, an increase in neonatal mortality and to higher mortality in patients with pulmonary carcinoma [47-50].

Particle pollution from household energy is increasingly recognized as an important contributor to climate change. Biomass fuels such as dung, agricultural waste, and wood and the fossil fuel coal are
the primary home energy sources for 50% of households worldwide [51]. The pollution burden from the use of biomass fuels is complex and includes significant black carbon (soot) and GHG emissions. Black carbon is linked to millions of premature deaths annually [52]. This invisible airborne particulate matter absorbs heat from the sun and accounts for 10% to 45% of global warming [51].

Forest fires, which release large amounts of fine dust and GHG such as CO and methane, will occur more frequently due to global warming [41, 42, 53]. Most studies about short-term health effects of forest fires come from Asia, Australia and the United States.

An example of climate change in an area of increasing asthma is the Southwest of the United States. Increasing swings between El Nino (wet winter) conditions and La Nina (dry winter) conditions along with higher year-round temperatures have altered historic forest fire patterns [54]. Heavy undergrowth production in wet years coupled with the death of large numbers of pines during drought conditions in dry years have increased frequency and intensity of forest fires. In addition, at least partially because of warmer temperatures, several species of bark beetles have devastated trees from Alaska to southern Arizona, leaving dead trees ready to burn. Current beetle infestations are the worst in recorded history [55]. The increased fire risk is dramatic. The resulting smoke along with other pollutant activities brought by increasing human habitation has deteriorated respiratory symptoms [56].

In recent years, the American Lung Association has given Maricopa County, Arizona, low grades for air quality. More than 390,000 Arizona adults (12%) were told by a health care professional that they currently had asthma. In addition, approximately 59% of the adults with asthma reported having an episode or attack within the past year [57].

Arizona remains a state with a good quality of life; it has just developed the same air pollution and pollen issues of other states with large cities. Even clean, Rocky Mountain air is not exempt from climate change. Winter pollution season (end of October through end of March) in the Denver metro area brings air quality action days [58].

In Europe only a few studies were performed, although forest fires occur frequently in the southern part of Europe (Greece, Spain, Italy, Portugal). In the greater Athens area an increase of daily mortality due to respiratory diseases over 16% was observed during the forest fires between 1998 and 2004 [59]. An increase in respiratory diseases was described during the forest fires in Lithuania 2002 and Spain 2003 [60, 61]. In 2002 the transport of fine dust and aerosols from the regions of forest fires of Russia, Belarus, Ukraine and the Baltic States resulted in an increased mortality in southern Finland [62].

Due to the world's increasing desertification, more sandstorms are to be feared. The Mediterranean region is particularly hit by sandstorms from the Sahara [63, 64]. PM\(_{2.5-10}\) and PM\(_{10}\) can be transported over thousands of kilometers with the result that in the affected regions hospital admissions and mortality due to respiratory diseases rise especially in older individuals [63-68]. In sandstorms, not only sand dust particles but also allergens, metals (arsenic, mercury), endotoxins [69] and microorganisms are transported (Figure 2).

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<td>Bacillus licheniformis</td>
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Figure 2: Bacteria isolated from dust particles in the Middle East [120].

ALLERGENS

It has already been documented that climate warming and higher carbon dioxide will produce longer pollen seasons [70-75]. The incidence of allergic
diseases such as asthma and rhinitis has increased in recent decades in children and adults particularly in metropolitan areas [76-79]. Although the reason is not clarified in detail, it is assumed that climate change in addition to the genetic predisposition will promote the manifestation of allergies (Figure 3).

In northern Europe trends in airborne birch pollen levels studied over 20 to 33 years indicated that the start for pollen release was significantly earlier in cities from Denmark, England, Belgium, Switzerland, Austria, and the Netherlands [71, 72].

In addition, significant increases in birch pollen were registered from locations in Denmark, England, Switzerland, and the Netherlands [80, 81].

In North America sampling reported significant increases in cumulative seasonal totals of Juniperus, Quercus, Carya, and Betula pollen from 1987 through 2000 [82]. Changes in plant distribution have taken place at high elevations where warmer temperatures permit the growth of trees above the former tree line [80, 82].

Upward migration of plant species has been documented in New Zealand, Bulgaria, Sweden, Switzerland, Spain, Alaska, and California [80, 72].

A northward shift of the US floristic and plant hardiness zones occurred from 1990 to 2006 [83].

The fertilizing effects of increased cabin dioxide on plants have been extensively studied in greenhouse, growth chamber, and whole ecosystem field experiments [84, 85].

Ragweed flowers earlier and produces more pollen in urban locations where carbon dioxide concentrations and temperatures are higher [84].

Experiments indicate that when carbon dioxide levels double, individual ragweed plant pollen production increases by 30% to 90% [73, 75, 84, 85].

The same effect can be seen on other allergenic species [73, 86].

In Germany, the pollen season has extended in the past 30 years because of the milder climate. Therefore, allergy sufferers are exposed to pollen over a larger period of time. Analyses of pollen flight data from 2007 to 2011 compared to 2000 to 2007 indicate an extension of the pollen season. Early bloomers such as Alder and Hazel already release their pollen in December of mild winters. Herb pollen of late bloomer are now detectable until late autumn [87].

Global climate change promotes also the immigration of plants with strong allergenic potential as Ambrosia (Ambrosia artemisiifolia), which is widely distributed in the United States [88, 89]. Ambrosia species are now particularly frequently found in Switzerland, in some regions of France, Hungary and

Figure 3: Possible effects of climate change on respiratory allergy [121].
Italy. Ambrosia can release its pollen already in early June with a peak period from mid-August to early-September. Ambrosia pollen are highly allergenic. Already a concentration of 5-10 pollen/m³ air can trigger rhinitis in sensibilized individuals [89]. In combination with high ozone concentrations, the allergenic effect of pollen is strengthened [90]. During thunderstorms, whose frequency and intensity has increased because of climate change, also allergens in high concentrations are released [76, 91-94].

Due to climate change, increase of extreme rainfall is expected which causes more flooding [95]. The resulting moisture in the affected buildings leads to bacterial and mold growth and causes respiratory infections or after longer exposure exogen allergic alveolitis (pneumonitis) [96-98]. In addition, allergic asthma can be exacerbated by molds and dust mites [99]. Moreover, mycotoxins, endotoxins and volatile organic compounds are formed in the damp buildings, which can cause damage other organs besides the respiratory tract [6, 23].

HEAT WAVES

During summer 2003 heat waves in Europe led to 22,000 to 55,000 heat-related prematurely death cases [100-102]. A more recent estimation calculated 70,000 dead [103]. In Germany, approximately 7,000 died of the consequences of the heat wave [100]. The increase in daily respiratory mortality ranged from 3.9% (Munich) to 92.5% (Milan) [104].

Extensive studies of mortality at high ambient temperatures show that worldwide the daily mortality rate at high temperatures increases. In Europe individuals older than 65 years with respiratory or cardiovascular disease or psychiatric disorders, and single adults were mostly affected. Similar results were described from the United States [105]. The increase of 1°C of the "maximum apparent temperature" above a certain threshold of 23.3°C (Mediterranean cities) and 29.4°C (Northern European cities) was associated with an increase in the daily respiratory mortality rate by about 7% [22, 106].

A current meta-analysis including 21 studies also showed a rise in respiratory daily mortality of 3.2% at a temperature increase of 1°C on hot days. However, no association to cardiovascular mortality was found [107]. The combination of air pollution especially by PM10 and temperature increase revealed a close relationship with the respiratory mortality [108-114]. From 12 European cities using data from 1990 to 2001, a study found that an increase in the "maximum apparent temperature" by 1°C over a defined temperature threshold elevated the daily hospital admissions due to respiratory diseases by 3.1% in Northern European cities and up to 4.5% in Mediterranean cities in the over-75 year old individuals [115].

PROGNOSIS

The emission of the so-called GHG will continue to rise in the coming decades and the global average temperature will increase [3]. For Germany, a temperature rise is estimated of 1°C by 2040, so that the total temperature increase from 1951 till 2040 will be 2°C. By 2100 the global average surface temperature is estimated to increase between 1.1°C and 6.4°C and the sea level may rise up between 28 cm and 79cm [4]. However, these forecasts are controversially discussed [10].

For Germany, it is predicted that the heat-related death rate could increase in the period of 2071 to 2100 to 5,000-8,000 annually [97].

In Europe after the heat wave in 2003 preventive steps were performed to minimize the health risk in particular for groups such as children, elder and sick individuals due to climate change. These include national and regional heat plans, creating heat warning systems and information of the public. Worldwide, the man-made causes of climate change need to be tackled intensively to minimize the global temperature increase, so that for future generations, the health risks of climate change remain bearable [116-119].

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