Chapter 21
The Impact of Climate Change and Air Pollution on the Caribbean

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Abstract A review of air pollution, the impact of climate change on air pollution, and the population health impacts of these in the Caribbean region are discussed. Air quality standards are not usually enforced in many Caribbean countries thereby increasing the risks of morbidity and mortality from exposure to air pollutants. Among people living in the Caribbean, an increase in respiratory diseases such as asthma has been linked to exposure to air pollutants resulting from natural events and especially human activities. Unfortunately, dependence on fossil fuels (regionally and globally), poor land use and waste management, and industrialization all contribute to poor air quality in the Caribbean. In addition, climate change is predicted to exacerbate air pollution and its negative health effects in a region considered to be one of the most vulnerable to global climate change. Key drivers of air pollution in the region are discussed, and recommendations on climate change adaptation and mitigation strategies are highlighted.

Keywords Air pollution • Caribbean • Particulate matter • Air quality • Climate change • Health impacts

Introduction

History is replete with the negative human impacts of air pollution (WHO 2008). Although it is hard to find historical data on air pollution in the Caribbean, there are reports suggesting a long history of air quality issues in the region (de Koning et al. 1985; Romieu et al. 1989; Sanhueza et al. 1982). For example, a 1996 World Bank report on global air pollution from automobiles showed that one of the most industrialized countries in the Caribbean produced leaded gasoline for local use while exporting unleaded fuel (The World Bank 1996, p. 226); by the mid-1990s, the use of leaded gasoline had significantly declined in many developed countries due to public health safety concerns (Nriagu 1990). In a 2005 review of the public

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health impacts of urban air quality in Latin America and the Caribbean, Cifuentes and his colleagues suggested that exposure to particulate matter in 26 cities across the region is "more than twice the US standard"; while ground-level ozone might be a problem in the region, the lack of data made it difficult for the authors to conduct ozone exposure-impact analysis (Cifuentes et al. 2005). Although countries in WHO's Southeast Asia and Western Pacific regions are the hardest hit, a couple of population-based studies across the Caribbean suggests that significant air quality problem still exists in the region (Akpinar-Elci et al. 2015, 2015; Amadeo et al. 2015; Bautista et al. 2009; Brauer et al. 2015; Chafe et al. 2015; PAHO-WHO 2005).

Clean air is considered a fundamental human right globally; unfortunately, air pollution remains a major contributor to morbidity and mortality, especially in developing countries (including Caribbean countries) due to the general lack of air quality regulations and enforcement coupled with socioeconomic, geographic, and climatological factors (Amadeo et al. 2015; Jessamy 2016; Krzyzanowski and Cohen 2008; Macpherson and Akpinar-Elci 2015; Schwindt et al. 2010; Segal and Nilsson 2015; Tanveer et al. 2014). According to WHO, the attributable mortality and disability adjusted life years (DALYs) due to outdoor air pollution in the Americas subregion B (which include states and territories in the Caribbean) were 30 deaths and 307 DALYS per 1000 population; these values exceed the attributable mortality and DALYs (28 deaths and 200 DALYs per 1000 population) reported from their more developed neighbors (the Americas subregion A including Canada and the United States) (Ostro 2004). These statistics are not surprising as air pollution is considered the largest environmental health risk factor globally. In fact, the World Health Organization (WHO) estimated seven million deaths were linked to air pollution in 2012. During the same year, outdoor air pollution accounted for 3.7 million deaths globally (WHO 2014a). It is projected that deaths from air pollution will increase in the future as air quality deteriorates in major cities of low- and middle-income countries. Globally, carbon dioxide (CO2), ground-level ozone, nitrogen dioxide, particulate matter, and sulfur dioxide remain the major air pollutants (Jacobson 2009).

In general, maintaining ambient air quality standards remain a challenge in many parts of the Caribbean (Cifuentes et al. 2005; Jessamy 2016; Prospero et al. 2014). This is likely to be compounded by climate change given that meteorological and climatological factors (including local temperature, wind speed, wind direction, poor air circulation, precipitation, and level of humidity) significantly impact air quality (Jacob and Winner 2009; UNEP 2005, p. 3). Additionally, scientific evidence has emerged suggesting a relationship between long-term weather patterns (the climate) and human activities (IPCC 2007). For example, a change in the climate favoring a rise in atmospheric temperature (either from natural or human activities) is likely to increase the demand for air conditioning especially in tropical climates where the mean daily minimum temperature is typically above 180 °C (Trewin 2014). This invariably increases energy consumption in residential and commercial buildings. Because energy production is largely dependent on the burning of fossil fuels, the downstream effects are an increase in the atmospheric

concentration of air pollutants (e.g., particulate matter such as black carbon) and greenhouse gases (GHG). The long-term cumulative effects of GHG include global warming, an important indicator of climate change (IPCC 2007). Also, there is scientific evidence that a changing climate will alter the concentration of airborne respiratory allergens due to the effect of CO_2 and temperature on plant growth and the health burden of meteorological events such as windblown dust and mold (Gennaro et al. 2014; Gyan et al. 2005; Jacob and Winner 2009; Monteil 2008). Since the Intergovernmental Panel on Climate Change (IPCC) was established to assess the evidence on climate change in 1988, studies on the link between air pollution and climate change have been widely investigated. Similarly, the scientific community ramped up efforts to address air pollution-climate-sensitive health issues. In this chapter, we will review the relationship between air pollution and climate change and their impacts on the health of people in the Caribbean. Small Island Developing States (SIDS) communities constitute around 5% of the global population (AOSIS 2015). Caribbean states are developing economies and represent about half of the Alliance of Small Island States (AOSIS 2015; UN 2012; UNEP et al. 2004). We especially focused on the Caribbean in this chapter due to their large coastal areas and relatively small economies, which makes the region highly vulnerable to the impact of climate change despite contributing little to global greenhouse gas emission (GHG) (CDKN and ODI 2014).

Climate change and air pollution impact a range of health indicators in Small Island Developing States (SIDS) raising problems for economies and national security. While a comprehensive presentation of the scientific evidence is beyond the scope of this chapter, we have tried to highlight some of the key relationships between climate change and air pollution. Although historical events are alluded to in this chapter, our assessment of the air quality issues facing people in the Caribbean (Fig. 21.1.) is based on a review of epidemiologic studies, anecdotal reports, and evidence presented in the 2014 IPCC Fifth Assessment Report. These are followed by suggestions for mitigation and adaptation strategies to combat the negative impacts of climate change.

Sources of Air Pollutants in the Caribbean

Generally, the main cause of air pollution in the Caribbean is human activities including those related to the use of fossil fuels (Akpinar-Elci and Sealy 2014; CDKN and ODI 2014; IPCC 2014). Some air pollutants, particularly GHGs, alter the composition of the atmosphere and worsen the health impact of air pollution on the Caribbean people despite the region contributing relatively little to global GHG emissions (Akpinar-Elci and Sealy 2014; CDKN and ODI 2014; Dodman 2009). As an indicator of urban air quality, the majority of the Caribbean countries reference the WHO Air Quality Guidelines (AQG) for ambient PM2.5 (i.e., 10 μg/m3 annual mean and 25 μg/m3 24-h mean) and PM10 (i.e., 20 μg/m3 annual mean and 50 μg/m3 24-h mean) (Cifuentes et al. 2005; Krzyzanowski and Cohen 2008). However,

Fig. 21.1 Islands in the Caribbean region

air quality data from the Caribbean are sparse; hence, we have to rely on pockets of scientific evidence suggesting that air pollution is still a problem in the region (Amadeo et al. 2015; Bautista et al. 2009; Cifuentes et al. 2005; Gyan et al. 2005; Matthew et al. 2009).

Other than a couple of volcanic air pollution, the process of burning fossil and biomass fuels to generate electricity, and for heating, cooking, and transportation, especially leads to the emission of major air pollutants (including PM2.5, PM10, carbon monoxide, nitrogen dioxide, lead, sulfur dioxide, ground-level ozone, and CO2 in the Caribbean) (Akpinar-Elci et al. 2015; Akpinar-Elci and Sealy 2014; Amadeo et al. 2015; Bautista et al. 2009; Cadelis et al. 2013; Cifuentes et al. 2005; Han and Naeher 2006; Macpherson and Akpinar-Elci 2015; Monteil et al. 2004; UNEP 1998). The sources of these pollutants largely fall into one or more of the fuel types listed in the 2006 IPCC Guidelines which include crude oil and petroleum products (e.g., gasoline), coal and coal products, natural gas, peat, biomass (e.g., wood/wood waste, charcoal, and the biomass fraction of municipal wastes), and other fossil fuels (e.g., municipal waste, industrial wastes, and waste oils) (IPCC 2006).

In the Caribbean, the CO2 emission and contribution to air pollution and climate change of each member state vary widely. For example, Grenada has a small population and economy (population 104,000; gross national income per capita US$ 8430); Barbados is a midsized country (population 256,000; gross national income per capita US$ 18,240); and Trinidad and Tobago is a larger, wealthier, and more industrialized country (population 1,339,000; gross national income per

capita US$ 24,240) (The World Bank 2016). United Nations data show that in 2011, Trinidad and Tobago emitted significantly more CO2 per capita than the United States (37.2 and 16.8 metric tons of CO2 per capita, respectively), while emissions in Barbados and Grenada were significantly lower (5.6 and 2.4 metric tons of CO2 per capita, respectively) (The United Nations 2015). Therefore, air pollution is a huge public health concern in the highly industrialized Trinidad and Tobago. Because of the close proximity of the Caribbean islands, air pollutants from one island travel around the whole region, hence impacting the health of people at distant sites.

According to a recent report, the energy and transportation sectors are responsible for most of the air pollution in Trinidad and Tobago (UNFCCC 2013). In fact, Trinidad, along with the Bahamas and Saint Kitts and Nevis, has one of the highest registered vehicles rate per 1000 population in the Caribbean (WHO 2013). The preponderance of older cars on many islands (Jacobson estimates that 1000 old cars without emission controls produce as much pollution as 100,000 new cars), along with the fact that many of these idyllic places burn sugarcane, winds up causing pollution (Jacobson 2009; The World Bank 1996). Additionally, unhealthy practices such as sugarcane harvesting burning practices and the uncontrolled burning of forest and bushes are not uncommon in the country and in other parts of the Caribbean (Akpinar-Elci, Coomansingh et al. 2015; EMA 2001; Macpherson and Akpinar-Elci 2015). Recent population-based studies and focus group discussion conducted in Grenada found domestic bush burning is a common practice on the island (Akpinar-Elci et al. 2015; Macpherson and Akpinar-Elci 2015). In addition to CO_2 emission, vehicle emissions and ash from bush/forest burning generate a significant amount of fine particles (i.e., $PM_{2.5}$).

Air quality is also impacted by pollutants from natural sources including windblown dust, wildfires, and gases and PM emitted during volcanic eruptions. Of note, air pollutants can originate from a local/regional source or from a distant/global source. Some natural events, such as the transportation of volcanic ash and dust across long distances, have been shown to contribute to air pollution and respiratory diseases in some Caribbean countries. In a 2015 study of air pollution and respiratory health among elementary school children in Guadeloupe, the authors found that the mean PM10 levels in over 70% of the schools exceeded the WHO AQG (Amadeo et al. 2015). There is a high index of suspicion that Saharan dust is responsible for the high PM10 levels in Guadeloupe. Similarly, climate-driven humidity interacting with dust from the Sahara has been shown to produce PM in Barbados, Grenada, Trinidad and Tobago, and US Virgin Islands, hence increasing visits to the emergency department due to exacerbated asthma in the Caribbean (Akpinar-Elci et al. 2015; Garrison et al. 2014; Gyan et al. 2005; Monteil 2008). Furthermore, ash from the Soufriere volcano in Montserrat was linked to an increase in asthma admissions in Guadeloupe after it erupted in 2010 (Cadelis et al. 2013). It is worth noting that the particle size of Saharan dust varies from less than 5 μm (as reported in studies from Barbados and Bermuda) to between 5 and 30 μm (Goudie and Middleton 2001). Similarly, studies have shown the particle

size of fine volcanic ash/dust (an admixture of PM, toxic gases like sulfur dioxide, and water vapor) to vary up to less than 60 μm (Lowe and Hunt 2001).

Air pollutants that are released directly into the atmosphere are classified as "primary pollutants" and are a source of indoor and outdoor air pollution in parts of the Caribbean (PAHO-WHO 2005). Fine particulate matter (e.g., particles less than 2.5 μm [$PM_{2.5}$]) has been reported to occur from indoor activities such as smoking, "cooking, cleaning, and other general activities involving either combustion (e.g., candles) or resuspension (e.g., any physical movement such as walking, dusting, vacuuming, etc.)" (Long et al. 2000). Direct exposure to $PM_{2.5}$ from cooking stove, for instance, is particularly common among low-income populations, as was found in a 2009 study of children in parts of the Dominican Republic (Bautista et al. 2009).

On the other hand, secondary pollutants are formed in the atmosphere following a series of photochemical reactions. Although studies suggest that the atmospheric concentration of secondary pollutants (especially ground-level ozone) in the Caribbean is less compared with developed countries, industrialization and increase in fossil fuel-powered vehicles in countries like Trinidad and Tobago may reverse this trend (Amadeo et al. 2015). Both short- and long-term exposures to ozone increase the risk of morbidity and mortality from cardiovascular and respiratory diseases (Bell et al. 2005).

Overall, domestic and commercial activities including the use of fossil fuels are likely to contribute more to air quality problems in the Caribbean, especially as the demand for energy increases as population grows. However, if Caribbean countries and the global community adopt the "stringent mitigation scenario," in addition to effective adaptation strategies, air quality in the region is likely to improve in the near future (Akpinar-Elci and Sealy 2014; IPCC 2014).

Air Pollution, Climate Change, and Health Effects

The human health impact of air pollution on the Caribbean people is well documented. According to a USAID 2009 report: "The burden of disease associated with non-communicable chronic diseases (NCDs) is greater than the burden of disease associated with communicable diseases or injuries in Latin America and the Caribbean (LAC); however, much less attention has been given to NCDs" (Anderson et al. 2009). Current literature reports smoking, allergy, infection, tropical climate, diesel exposure, charcoal smoke, mite, and Sahara dust as risk factors for asthma in the Caribbean (Bautista et al. 2009; Calo et al. 2009; Ivey et al. 2003; Matthew et al. 2009; Milián and Díaz 2004; Monteil 2008; Monteil et al. 2004). Outdoor air pollution is particularly a major public health concern in the Caribbean with a 2014 ambient air pollution data from the WHO showing the annual mean concentrations of $PM_{2.5}$ in some Caribbean countries were above the recommended annual mean of 10 μg/m3 (WHO 2014b) (Fig. 21.2.).

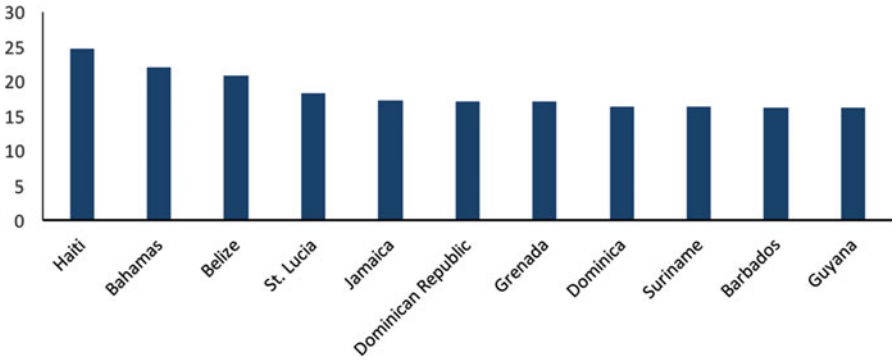

Fig. 21.2 Caribbean countries with annual mean concentrations of $PM_{2.5}$ in urban areas exceeding the WHO recommendation of 10 μg/m^3 (Source of data: WHO http://gamapserver.who.int/gho/interactive_charts/phe/oap_exposure/atlas.html)

There is a growing concern that climate change will exacerbate the human health impacts of air pollution among the Caribbean people (Macpherson and Akpinar-Elci 2015). Climate change is predicted to impact air quality by altering the concentration and distribution of major air pollutants particularly CO_2, ozone, fine particulate matter, and aeroallergens. For example, extreme weather events (including hurricanes, heavy precipitation, and flooding) in the Caribbean create environments conducive for mold, mildew, and other bioaerosols (Ivey et al. 2003; Milián and Díaz 2004). The complex relationship between air-polluting GHGs, climate change, and health is another public health issue. Based on evidence presented in the 2014 IPCC Fifth Assessment Report, the global impact of climate change over the last few decades is significant. According to the report, there is high confidence that climate change will have a major impact on terrestrial ecosystem (i.e., forests) of small islands, hence increasing atmospheric carbon concentration via a reduction in natural carbon sinks. This scenario is likely to be exacerbated by poor land use management, indiscriminate forest and bush burning practices, urbanization and industrialization, rapid population growth, and an increase in energy demand by the Caribbean people and tourists.

In the 2014 Office of Evaluation and Oversight of the Inter-American Development Bank (OVE) evaluation of climate change in nine Caribbean countries (including the Bahamas, Barbados, Belize, Dominican Republic, Guyana, Haiti, Jamaica, Suriname, and Trinidad and Tobago), OVE found that the use of fossil fuels for the production of electricity accounts for 60% of GHG emissions in these countries (OVE 2014). In addition, the report found that 90% of the power plants in the nine countries depend on fossil fuels making electric power generation the largest contributor to air pollution in the Caribbean. The process of burning fossil fuels to generate electric power leads to the release of CO_2 (a major GHG and that is also essential for plant growth), sulfur dioxide, and nitrogen oxides (a precursor of ozone, an air pollutant that affects cardiovascular and respiratory health) (Elenikova et al. 2008).

Extrapolating from studies conducted in other parts of the world, climate change is predicted to affect the respiratory and cardiovascular health of populations across the Caribbean. The impact on the population's health will result from increases in environmental exposure to PM (e.g., black carbon, soot, and Saharan dust), pollens, mold, other bioaerosols, and ground-level ozone. $PM_{2.5}$, for instance, has been proposed to induce and worsen inflammation and oxidative stress in both the pulmonary and cardiovascular systems (Brook et al. 2010). Aeroallergens also affect respiratory health by inducing inflammatory reaction in the respiratory airway. Studies suggest that increased atmospheric CO_2 levels is associated with an increase in ragweed, an allergenic and immunogenic weed that flourishes in tropical and subtropical climates and native to Guadeloupe, Jamaica, and Martinique (CABI 2016; Ziska et al. 2011). Unfortunately, aeroallergens from pollen-producing plants are expected to rise in the future (Richter et al. 2013).

Adaptation Strategies to Climate Change

According to IPCC, an integrated approach to climate adaptation and mitigation is the best way to combat climate change (IPCC 2014). With regard to air pollution, atmospheric pollutants in most Caribbean countries are either generated locally (e.g., from automobiles), while most result from activities at distant sites (e.g., Sahara dust, GHGs emitted by "heavy polluters," and volcanic eruption). Considering the relatively lower socioeconomic and political status and the low carbon footprint of Caribbean countries in general, the Caribbean people need the collaboration of the global community in implementing climate mitigation and adaptation strategies in the region. We believe these strategies should include (1) the enactment of laws and regulations targeted at reducing uncontrolled forest, bush, and trash burning [e.g., sustainable municipal waste management, improved land use management, and agricultural practices such as reforestation], (2) investment in sustainable and green technologies that reduce dependence on fossil fuels, (3) strengthening of public health infrastructure and surveillance systems, and (4) education of the population on the health risks of air pollution and climate change.

The Nairobi Work Programme of the United Nations Framework Convention on Climate Change (UNFCCC) also recommends a number of good practices in the adaptation planning process. These include engaging members of the community in the development of a structured and iterative knowledge base, establishing monitoring systems that are participatory to provide a consistent and reliable source of information, leveraging technology to increase the capacity of the health sector to respond to climate change variability, and raising public awareness of the potential health risks under a changing climate and the need for taking action to address these risks (UNFCCC 2015).

Conclusions

In summary, the burden of air pollution on the Caribbean people will increase with climate change, unless stringent measures are taken at the community, country/government, and global levels. Particularly, given the established human health effects of air pollutants such as ozone, environmental surveillance of these pollutants and longitudinal studies of their impact on the health of populations across the Caribbean are recommended. Finally, how climate change is likely to influence the effects of air pollution on states and territories in the region should be considered.

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