Research for Action on Climate Change and Health in the Caribbean:
A Public, Private, People's and Planetary Agenda

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5. AIR QUALITY

5.1. WHAT IS HAPPENING?

The burden of disease attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diets and tobacco-smoking. In 2015, the World Health Assembly adopted a resolution on air quality and health. The resolution recognises air pollution as a risk factor for noncommunicable diseases (NCDs) such as ischaemic heart disease, stroke, chronic obstructive pulmonary disease, asthma and cancer, as well as the economic impact of the toll air pollution takes on human health (WHO, 2021). Air pollution can also shorten survival in people with lung cancer (Eckel et al., 2016). It can contribute to the spread and aggravate the symptoms of communicable respiratory diseases such as COVID-19, as demonstrated in Latin American and Caribbean countries (Bolaño-Ortiz et al., 2020). People who are highly susceptible to illnesses resulting from air pollution include those with pre-existing respiratory or cardiovascular diseases, older people, infants and children. Outdoor workers are highly exposed (US Centers for Disease Control and Prevention, 2019). There is evidence that air pollution is a major cause of premature birth, low birthweight and stillbirth (Bekkar et al., 2020). Air pollution affects air quality, and food, water and economic security, both directly through its negative effects on public health, agriculture and ecosystems, and indirectly through its impact on the climate (Kumarsingh, 2021).

In this chapter, we mainly address toxic air pollutants. These have direct adverse effects on human health. We also touch on climate pollutants, most of which indirectly harm human health because they contribute to climate change, either as greenhouse gases (GHGs) or by absorption of solar radiation because they have low albedo.

Weather conditions influence the transportation, distribution and concentration of airborne pollutants. Climate change affects human exposure to air pollutants by:

- Changing weather patterns, which influence local and regional concentrations of pollutants;
- Changing human-made emissions, including through adaptive responses involving increased fuel combustion;
- Affecting natural sources of air pollutants;
- Changing the distribution, types and amounts of airborne allergens (Taylor et al., 2010);
- Causing wildfires (by exacerbating heat and drought), which emit particulate matter and other toxic air pollutants.

As an example of how climate change is affecting humans' exposure to air pollutants through an adaptive response, air conditioning (AC) is highly protective against heat-related mortality and morbidity, and its use is increasing as temperatures rise. This is increasing human-made GHG emissions and toxic air pollution from fossil fuels used to generate the electricity to power AC systems (unless alternative sources of energy are used). AC systems also use hydrofluorocarbons (HFCs), which are potent GHGs used for refrigeration, and which may escape into the atmosphere (Dubrow, 2021).

Anthropogenic GHG emissions are the main contributor to climate change, with the main climate pollutants being carbon dioxide, methane, nitrous oxide and fluorinated gases. Measures to reduce GHG emissions have health co-benefits because they also reduce toxic air pollutants, most notably ground-level ozone precursors and particulate matter emitted from burning fossil fuels (Kumarsingh, 2021). Such measures are detailed in Section 5.2, "What should be done?".

The main types of toxic air pollution of concern can be classified as follows:

- Particulate matter, including Saharan dust;
- Harmful chemicals and gases;
- Airborne organic matter, including pollen, mould, viruses, bacteria and small insects.

Often, more than one type of air pollution is present at the same time, and weather conditions such as extreme heat can magnify their negative impacts. Furthermore, natural phenomena can add to pollution. Examples are Saharan dust (discussed later in this subsection) and volcanic eruptions, such as the Soufrière Saint Vincent eruption of December 2020–April 2021. The ash plume from the volcanic explosion was blown eastwards and large quantities of ash fell on Barbados, causing respiratory problems among inhabitants and other challenges on this island and Saint Vincent and the Grenadines.

Particulate matter is a mixture of solid and liquid particles in the air that are small enough not to settle on the Earth's surface under the influence of gravity, and are classified according to their aerodynamic diameter (WHO, 2021). Health effects are strongly linked to particle size. Very small particles, with an aerodynamic diameter equal to or less than 2.5 µm ($PM_{2.5}$), are the most dangerous, as they can be inhaled deeply into the lungs and pass into the bloodstream. The inhalation of $PM_{2.5}$ is associated with lung and heart diseases, including heart attacks, the aggravation of chronic conditions such as asthma and bronchitis, and elevated all-cause mortality (Taylor et al., 2010; Xing et al., 2016). Long-term exposure is associated with an elevated risk of infant mortality, low birthweight, diabetes, dementia and death from lung cancer (American Lung Association, 2022; Liu et al., 2021). Large particles, with an aerodynamic diameter equal to or less than 10 µm (PM_{10}), can irritate the nose and eyes and increase rates of respiratory diseases (US Centers for Disease Control and Prevention, 2019).

In the Caribbean, key sources of particulate matter are bush and forest fires (increasing owing to rising temperatures), the burning of waste, the combustion of fossil fuels and Saharan dust. Fossil fuel use in transport is a major source of exposure in the Caribbean. The use of wood-burning stoves is a source of indoor exposure for some women on low incomes (WHO and UNFCCC, 2021). Following Hurricanes Irma and Maria in 2017, there was an increase in the incineration of waste because of the massive amount of debris resulting from damage to property and vegetation. In addition, there were delays in the removal of organic waste from homes due to damage to roadways. In Dominica, the disposal of downed trees by chopping and shredding released wood dust into the air. Dust may also increase because of construction to rebuild infrastructure damaged by severe weather events (Allen et al., 2019; CARPHA, 2018).

Saharan dust, a complex form of particulate matter containing both $PM_{2.5}$ and PM_{10}, is composed of organic and mineral matter, chemicals, and viruses and bacteria, has been blown across the Atlantic to the Caribbean for hundreds of years. It has some beneficial properties, contributing important nutrients to marine and terrestrial species (Mendez-Lazaro, 2021). It is predicted that increased atmospheric and sea surface temperatures may decrease wind speeds and the amount of Saharan dust that reaches the Caribbean, causing concern about biodiversity loss and damage to agriculture and fisheries (Kumarsingh, 2021). On the other hand, desertification in Africa, caused in part by climate change, may result in increased amounts of Saharan dust.

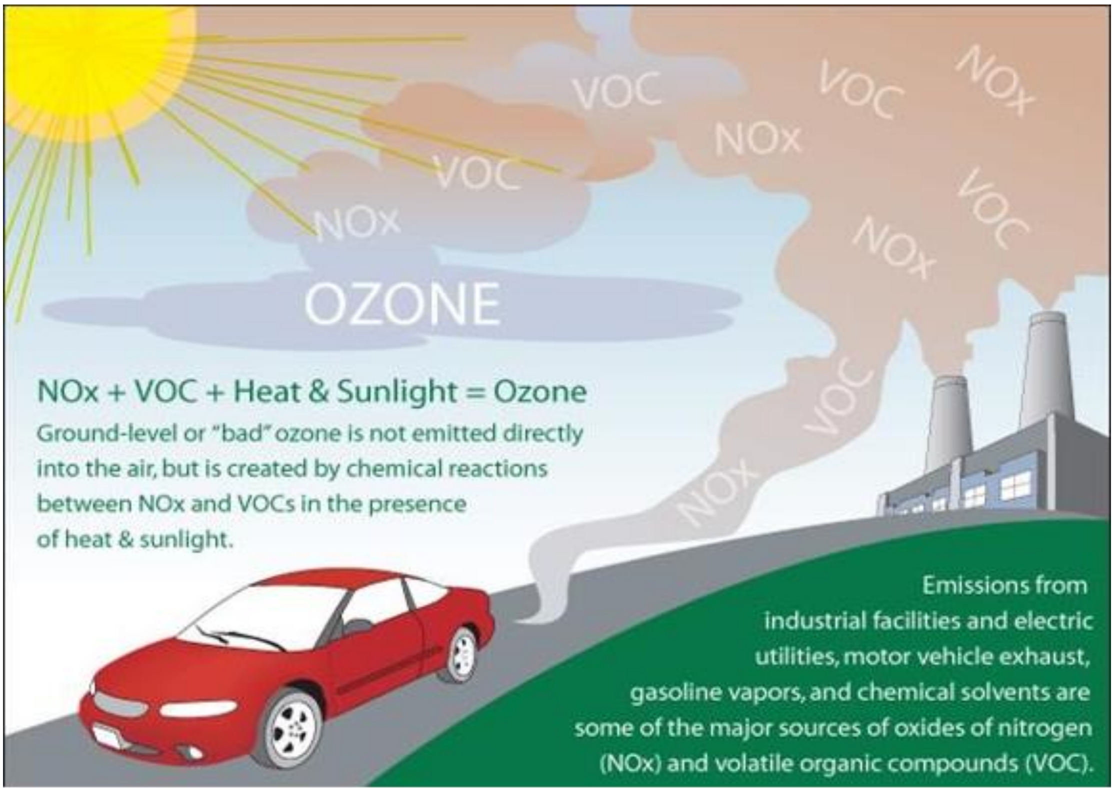
Several constituents of Saharan dust have negative health impacts, and PM_{10} concentrations have been found to exceed World Health Organization (WHO) guidelines at some times of the year (Sealy, 2021). A variety of chronic and acute conditions may result from exposure to Saharan dust (Mendez-Lazaro, 2021; Monteil and Antoine, 2009; Prospero et al., 2008, 2009, 2014). In the Caribbean, Saharan dust has been shown to be associated with seasonal allergies (with the vast majority of dust arriving between April and September), and health crises among people with asthma (Akpinar-Elci et al., 2015; Cadelis et al., 2014; Gyan et al., 2005). Furthermore, exposure to the dust may increase the risk of meningococcal meningitis because of bacteria carried in the dust (Yarber et al., 2023). The levels of dust in the air are sometimes thick enough to impair visibility, making road conditions hazardous (Bozlaker et al., 2017; Mendez-Lazaro, 2021). In an island-wide survey in Puerto Rico following the massive, so-called Godzilla Saharan dust event that took place there in June

2020, nearly 90% of respondents reported that their health had been negatively affected. However, only 12% visited a physician owing to Saharan dust complications. Asthma was the most reported condition (55%), and many reported postnasal drip, red or itchy eyes, shortness of breath and fatigue (Mendez-Lazaro, 2021).

Harmful chemicals and gases, most notably ground-level (i.e. tropospheric) ozone, may be by-products of industrial and domestic activities as well as natural processes. Natural processes may themselves be altered by climate change. For instance, climate change has altered the balance of nutrients in the ocean. This has led to the proliferation of *Sargassum* seaweed around Caribbean coastlines, gathering in piles on beaches. As the seaweed decays, it releases the toxic gas hydrogen sulphide (Dubrow, 2021).

Ground-level ozone is an important concern in the Caribbean, given the heavy use of fossil fuels in hot conditions (including in vehicular transport and industrial activities) and the high level of urbanisation (World Bank, 2021). It is formed when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants and other sources (including some natural sources) chemically react in the presence of heat and sunlight (Figure 1). Ground-level ozone, which is most likely to reach unhealthy levels on hot, sunny days in urban environments, is projected to increase with rising temperatures. Inhaling ozone can cause coughing, shortness of breath, asthma, bronchitis and other lung diseases, irritation and damage to airways, and premature death from lung diseases. In addition, it can increase the severity of asthma (United States Environmental Protection Agency, 2022). Ground-level ozone is also harmful to vegetation and can reduce agricultural production (Kumarsingh, 2021).

Figure 1: Ground-level ozone formation



Source: United States Environmental Protection Agency (2022).

Airborne organic matter can cause disease, especially when present in higher quantities than previously experienced. As mentioned, viruses and bacteria may be present in Saharan (and other) dust. It is forecast that in a climate-changed future there will be higher concentrations of airborne allergens, such as pollen and moulds. This is predicted to increase the incidences of asthma and allergies (Hambleton, 2008). High aridity caused by rising temperatures may increase the concentration of particulate-carried fungal spores in the air, increasing the potential for pulmonary and systemic fungal infections (Taylor et al., 2010). The predicted combination of more episodes of flooding and hotter conditions in the Caribbean may increase air pollution, as mould and other pathogens that grow on walls and other materials in the aftermath of floods are dried and carried in the air (Dubrow, 2021).

Finally, most **climate pollutants** do not directly affect health, but harm health because they contribute to climate change. Methane is the second most important anthropogenic GHG. Important anthropogenic sources of methane are animal agriculture (especially concentrated animal feeding operations), fossil fuel production and consumption, and the decomposition of organic waste. HFCs used in AC and refrigeration leak into the atmosphere. Black carbon $PM_{2.5}$ (i.e. soot), formed by the incomplete combustion of fossil fuels, is a climate pollutant that directly harms human health and contributes to climate change by absorbing solar radiation. Ground-level ozone is another pollutant that both directly harms human health and contributes to climate change (as it is a GHG). Carbon dioxide is, of course, the main anthropogenic climate pollutant. Measures to reduce carbon dioxide emissions, most notably transitioning from using fossil fuel energy to renewable energy, are closely linked to a reduction in the emission of toxic air pollutants from the burning of fossil fuels.

Primary research on air quality and health in the Caribbean has focused on the impacts of Saharan dust more than any other pollutant, with some exploration of other correlates of respiratory illnesses such as pollen counts and humidity (CARPHA, 2018; Rise et al., 2022). To date, research in the Caribbean has concentrated on hospital admissions for asthma during Saharan dust events, with varied results as to whether the events lead to significant increases in admissions (Akpinar-Elci et al., 2015; Cadelis et al., 2014; Gyan et al., 2005; Hambleton, 2008; Monteil and Antoine, 2009; Prospero et al., 2008, 2009). Climate change has been mentioned as an associated factor but has not taken centre stage. Toxic air pollutants are a major cause of morbidity and mortality. Climate pollutants emitted together with these pollutants are the primary cause of climate change, and climate change itself has significant effects on air pollution, all with consequences for the health of Caribbean people that extend beyond the scope of the current research.

5.2. WHAT SHOULD BE DONE?

Individual and community actions and how to support them

Provide knowledge and economic incentives to enable individuals and communities to reduce their air-polluting activities

Individuals and communities should be provided with information about how to reduce their own air-polluting activities along with incentives to do so. Nongovernmental organisations and community groups can play important roles in raising awareness and improving knowledge through face-to-face interactions, the media and electronic communication. Most importantly, actions that decrease fossil fuel consumption, which reduces the emission of both GHGs and toxic air pollutants, should be facilitated. These actions include, but are not limited to, installing (ideally with the use of government incentives) rooftop solar panels on homes and solar arrays in communities, promoting the use of electric vehicles, promoting active transport (i.e. walking and cycling) and instituting measures to increase energy efficiency and conservation. Governments should actively encourage the use of clean sources of energy.

In Barbados, tax breaks are available for people who install solar panels on their homes, and some charging stations for electric cars have been installed in public areas such as car parks. Demand for electric and hybrid vehicles, which are more efficient than and substantially less polluting than conventional internal combustion engine vehicles, remains low in the Caribbean owing to their relatively high prices. This is despite local governments beginning to provide fiscal incentives for the purchase and importation of such vehicles. To facilitate individual and community action, the price of clean energy and clean vehicles should be decreased to below that of fossil fuels. Other examples of individual and community actions are recycling food waste to create compost and thereby reduce methane gas at landfills; and facilitating the planting and care of plants and trees, which absorb carbon dioxide.

Alternative fossil fuel products have been developed and are now marketed in Caribbean countries. Liquid petroleum gas and compressed natural gas emit fewer hydrocarbons and particulates, and less carbon dioxide, and contribute less to ground-level ozone than conventional petroleum (Bielaczyc et al., 2016). However, the production chain for these products has been found to consume even more energy than conventional petroleum, and natural gas systems leak methane (Zhiyi and Xunmin, 2019). Therefore, these products do not provide a solution to the generation of air pollution in the production and consumption of fossil fuels.

Personal protection against air pollution

Individuals should be encouraged to adopt personal protective measures if levels of air pollution are elevated, for example because of wildfire events, particularly if they have pre-existing conditions, such as asthma, that render them vulnerable. Public agencies are responsible for releasing accurate and clear information about air quality and advice regarding health protection. Residents should keep track of air quality and adjust their behaviour and exposure accordingly. If an area is likely to be exposed to extremely high levels of toxic pollution, owing to an event such as a wildfire, the temporary relocation of residents may be necessary. This relocation requires the support of public agencies and community collaboration. A level of protection from ambient air pollution may be afforded by staying indoors and closing doors and windows, setting air conditioners to recirculation mode, using portable air cleaners, and using central air conditioners with filters. A limitation is that most air filters reduce exposure to particulate matter but not gaseous pollution. Heavy and prolonged physical activity should be avoided when air pollution levels are high. Wearing certain types of face masks (N95, PN95, KN95 and P100) can reduce exposure to particulate matter, viruses and bacteria, but not gaseous pollutants (Xu et al., 2020).

Structural/governmental and private sector actions

Develop a strong framework of government regulation and support

A strong framework of government regulation and support is needed to enable the individual and community actions required to achieve reductions in air pollution and associated diseases. The Intergovernmental Panel on Climate Change's Sixth Assessment Report notes that improving air quality through increasing the use of renewable energy sources is a highly effective measure that both reduces GHG emissions and benefits health and well-being. It also notes that there are major gaps between policy and action in addressing the interrelationships between air quality and climate risk. This indicates that, in addition to strong policies, enabling and reinforcing actions are needed from governments to improve air quality (IPCC, 2022).

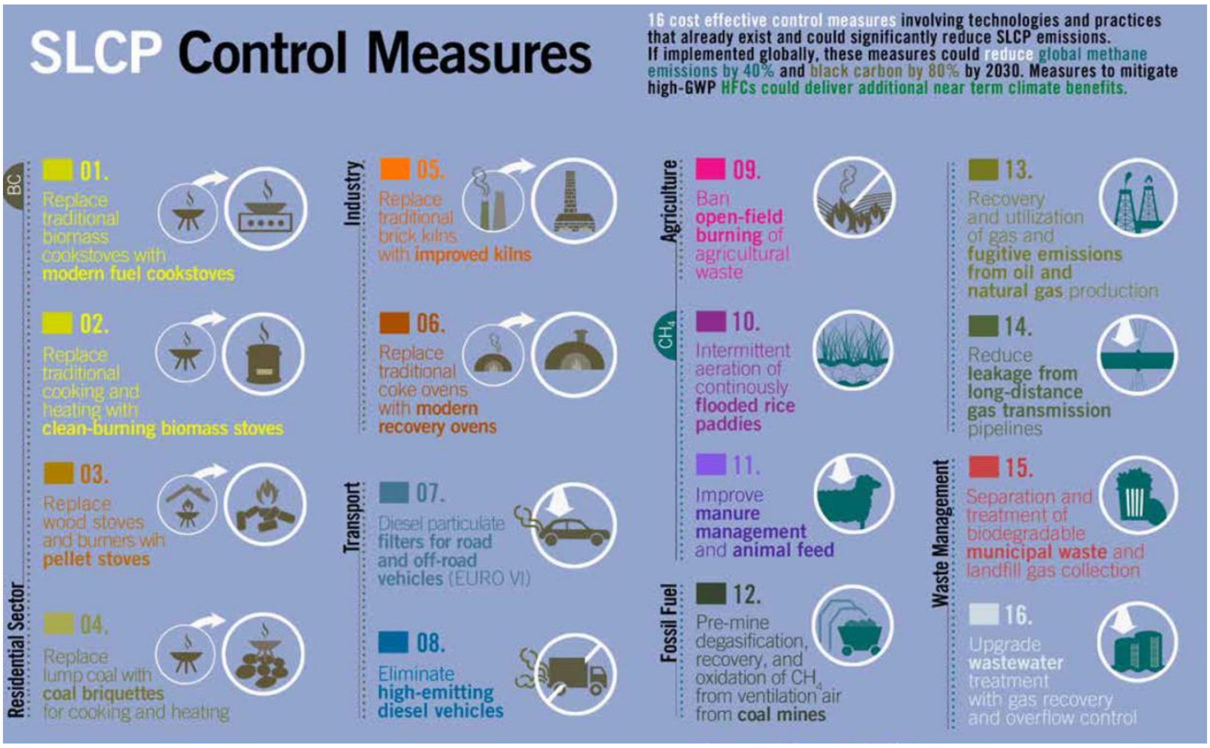
Specific recommendations are as follows:

- Develop coherent multisectoral policies and actions across the transport, industry, power generation, waste and wastewater management, agriculture, buildings and land use sectors for preventing air pollution. Most important are mandatory targets for transitioning from a fossil-based economy to a renewable energy-based economy (IPCC, 2022). Given the Caribbean's bountiful supply of free sunlight and wind, it is especially well-suited to a productive renewable energy-based economy that will substantially reduce both climate pollutants and toxic air pollutants.
- Establish and enforce air quality standards, in line with WHO air quality guidelines (WHO, 2021).
- Set a standard and example by aggressively reducing climate and air pollutants by converting to renewable energy in government facilities.
- Implement the package of control measures to reduce short-lived climate pollutants (black carbon, methane and HFCs) recommended by the World Meteorological Organization and the United Nations Environment Programme (UNEP). This package includes measures for households; industry, including the fossil fuel industry; transport; and waste management. Some of the measures are illustrated in Figure 2.

The UNEP reported in 2017 on actions taken by 12 Caribbean governments[1] to improve air quality, in the areas of industrial activities, road transport, open waste-burning, indoor air pollution and general legislative efforts. Its assessment showed that action was still required in most of these areas in most Caribbean countries. However, in six (half) of the countries, government incentives were in place to minimise industrial emissions. A couple of examples from Barbados are notable. The Renewable Energy Rider initiative allowed customers who use renewable energy to sell excess energy generated from renewable sources to the Barbados Light & Power Company Limited. Barbados has a zero value-added tax rate on all renewable energy and energy-efficient systems and products; in addition, developers, manufacturers and installers of renewable energy products are granted a 10-year income tax holiday. Puerto Rico has similar incentives.

[1]The following countries were included in the assessment: Antigua and Barbuda, the Bahamas, Barbados, Cuba, Dominica, the Dominican Republic, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, and Trinidad and Tobago.

Figure 2: Recommendations to reduce short-lived climate pollutants



Sources: Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (2022).

In the area of transport, the UNEP reported poor progress. Only two countries had implemented initiatives to expand their public transport system and thus reduce the number of vehicles with harmful emissions. Only one country had implemented vehicle emission standards. Only two countries had established fuel quality standards that restricted sulphur content to below 500 ppm (United Nations Environment Programme, 2017). The UNEP report revealed major gaps in progress in addressing causes of air pollution with major health impacts. There is a need to update this assessment and conduct further analyses to assess progress over time.

Resources needed to support government actions include technical support to develop and implement monitoring systems (see the subsections "Research gaps and how to address them" and "Surveillance gaps and how to address them"), improved information technology systems to support the sharing and dissemination of information, and mechanisms to improve collaboration between agencies (R4ACCHC, 2023).

Support the development of green spaces and active transport to maximise the health co-benefits of climate change mitigation

Developing parks, woodlands, bicycle lanes, walkways, and linear parks along canals, rivers and streams helps reduce the risk of NCDs by providing opportunities for physical activity, while contributing to ensuring clean air and reducing GHG emissions. However, it is important to assess the extent to which active transport is a viable option for mass transportation, given that the Caribbean climate may be too hot for many to walk or cycle to workplaces and schools. Therefore, nature-based solutions and green infrastructure that provide cooling are essential. Shaded bicycle lanes and walkways should be part of urban design in the Caribbean. Integrated transport policies that reduce the use of single-occupancy vehicles and the associated air pollution should be developed, including use of renewable energy for vehicular transport and support of public transport and car-pooling (Gordon-Strachan, 2021). Further details are provided in Chapter 15, "Climate-friendly health-promoting infrastructure".

Provide resources for education, adaptation and mitigation

Private enterprises, governments, and regional and international agencies should provide expertise and financial support for the necessary measures. These include developing green spaces and providing an enabling environment for active transport, as detailed in the previous paragraph. To support individual and community action, resources are needed for public education and communication, making use of information tools such as early warning systems (EWSs). Information tools can be developed to encourage users to make choices that will lower their carbon footprint. Entrepreneurs can spearhead the development of tools, products and services that can facilitate risk communication and a reduction in air pollution. Governments should provide fiscal incentives for individuals and businesses to develop and adopt sustainable technologies. The burning of solid waste can be reduced by implementing policies to provide more recycling and waste disposal facilities (R4ACCHC, 2023).

Research gaps and how to address them

Research on patterns and trends in respiratory, cardiovascular and other illnesses in relation to air quality

The prevalence of asthma appears to be high in the Caribbean, yet there are few published data on patterns and trends in respiratory illnesses in relation to air quality. It is recommended that data are collected on topics including:

- Geographic and socioeconomic characterisation of communities that are most exposed to toxic air pollution in the Caribbean (R4ACCHC, 2022a);
- The role of natural sources of air pollution such as Saharan dust, as well as mould, pollen and spores resulting from hurricanes and floods, in the exacerbation of asthma and other respiratory diseases;
- Characterisation of the pathogens associated with Saharan dust;
- Effects of climate change on asthma incidence and exacerbation;
- Whether drought-induced increases in atmospheric concentrations of fungal spores increase the incidence of fungal infections (Dubrow, 2021);
- How above-normal heat affects ground-level ozone and particulate matter concentrations and the incidence of respiratory illnesses in the Caribbean;
- The relative contributions of climate change and human behaviour to wildfire outbreaks, determined by assessing the degree to which wildfires can be attributed to spontaneous combustion (due to increased heat and dryness resulting from climate change) compared with specific human actions (such as fire suppression or electric utility malfunctions) (R4ACCHC, 2023);
- Levels of household air pollution in different geographical locations, contributors to household air pollution and control measures that could be implemented (R4ACCHC, 2023).

Research is needed on patterns and trends in admissions to healthcare facilities, including outpatient care facilities, emergency departments and hospitals in general, related to air quality. More research is needed on admissions for a variety of air quality-related NCDs (respiratory and cardiovascular diseases, and others, such as diabetes and neurological diseases, for which there is not yet conclusive evidence of the effect of air pollution), as well as for infectious diseases (including COVID-19). Admissions and outcomes should be mapped against ambient air conditions and levels of specific pollutants (Gordon-Strachan, 2021; Mendez-Lazaro, 2022). To facilitate this research, air quality surveillance systems must be strengthened, as detailed in the subsection "Research and surveillance capacity-strengthening needs".

Research on links between climate change and Saharan dust

Research is needed to better understand whether/how climate change affects the amount and timing of the arrival of Saharan dust clouds in the Caribbean. It is also important to examine the effect of Saharan dust, if any, on Atlantic/Caribbean hurricanes. The association of Saharan dust events with respiratory disease symptoms and outcomes should be closely monitored (R4ACCHC, 2022b).

Operational research

To strengthen action to address air quality and health challenges, it is important to assess the state of play, answering questions such as the following through research (Gordon-Strachan, 2021):

- What is the current state of air quality monitoring in the Caribbean?
- What pollutants are monitored?
- Are the monitoring sites appropriately placed?
- Is the monitoring equipment up to date?
- What is the quality of the data?
- Who is responsible for collecting the data?
- How are the data used?
- What are the reporting requirements and are they being met?
- How is the information gathered incorporated into decisions made about the populations affected and the health services delivered?
- What are the legal (guidelines) and policy frameworks?
- How can we involve service providers and goods producers (not just policymakers) in actions to improve air quality?

Citizen science and action research

Individuals, communities and organisations can be engaged in research, fostering learning, knowledge exchange and public engagement on air pollution. For example, since the 2017 hurricane season in the Caribbean, community-based organisations in Puerto Rico have promoted actions to advance social transformation, sustainable development, community trust and cohesiveness, and social capital (Holladay et al., 2021). As another example, the organisation UrbanBetter works in African cities to promote sustainable urban environments for better health. UrbanBetter established the #Cityzens4CleanAir Campaign, whose members, known as Run Leaders, are mainly university students and members of running clubs. Their strategy is to use evidence collected during runs to advocate for both physical activity and clean air. Air quality is measured along running routes by attaching air quality monitors to the runners. The data they collect from routes around their cities provide evidence to advocate for improving air quality and promoting physical activity. To coincide with the youth and science-themed days at the 2022 United Nations Climate Change Conference (COP27), they carried out a social media campaign to highlight the effect of air pollution on both health and the climate, the inadequacy of air pollution measurement in most cities, the inequalities within cities in relation to air pollution and the critical role that young people can play in devising ways to reduce air pollution (UrbanBetter, 2022).

Similar strategies could be deployed in the Caribbean, especially given the popularity of running and the high level of urbanisation in the region.

Surveillance gaps and how to address them

Produce temporally and spatially granular air quality data

To ramp up research on climate change and health in the Caribbean, and to develop EWSs, it is critical to have a system that collects air quality data that enables comparisons among places and over time (Dubrow, 2021). Investments in newer technologies are needed to capture air pollution trends at a granular level (R4ACCHC, 2023). The major air pollutants listed by the WHO ($PM_{2.5}$, PM_{10}, ozone, nitrogen oxides, sulphur dioxide and carbon monoxide) should be monitored throughout the Caribbean (WHO, 2022). In addition, monitoring of Saharan dust is critical, specifically in the Caribbean. Furthermore, the antigenicity of components of dust, which carries allergens including pollen and insect parts, should be monitored (R4ACCHC, 2022a, 2023). State-of-the art air quality monitoring facilities and expertise are needed to achieve these goals. Box 1 provides examples of initiatives in various Caribbean countries.

Box 1: Examples of surveillance and communication activities related to air quality in the Caribbean

The Dust and Air Quality Forecasting Centre was established at the Caribbean Institute for Meteorology and Hydrology. It is based in Barbados, and covers the whole Caribbean region, parts of central and northern South America and dust source regions in North Africa. Seven-day forecasts are provided for dust, visibility associated with dust concentration, PM_{10}, $PM_{2.5}$ and ozone. The institute hosts the Regional Office for the Americas of the World Meteorological Organization's Sand and Dust Storms Advisory and Assessment System (Sealy, 2021).

In Trinidad and Tobago, the Environmental Management Authority set up the Ambient Air Quality Monitoring Network using data from five monitoring sites throughout the country. These monitor various air pollutants and meteorological parameters to generate an air quality index that provides real-time information to the public. In 2020, Trinidad and Tobago became the first Caribbean country to join the BreatheLife campaign. It pledged to reach an interim air quality target for fine particulate matter based on WHO air quality guidelines by the end of 2025, achieving this through action across the economy (Environmental Management Authority Trinidad and Tobago, 2020).

Since 2017, the University of Puerto Rico has collaborated with public health, atmospheric and meteorological scientists in a National Aeronautics and Space Administration-funded initiative to use data on Saharan dust from satellites (conducting remote sensing) and ground stations, weather information and public health data. The aim of the collaboration is to quantify the impact of Saharan dust on respiratory diseases in Puerto Rico as a proxy for the Caribbean. This has led to the co-design of a public health EWS for Saharan dust, which includes online visualisation tools (see the Caribbean Coastal Ocean Observing System's latest conditions and forecast). The University of Puerto Rico's Graduate School of Public Health develops infographics and conducts webinars to increase the population's knowledge of potential threats and protective measures and their preparedness for threats in collaboration with the weather service and a civil society organisation. Among the populations served by these information products are healthcare and emergency preparedness personnel and the general public, with a focus on populations at high risk (Mendez-Lazaro, 2021, 2022).

Air quality should be mapped against climate-related drivers of ill health, such as hurricanes, heat fluctuations, droughts and flooding (R4ACCHC, 2022a). Medical doctors can act as "sentinel physicians", providing data to monitor respiratory conditions alongside climate indicators (R4ACCHC, 2022b).

Monitor and strengthen the integration of air pollution into weather forecasting and early warning systems

Unlike risk factors such as diet and exercise, air quality is a risk factor over which individuals have very little control. Furthermore, individuals generally are not in a position to monitor their exposure to air pollution. This means that air quality surveillance and associated information services and EWSs are critical public health measures. Effective communication on air quality must be considered an essential component of climate information services for health. While weather forecasts on public television and radio stations in Caribbean countries now sometimes include predictions of dust concentrations alongside advice on protective measures, further information on air quality could be included. There is also a need to deploy the whole gamut of modern communication methods and media to ensure that people understand the information they receive about air quality, with a focus on vulnerable populations, such as older people and people with NCDs (especially respiratory and cardiovascular conditions) and their carers (Mendez-Lazaro, 2022). Box 1 provides examples of agencies in the Caribbean providing information about and communicating surveillance data.

Monitoring, forecasting and EWSs need to be linked with populations and agencies that can make use of the information these services provide. There should be a particular emphasis on providing information to geographical areas and populations at high risk of experiencing poor air quality. National and regional public health agencies should continue to strengthen their links with meteorological agencies engaged in the research and development of EWSs, such as the Caribbean Regional Climate Centre at the Caribbean Institute for Meteorology and Hydrology. Governments must also be engaged, including through their chief medical officers and disaster management units. Full use must be made of media, including social media. Platforms for the dissemination of information must be improved (R4ACCHC, 2023).

Research and surveillance capacity-strengthening needs

Capacity should be built in the Caribbean in the following areas (Gordon-Strachan, 2021):

- The design of air quality monitoring systems;
- Statistical disease modelling;
- Integrated surveillance systems that monitor weather, health and environmental indicators;
- The recruitment of pulmonologists and internal medicine specialists to assist with the development of direct indicators and proxy indicators (if necessary) for monitoring health impacts of air quality;
- Remote sensing;
- The communication of science related to air quality and health to the general public, vulnerable populations, policymakers and industrialists to encourage behaviour change.

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