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Impact of Climate Change on Air Quality and Public Health in Urban Areas

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Abstract

This review discusses how climate undergo changes and the effect of climate change on air quality as well as public health. It also covers the inter relationship between climate and air quality. The air quality discussed here are in relation to the 5 criteria pollutants; ozone (O_3), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter (PM). Urban air pollution is the main concern due to higher anthropogenic activities in urban areas. The implications on health are also discussed. Mitigating measures are presented with the final conclusion.

Keywords

climate change, urban air pollution, health effects, air pollutants

Introduction

Climate change is a universal phenomenon that leaves no part of the world untouched. For more than two decades, scientists have indicated that the Earth's climate is rapidly changing. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer."[1] Climate change can be attributed directly by natural process or indirectly through anthropogenic changes in the composition of the atmosphere. It is estimated that without new policies aiming to mitigate climate change, the global mean surface temperature is predicted to increase by 3.7°C to 4.8°C over the next 100 years.[1]

Climate change and air quality are closely related. Climate change can deteriorate air quality by increasing or concentrating the pollutants in the troposphere (lower atmospheric layer).[2] Air pollution can cause adverse impacts to human health and the ecosystem. The impacts of ecosystem drivers (such as deforestation, industrialization, urbanization, and agricultural practices) on climate, air quality, and human health are illustrated in Figure 1. Urban air pollution raises main

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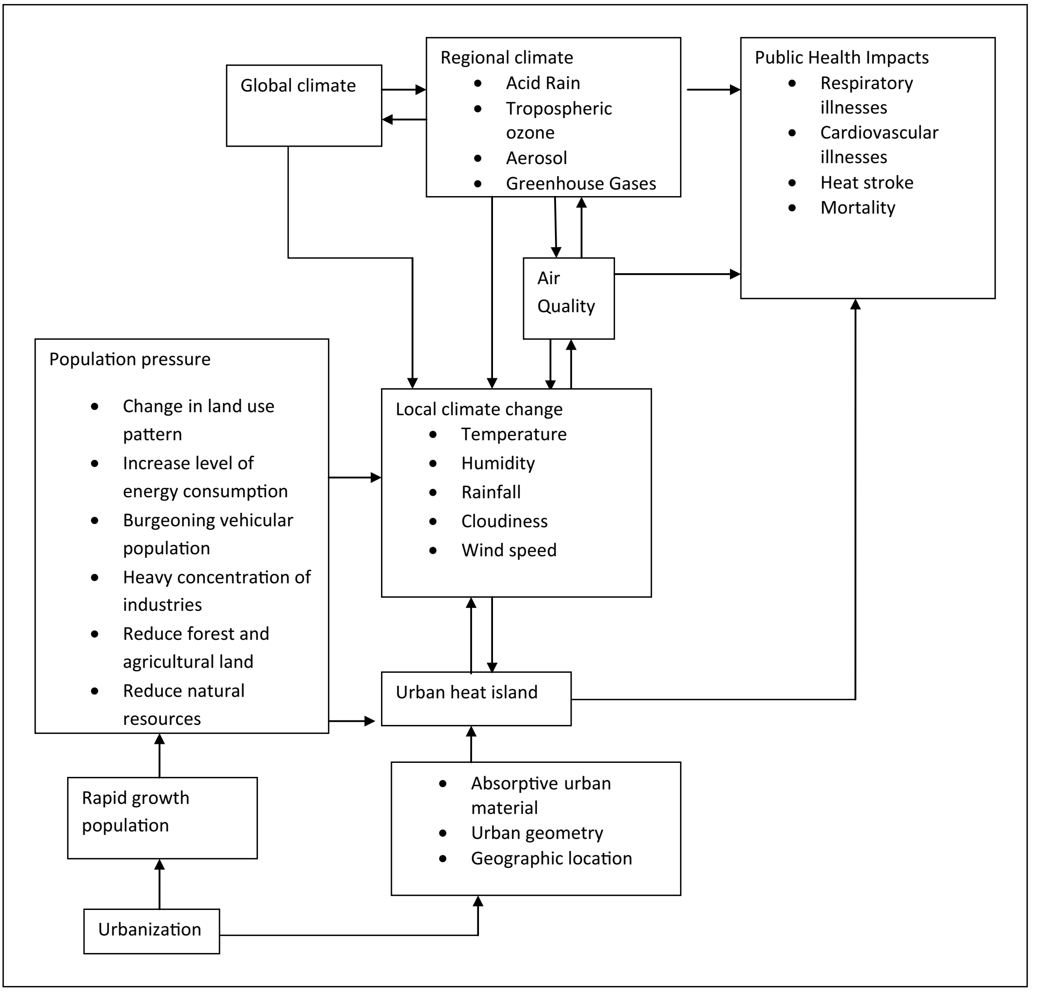

Figure 1. Climate change interaction with air quality and urbanization process.

concern due to higher anthropogenic activities in urban areas, which can further lead to urban heat island that aggravates air quality and increases health risk.

Methodology

Original articles were screened during the period from January 1, 2000 to December 31, 2014, using the following sources: PubMed, Google Scholar, and *The Lancet*, and were limited to articles written in English. Several combination keywords were used, including Climate Change, Air Quality, Urbanization, Human Health, Urban Areas, and Asia Pacific Region. The main criteria for the selection were articles that describe the interactions between climate change, air pollution and health, and health impacts in urban areas (Figure 2).

What Causes Climate Change?

Climate change in the early centuries can be explained by natural causes, such as volcanic eruptions, changes in solar energy, and natural changes in greenhouse gas (GHG) concentrations.

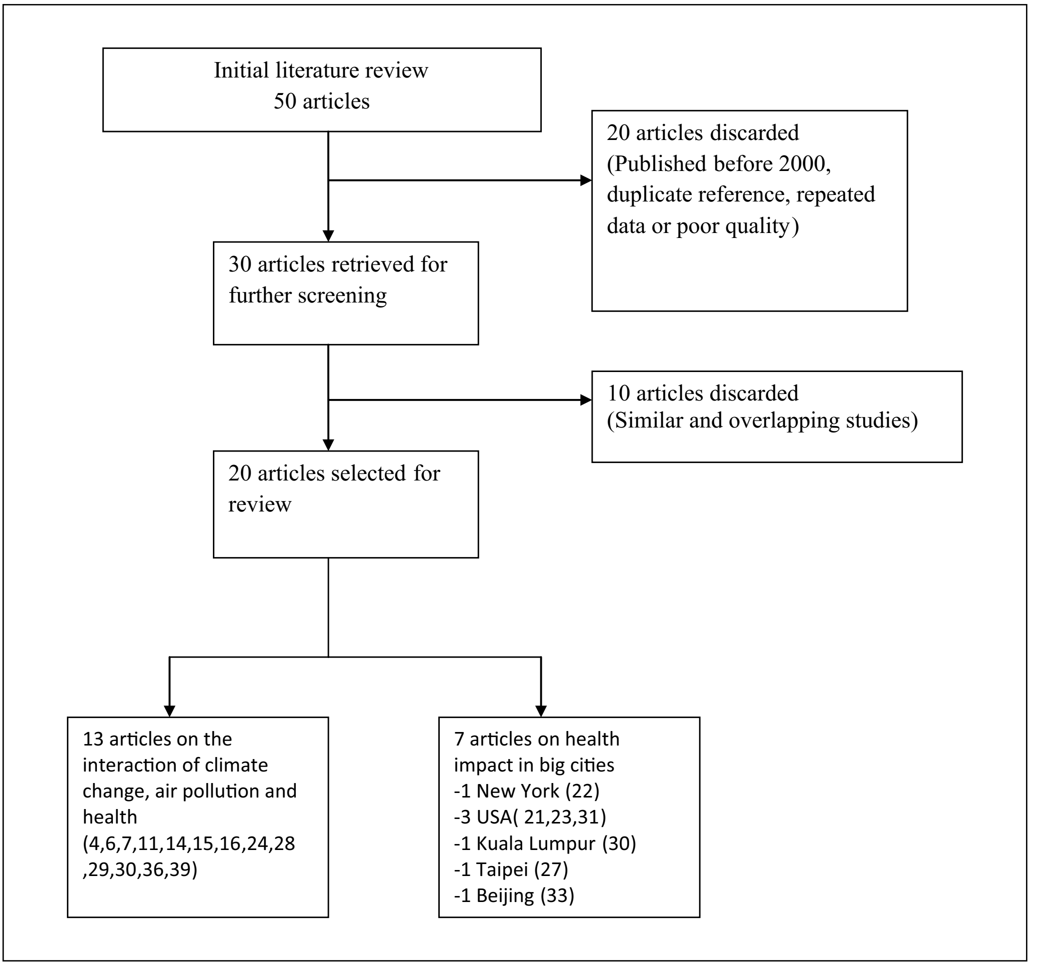

Figure 2. Flowchart of article selection process.

Research shows that anthropogenic activities can very likely explain most of the warming incidences since the mid-20th century, while natural causes are very unlikely to cause the observed warming.[2]

The planet absorbs energy from the sun and radiates the rest back to space as heat. The surface temperature of the earth depends on the balance between both the incoming and outgoing energy. GHGs such as carbon dioxide (CO2), methane (CH_4), and nitrous oxide (N_2O) emitted from anthropogenic activities, can trap the energy and prevent the heat from escaping. These GHG emissions have led to the greenhouse effect, which causes the earth's surface temperature to increase.

CO_2 is emitted naturally as part of the carbon cycle through animal and plant respirations, ocean-atmosphere exchange, and volcanic eruptions. Human activities emit large amount of carbon through industrialization and urbanization processes. It is believed that human activities emit 30 billion tons of CO_2 into the atmosphere every year.[2] The National Research Council reported that the current level of CO_2 is higher than it has been since the past 800 000 years. The concentrations increased by almost 40% since preindustrial times. In 2010, it is reported that the CO_2 concentrations were approximately around 390 ppmv compared with 280 ppmv in 1975.[2]

Table 1. World Health Organization's Guideline Values for Air Pollutants.[5]

Air Pollutants	Guideline Values
$PM_{2.5}$	10 μg/m^3 annual mean; 25 μg/m^3 24-hour mean
PM_{10}	20 μg/m^3 annual mean; 50μg/m^3 24-hour mean
O_3	100 μg/m^3 8-hour mean
NO_2	40 μg/m^3 annual mean; 200 μg/m^3 1-hour mean
SO_2	20 μg/m^3 24-hour mean; 500 μg/m^3 10-minute mean

CH_4 is more abundant today than at any time in the past 650 000 years. Its concentration was sharply increased in the 20th century. Globally, more than 60% of total CH_4 emissions come from anthropogenic sources.[3] CH_4 is released from natural sources such as wetlands. It is removed from the atmosphere by natural processes in the soil and by chemical reactions. CH_4 has a shorter lifetime in the atmosphere compared with CO_2, but it is more efficient at trapping radiation than CO_2.[4]

Similar to CO_2 and CH_4, N_2O is produced through natural and human activities. Globally, about 40% of total N_2O emissions come from anthropogenic sources.[3] Fuel burning, agricultural activities, and some other processes also create N_2O. The concentration of N_2O has risen by 18% since 1975 with a sharp increase at the end of the 20th century.[3] The molecules of N_2O stay for an average of 120 years in the atmosphere before being removed by a chemical reaction. The impact of 1 pound of N_2O on warming of the atmosphere is more than 300 times that of 1 pound of CO_2.[2]

Other GHGs include water vapor, tropospheric ozone (O_3), and F-gases. Water vapor has the shortest atmospheric lifetime, yet the most abundant GHG. It is not substantially affected by human activities as it is controlled by temperature. It is also influenced by the overall rate of evaporation and precipitation.[2] O_3 also has a short atmospheric lifetime. It is created from nitrogen oxides and volatile organic compounds emitted from power plants, automobiles, and other sources in the presence of sunlight. F-gases are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbon (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). They are used in aerosol propellants, foaming agents, fire extinguishers, coolants, solvents, and pesticides. Unlike water vapor and ozone, the F-gases have longer atmospheric lifetime.[2]

Climate Change Impact on Air Quality

Air quality is strongly coupled with weather and is therefore, sensitive to climate change. Meteorological variables such as humidity, wind speed and direction, temperature, and mixing height (the vertical height of mixing in the atmosphere) play crucial roles in determining trends of air quality. The air pollutant formation, chemical transformation, dilution, dispersion, transport, and deposition are highly dependent on these meteorological variables and cyclonic systems. Spickett et al[4] stated that bushfires and heat waves can also influence air quality and may be affected by climate change. Higher temperature will cause more frequent droughts and higher possibility of fire danger.[4]

Many countries regulate their own air quality guidelines. The World Health Organization Air Quality Guideline represents the most widely agreed and the latest assessment of health effects of air pollution (Table 1).[5] In this discussion, it covers 5 criteria of air pollutants namely particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon dioxide (CO_2). PM is a mixture of solid particles and liquid droplets found in the air. They can generally be categorized into 3 major fractions based on their particle size: coarse particles that are larger than 2.5 μm in aerodynamic diameter, fine particles smaller than 2.5 μm in aerodynamic diameter ($PM_{2.5}$), and ultrafine particles smaller than 0.1 μm (100 nm). Coarse particles are emitted from sources such as vehicles traveling on unpaved roads, crushing and grinding operations, material handling, and windblown dust, while fine particles may come from fuel combustion (motor vehicles, power generation, industrial processes), wood stoves, and residential fireplaces. The relationship between PM and the climate change is complex but can also be significant.[6] Gases such as SO_2, NO_2, and volatile organic compounds can form fine particles in the atmosphere through chemical reactions involving atmospheric oxygen and water vapor. The formation of secondary particles also depends on solar radiation and relative humidity.

Particles in the atmosphere have a vital role in changing the solar radiation amount transmitted through the Earth's atmosphere. Sulfate particles will exert a direct effect by scattering incoming solar radiation back to space and causing a cooling effect. In contrast, black carbon particles absorb solar radiation and cause a warming effect. Wind speed and wind direction also have a significant impact on particle concentration. The concentrations generally decrease by an order of magnitude between polluted regions and the diluting background air.[7] An example is during the Southeast Asia Haze in 2005 whereby the PM_{10} reading in Malaysia[8] and Thailand[9] were 529 and 108 μg/m^3, respectively, in the same month. The PM_{10} level dropped when the wind changed direction southwesterly to southeasterly, hence the air mass trajectory did not pass the forest-fire region. Particles also have an indirect effect on the size and number of cloud droplets which then causes more solar radiation to be reflected back to space, subsequently causing a cooling effect. However, the magnitude of the overall indirect effects of aerosols on climate is very uncertain.[10]

Atmospheric ozone (O_3) is present in the stratospheric and tropospheric O_3. The main environmental concern is the tropospheric O_3, also known as the ground-level O_3. It is highly dependent on the temperature, sunlight and precursor levels such as nitrous oxides and volatile organic compounds. Research showed that ozone levels are higher in warmer seasons,[11] and very high levels of ozone have been recorded during heat waves.[12] Generally, temperature accelerates the photochemical reaction rate in the atmosphere and hastens the rate of tropospheric O_3 formation; other hydroxyl radicals are also produced. O_3 concentration also depends on the wind speed. Lower wind speed leads to reduced ventilation and causes higher formation of O_3 and its precursors, while increased water vapor will lower the potential for O_3 formation. O_3 concentration can be reduced by modifying factors that govern O_3-producing reactions, for instance, the intensifying hydrologic cycle will increase the number of cloudy days. More cloud cover in the morning could diminish reaction rates, and thus lower O_3 formation.

Nitrogen oxides (NO_x) and SO_2 are emitted from high-temperature combustion processes, such as from power plants and automobiles. NOx and SO_2 oxidize in the atmosphere to form nitric acid and sulfuric acid, respectively. These acids can be deposited to the earth's surface in "wet" form as acid rain or in "dry" form as gases or aerosols. The wet deposition is determined by atmospheric chemistry and precipitation patterns. The amount, duration, location of precipitation, and changes in the total acid levels play a vital role in the deposition.[13] Factors that influence O_3 formation will influence acid deposition. The increase in temperatures will hasten the oxidation rates of SO_2 and NO_x to sulfuric and nitric acids, thus increasing the potential for acid deposition. Similar to O_3, vigorous hydrologic cycle will increase the cloud cover, and may reduce the rates of conversion from SO_2 to acidic materials, thus lowering the potential for acid deposition. The location of acid deposition is determined by the circulation and precipitation patterns that will transport the acidic materials.

In urban areas, the most abundant pollutants are O_3, NO_2 and particulate matter. SO_2 is largely concentrated in industrial areas mainly due to coal combustion. Air pollutants can be generated by various sources such as motor vehicles, power plants, dry cleaners, factories, and even windblown dusts and wildfires. In China, air pollution is closely associated with industrialization and urbanization.[14] Afroz et al[15] reported that 3 major pollutant sources in cities in Malaysia are mobile sources (~70%-75% of total air pollution), stationary sources (~20%-25%), and open-burning (~3%-5%). Other sources of pollutants included dust and fine particulates from inefficient diesel-powered vehicles and smoke aerosols from fires, which contributed to the haze in the Klang Valley.[16] In the United States, it is estimated that half of its population occupies areas where levels of O_3, SO_2, NO_2, and particulate matter exceed the National Ambient Quality Standards, as monitored by the US Environmental Protection Agency (EPA).[17] Because of the higher pollutant load, urban population is likely to be the primary group affected by air pollution.

Climate Change Impact on Air Quality and Public Health

Climate change is likely to have long-term consequences on public health. The health effects of the climate change will vary by population group, region, and competency for public health responses. In recent years, the incidence of respiratory diseases has grown markedly in the United States.[11] Both climate change and air pollution may aggravate respiratory symptoms. Most of the allergic respiratory diseases such as asthma and rhinitis are seasonal with climate-sensitive components, hence climate change may worsen the incidence and exacerbate such allergic reactions. Experts hypothesized that the global raise in asthma was indirectly related to climate change and studies showed that the prevalence of asthma was higher in urban areas.[18,19] Urban dwellers are exposed to air pollutants from urbanization and industrialization activities. Table 2 describes the health effects of air pollutants as discussed in the previous section. The data were collected from several findings from big cities throughout the world. The vulnerability to air pollution has been demonstrated by different populations, which include children, the elderly, and people with existing asthma and cardiovascular problems. In summary, all the pollutants discussed can lead to the reduction in lung functions,[20,21,28,30] aggravation of respiratory symptoms,[30] increase hospital admission for cardiovascular and respiratory diseases,[22,23,30] and even to death.[11,22,24,25,33] The coefficient data from the Committee on the Medical Effects of Air Pollutants (COMEAP) represent the relationship between the concentrations of air pollutants and their adverse health effects.[32]

With global warming forecasted to continue in the future, heat waves are expected to increase in both frequency and intensity.[36] During episodes of heat waves, air pollution will rise and the urban heat island effect will exacerbate the unhealthy conditions. Urban heat islands can result from lower evaporative cooling, increased sensible heat flux and heat storage, and can be caused by the lower vegetation cover, increased impervious cover and complex surfaces of the cityscape.[37] Tan et al[36] found that cities that are exposed to heat island effects registered temperatures of 5°C to 11°C warmer than the surrounding rural areas, and the mortality rate during a heat wave increases exponentially with the maximum temperature and the effect is enhanced by the urban heat island.

Storms can also worsen air pollution by enhancing the particulate matter levels in cities. The aerosol particles can cause thunderstorm clouds to linger for longer and increase the temperature at night through the convection process. Merrifield et al[38] found that the dust storms in Australia in 2009 were highly associated with a large increase in respiratory emergency department visits, while Kwon et al[39] reported that dust storm events were associated with a risk of death due to cardiovascular and respiratory causes.

Mitigation and Recommendation

Climate change mitigation mainly seeks to limit the magnitude and/or the rate of long-term activities which cause climate change. The main mitigation generally involves reductions in human (anthropogenic) emissions of GHGs. The United States, for example, has converted CH_4

Table 2. Adverse Health Effects of Air Pollutants.

Air Pollutants	Adverse Health Effects	Coefficient Data from COMEAP[32]
Ozone (O_3)	Coughing, throat irritation, chest pain, and congestion, worsen bronchitis, asthma, and emphysema[20]	NA
	Increased in susceptibility to respiratory infections, medication use by asthmatics, emergency department visits, medical personnel visits, and hospital admissions[20]	+3.5% per 50 μg/m^3 increase of O_3 8-hour mean
	Inflame the linings of the lungs[21]	NA
	Mortality, specifically due to cardiovascular and respiratory mortality[11]	+3.0% per 50 μg/m^3 increase of O_3 8-hour mean
Particulate matter (PM)	Larger particles of solid and liquid will be trapped in the upper respiratory tract while tiny particles (smaller than $PM_{2.5}$) can get deep into the alveoli where they can cause serious health problems	NA
	Increased respiratory symptoms, irregular heartbeat, non-fatal heart attacks, development of chronic bronchitis, decreased lung function, aggravated asthma, and premature deaths in people with heart or lung diseases[30]	NA
	Caused deaths[22,33]	+0.75% per 10 μg/m^3 increase of PM_{10} 24-hour mean +6% per 10 μg/m^3 increase in $PM_{2.5}$
	Increased respiratory and cardiovascular hospital admission[22]	+0.8% per 10 μg/m^3 increase of PM_{10} 24-hour mean
	High plaque deposits in arteries and cause heart attacks and other cardiovascular diseases[23]	NA
	Caused 5% of trachea, bronchus, and lung cancer mortality; 3% of adult cardiopulmonary disease mortality, and about 1% of mortality in children from acute respiratory infection[24]	+0.75% per 10 μg/m^3 increase of PM_{10} 24-hour mean
Nitrogen dioxide (NO_2)	Hospital admission specifically for respiratory disorders such as myocardial infarction, ischemic heart disease, and all cardiovascular diseases[25]	+2.5% per 50 μg/m^3 increase of NO_2 24-hour mean
	Coughing and bronchitis among children[26]	NA
	Low birth weight[27]	NA
	Long-term exposures to NO_2 can reduce lung function in children[28] and cause lung cancer[29]	NA
Sulfur dioxide (SO_2)	Increased hospital admissions for respiratory illnesses[30]	+0.5% per 10 μg/m^3 increase of SO_2 24-hour mean
	Increased hospital admissions for cardiovascular illnesses[30]	NA
	Caused death[31]	+0.6% per 10 μg/m^3 increase of SO_2 24-hour mean

Abbreviations: COMEAP, Committee on the Medical Effects of Air Pollutants; NA, not available.

to be used as energy, as an alternative to reduce CH_4 in the atmosphere.[3] As an alternative to reduce the N_2O emissions in the agricultural sector, the use of nitrogen-based fertilizer has been reduced in the United States.[3]

Mitigation may also be achieved by increasing the capacity of carbon sinks, for example, through reforestation and reduction of forest clearing or lumbering. Other measures of mitigation include switching to low-carbon energy sources, such as wind, solar, and nuclear energy, and expanding forests and other "sinks" to remove greater amounts of CO_2 from the atmosphere.[40]

Locally managed carbon budgets for transport and housing are also the mitigating measures that could be highly effective in reducing GHG emissions. Among the strategies that could be implemented include car-pooling schemes and sustainable building codes for new constructions.[40] Transport emissions could be based on the measurements of distance traveled in vehicles and building emissions could be calculated from the data gathered on energy use.[40]

The improvement of building insulation can also contribute to the mitigation of measures for efficient energy use which not only applies to thermal but also to acoustic, fire, and impact insulation.[37] Green roofs are excellent insulators during the warm weather months and plants cool the surrounding environment. The heat island effect can also be counteracted slightly by using white or light-colored concrete to build roofs, houses, pavements, and roads, thus increasing the overall albedo of the city.[37]

The United States has announced the establishment of 7 "climate hubs" in regional areas to help reduce carbon emissions and deal with climate change.[35] These climate hubs will promote the development of next generation climate solutions, enabling the country's agricultural sector to build innovative tools and technologies they need in the wake of the changing climate. They will provide guidance to farmers, ranchers, and forest landowners to cope with the challenges posed by the climate change in which fires, invasive pests, flooding, and droughts are to be researched by the hubs.[35]

In the Asia Pacific Region, combating air pollution and developing clean energy economies are among the measures taken to reduce the climate change and air pollution issues. Vietnam, Korea, China, Japan, India, and Australia have participated in combating climate change by curbing pollutants through the Global Methane Initiative.[41] The objective of the program is to reduce global methane emissions and to simultaneously enhance economic growth, promote energy security, improve the environment, and reduce GHG emissions. The Global Methane Initiative targets 4 major methane sources for action namely landfills, underground coal mines, natural gas and oil systems, and agriculture (manure management).[41]

Several Asia Pacific countries have collaborated with the US EPA to improve air quality in their countries. China has promoted integrated air quality and regional multipollutant air quality management strategies, and developed the frameworks and technical capacities to adopt effective emission reduction strategies, such as emission control and trading mechanisms.[42] They have also developed sulfur dioxide emission cap and trading mechanisms to promote cleaner fuels and vehicle emission reductions. China had also established the AirNOW international monitoring system in Shanghai.[42] In Indonesia, the US EPA has collaborated to evaluate air emissions from forest fires and to phase out lead in gasoline. Over the years, the US EPA has been cooperating with their Indonesian partners and the United Nations Environment Programme through the Global Partnership for Clean Fuels and Vehicles. They also collaborated for "Breathe Easy, Jakarta," a program aiming to improve air quality and protect human health in the capital region.[42] Other countries like Japan and Australia were involved in The Clean Air and Climate Coalition to reduce short-lived climate pollutants. Under this initiative, partners will provide technical assistance, training, and capacity building during their transition toward having more sustainable waste management options.[42]

The key challenge confronting the effective implementation of the climate change program is the lack of thorough knowledge on climate change vulnerabilities and adaptation options due to the limited scope of modeling potential impacts.[43] A further challenge is the need to communicate with specific stakeholders and public at large effectively. They need to have a robust understanding of climate change and health implications, so that they will better support and participate in the program.[44] Participatory approaches from the stakeholders such as land use planners and infrastructure developers to identify areas where early adaptation is a possibility are needed to support institutional arrangements for linking federal, state, territory, and local responses with the climate change, community vulnerability and adaptation.[45]

Conclusion

Since climate change and air quality are closely related, countries should review their strategies on their air quality program in the future and progress toward carbon budget. They should consider further how this is best achieved, possibly within the local context, by reviewing the local air quality management system. An immediate priority is to work toward compliance with the current air quality limits. Where the impact of possible policy interventions is uncertain, new tools or evidence-gathering approaches may need to be developed, potentially in collaboration with other institutions or countries.

Adaptation strategies and mitigation measures are vital for primary health care providers. Improved monitoring of pollutants such as particulate matter and ozone as well as the associated outcomes such as hospital admission for cardiovascular and respiratory symptoms will be an important adaptation strategy.[4]

The forecasting and projecting of future air pollution scenarios and the identification of members in the community who may be vulnerable to the deterioration in air quality are important to reduce the consequential effects on human health.[4] To implement it, accurate information on the interaction between climate change, air pollution, and human health should be clearly understood. Countries should continue to work and to develop improved understanding of the complex linkages between air quality and climate change to ensure well-targeted and cost-effective policies and a coherent policy framework.[4] In particular, further work is needed to facilitate the comparison of air quality and climate change impacts.

The limitations of this review lie in the fact that articles accessed are limited to articles written in English, and there is a paucity of original papers that concentrate on the assessment of the impact of climate change, as well as air pollution in urban areas in the Asia Pacific Region. Most of the articles and reports discuss scenarios strictly in the United States, the United Kingdom, and European countries. In addition, no primary data have been included in this study due to time and financial constraints.

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