CHAPTER

17

Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus

Nidhi Singh, Saumya Singh, R.K. Mall

DST-Mahamana Centre of Excellence in Climate Change Research, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, Uttar Pradesh, India

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1. Introduction

The world experienced an upsurge in human population during the Industrial Revolution in the 19th century (Grimm et al., 2008) which accelerated the process of urbanization since then. The unregulated urbanization has caused intense alterations in the physical land surface properties (roughness, thermal inertia and albedo) (Fan et al., 2017). These changes have correspondingly affected the surface-atmosphere coupling including the exchange of water, momentum and energy in regions undergoing urbanization (Li et al., 2017). This further influences regional meteorological variables such as temperature, wind speed, and planetary boundary layer (PBL) height and air quality (Civerolo et al., 2007). In an urban area, the roads and buildings are manufactured from impervious materials, e.g., asphalt, concrete. Due to low albedo and high solar absorption, these surfaces absorb high solar radiation and reradiate it later (Wang et al., 2017). In addition, the materials used in construction have elevated thermal inertia and heat storage that is released during the night-time causing decrease in the difference between day and night temperature and thus consequent decrease in diurnal temperature range (Hardin and Vanos, 2018). The increase in overall temperature due to the above process is responsible for *urban heat island* (*UHI*) *effect*, extensively observed over urban dwellings. Street canyons referred as a U-shaped space between the adjoining building structures can also trap the longwave radiation attributed to reduction in sky view factors (SVFs) (Qiao et al., 2013) and increase the temperature around. On the other hand, pervious surfaces such as urban parks and lawns help in creating cooling effect due to evapotranspiration referred to as *urban oasis effect*. The water content in the soil governs the ground heat fluxes that in turn regulate surface temperatures. But the continuous decrease in the open and green spaces in urban areas cannot counter the accelerated increase in surface temperature. The intensification of urbanization has played the biggest role in the transformation of social, economic and environmental processes. Importantly, among all the others, urbanization has a profound and multifaceted effect on environment manifested at several spatial scales (Parrish and Stockwell, 2015).

Apart from UHI, unregulated urbanization has created piles of environmental challenges including air pollution; changes in biogeochemical cycles and water pollution; changes in land-use and ecosystem functions; solid waste management and climate. Among them, air quality and UHI are likely to pose the greatest threat to the environment (Rosenzweig et al., 2010; Parrish and Stockwell, 2015). Urbanization brings changes to urban meteorology that in turn influences ambient air pollutants. The changes brought by meteorology in emission rates, chemical reaction rates, gas—particle-phase partitioning of semi-volatile species, pollutant dispersion, and deposition play an important role in determining air pollutant concentrations (e.g., biogenic volatile organic compounds (BVOCs) and evaporative emissions of gasoline). Among air pollutants, particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}), nitrogen oxides (NOx) and ozone (O_3) pollution are major public health concerns. Like UHI, anthropogenic pollutant emissions peak in urban region, and thus the pollutant load is much higher in urban environment than rural. It is interesting to notice that the two phenomena are driven by urbanization, and the UHI and air pollution influence each other too. UHI has been found to exacerbate air pollution. Increased near-surface temperature and presence of primary pollutants due to vehicular emission pave the way for formation of secondary pollutants such as O_3

in urban area. The turbulent fluxes upstream have the potential to transport the pollutant load to the downstream region where they are trapped in night time due to inversion and disperse during day deteriorating the ambient air quality as well as weather in case of surface aerosol transfer. Sarrat et al. (2006) applied mesoscale model with urban parametrization to state that UHI modifies the dynamics of atmospheric boundary layer causing turbulent fluxes to drive the spatial distribution of primary (NOx) and secondary pollutants (O_3) in urban areas. It was observed that UHI and air pollution are responsible for large health impacts. According to a report by World Health Organization, indoor air pollution causes an estimated 3.8 million deaths every year and around 4.2 million deaths each year are attributed to ambient (outdoor) air pollution (WHO, 2016). Moreover, the population living in places where air quality index exceeds WHO guideline limits is estimated to be around 91% (WHO, 2016). Therefore, regulating urbanization can have two-way benefits.

In a similar manner, the number of people exposed to heatwaves is increasing year by year. A total of around 125 million people have been affected by heatwave exposure between 2000 and 2016, particularly in the year 2015. These heatwave events can last for many consecutive days to weeks and can cause excess mortality. For example, the heat waves of 2003 killed around 70,000 people between June and August in Europe (Robine et al., 2008). Further, in the Russian Federation a 44-day heatwave in 2010 caused 55,000 excess deaths during the event (Barriopedro et al., 2011).

It is projected that climate change may worsen air quality through increasing temperatures, seasonal shifts, extreme events and increased episodes of sporadic rainfall may increase public health issues further (Fann et al., 2016). UHI also acts as a driver for extreme weather events. The present chapter discusses the phenomena of urbanization, how it drives the UHI effect and its impact on human health. Further, the chapter discusses the effect of urbanization on air pollution, the mechanism and process behind it, the sources of UHI and air pollution and their effect on public health. In the latter section we have discussed the synergistic effect of UHI and air pollution in the era of climate change and concluded with the mitigation and adaptation strategies that can be planned to increase the population's resilience.

2. Urbanization, Urban Heat Island (UHI) and its effect

2.1 Urbanization and UHI

More than half of the world's population is residing in urban areas with Asia alone accommodating 54% of the urban population (United Nations, 2018). Urban sprawl owing to population growth and increased migration has a profound impact on the changing dynamics of urban landscapes (Feng et al., 2014). Kalnay and Cai (2003) attributed the decrease in diurnal temperature and increase in surface warming to land-use changes and urbanization. Declining natural vegetation and increase in concrete and asphalt surface which release the heat absorbed during day back to the atmosphere at night have a significant impact on warming of the environment (Wang et al., 2007). Bek et al. (2018) studied the impact of unplanned urbanism on the thermal behaviour of two areas in Egypt and found a difference of 1−4°C between a planned area with green spaces and a highly populated unplanned settlement. Urbanization has a profound impact on the characteristics of rainfall as well. A meta-analysis on the role of urbanization in modification of rainfall pattern by Liu and Niyogi (2019) found that urbanization enhances mean precipitation by 16% over the urban areas while over 18% downwind of the city. Thus, urbanization plays a key role in modification of local climate.

The urban environment differs significantly from the rural settings on the account of its infrastructure, geometry, energy balance, air and water quality, etc. (Taha, 1997). These structures and processes modify the local climate of the urban areas and can be perceived as a manifestation of anthropogenic influences on the climate (Kalnay and Cai, 2003). Urban Heat Island formation is primarily attributed to an increase in sensible heat and reduction in latent heat fluxes due to reduced evapotranspiration in the urban areas. Rising heat transport due to mechanical turbulence caused by highrise buildings and dense infrastructural setup and surge in anthropogenic heat emissions contribute to UHI. The urban canyons having low SVF with limited radiative capacity interfere with the heat exchanges rising the temperature many folds inside the buildings, which may shade the streets during the day. SVF is a ratio between the visible sky and the dominant hemisphere over the location (Oke, 1982). On the other hand, heat released during the night from these built-up patches raise the temperature of the surrounding significantly (Arnfield, 2003) and thus leads to diverse and adverse environmental consequences.

2.1.1 *Global scenario*

UHI and its impact have been studied globally using UHI intensity (UHII), which refers to the temperature difference between urban and surrounding suburban/rural areas (Zhou et al., 2015). UHI intensity is measured as atmospheric urban heat island (AUHI) and surface urban heat island (SUHI) intensities. While lack of consistent weather station data impedes the AUHI measurement, satellite-based radiometers measure the land surface temperature also known as the skin temperature of the earth, which is the widely used metric to estimate SUHI intensity (Li et al., 2017). Yang et al. (2017) noted the lack of a comprehensive understanding in the effect of SUHI intensity and so studied the relationship of SUHI effect with landscape pattern in 332 Chinese urban areas located in different climatic zones. It was found that SUHI intensity exhibited seasonal, diurnal and climatic variation and changes with landscape characteristics. Li et al. (2017) assessed variation in SUHI intensity with expansion in 5000 urban regions of United States and found an increase of 0.7°C with a twofold increase in the size of urban area. Similarly, Imhoff et al. (2010) studied 38 cities of USA and found seasonal and diurnal variation in SUHI intensity to be higher in summer by 3°C compared to winter. Zhao et al. (2017) found that periodic changes in solar radiation and difference in rate of evapotranspiration contributed to the temporal variation of SUHI in rural and urban region. Zhou et al. (2015) on the other hand emphasized the need to understand both the magnitude and extent of UHI, i.e., UHI footprint. They quantified UHI footprints in terms of UHI intensity and urban size in 32 major cities of China. The UHI intensity varied spatiotemporally reaching 3.9 times during the night as compared to 2.3 during the day depending on the size of the urban area. However, this approach still needs to be explored to open new avenues in understanding and quantifying the impact of UHI effect.

2.1.2 *Indian scenario*

As urbanization in India is on the rise, the country is very much prone to UHI effect. As a result, several studies have been done to investigate UHI effects in highly urbanized cities of

India (Mohan et al., 2011; Borbora and Das, 2014; Singh et al., 2017). Nesarikar-Patki and Raykar-Alange (2012) investigated the role of land use land cover change in influencing the temperature variability in Pune during 1999–2006 and observed a tremendous rise of 1–4°C with UHI effect being higher over urbanized areas as compared to vegetated areas. Mohan et al. (2011) studied the annual and seasonal temperature trends over the rapidly urbanizing National Capital Region of Delhi and observed an increasing mean minimum temperature attributed to UHI. Sharma and Joshi (2014) used a land surface temperature anomaly–based approach to study the seasonal and temporal variations of UHI effect in Delhi. The study found annual UHI intensity was highest in the industrial and commercial zones due to high-density built-up area, concrete surface and less green cover. Similarly, Joshi et al. (2015) also found UHI effect to be more pronounced in industrial and urbanized areas and seasonally higher in summers in Ahmedabad city. Singh et al. (2017) observed that UHI effect was positively correlated with normalized difference vegetation index (NDVI) and urban thermal field variance index (UTFVI) with highest UHI effect observed over the urbanized central area. This gives us an overview that UHI effect has similar spatial and seasonal variations globally.

2.2 UHI and health effects

UHI has a profound impact on human health which manifests as a function of extreme temperature, the influence of heatwave and air pollution (Singh et al., 2019; Mall et al., 2017). High ambient temperature, absence of nighttime heat discharge, lack of surface moisture and vegetations with reduced diurnal temperature variations increase the risk of heat-related morbidity and mortality of urban inhabitants (Fig. 17.1). The thermoregulatory mechanism of human body responds to increased temperature by dissipating heat in order to resist any changes in the internal state. However, in the event of unusually high ambient

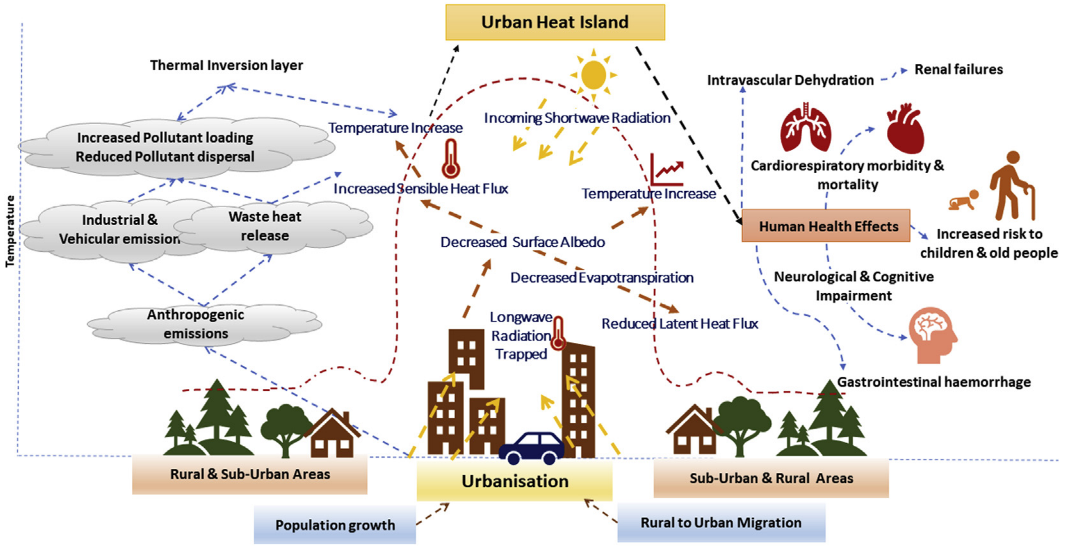

FIGURE 17.1 Urban Heat Island effects and its health impacts.

temperature body fails to maintain the homeostasis and suffers from severe dysfunctionalities. Reduced cardiac output and intravascular volume inhibit effective heat transfer in older people and puts them at a heightened risk. Vasodilation lowers the blood pressure and it is found that with 1°C rise in ambient temperature there is a reduction of 0.659 and 0.368 mmHg in systolic and diastolic blood pressures, respectively. Increase in indoor temperatures which is a characteristic of UHI phenomenon has significantly higher impact on change in human blood pressure than the outdoor temperature putting the residents at higher risk (Kim et al., 2012). Heat strokes alone attribute to 40%–64% mortality and increase the risk every time body temperature reaches above 40°C (Shahmohamadi et al., 2011). Apart from cardiorespiratory system other organs also suffer from severe impact of extreme temperature. Intravascular dehydration causing dizziness, nausea and unconsciousness can trigger renal failure and imbalance in electrolytes may cause hypoglycaemia, cerebral ischaemia and sepsis (Ev and Sharma, 2019). Hyperthermia induces neurological and cognitive dysfunction adversely affecting memory, attention and information processing. In a recent study it was found that at an elevated temperature of 38.8°C memory impairment occurred (Walter and Carraretto, 2016).

Heatwaves show a synergistic impact with UHI increasing the risk (Heaviside et al., 2016). Founda and Santamouris (2017) studied the synergistic behaviour of UHI and heat waves during the 2012 heat wave in Athens and found that heatwaves tend to intensify the UHI intensity. During the heatwave period, excess radiative heat released during night time in the urban areas raises the UHI intensity by 1.5°C on an average thereby prohibiting the nighttime cooling (Founda and Santamouris, 2017). A WRF model simulation-based study revealed that 52% of the mortality was attributed to the enhanced ambient temperature due to UHI effect during West Midlands heatwave episode in August 2003 (Heaviside et al., 2016). Kouis et al. (2019) reported mortality risk to be a function of extreme temperature rising steeply at a threshold of 33°C with an increase of 4.4% and 5.9% in cardiovascular and respiratory mortality risk in Greece. This threshold varies depending on the latitude where generally higher thresholds are observed in regions at lower latitude as the population is adapted to extreme temperatures.

3. Urbanization, air pollution and its effects

3.1 Air pollution: a general introduction

Air pollution is defined as the mixture of solid, liquid and gaseous particles suspended in the atmosphere. Small air particles such as black carbon (BC), nitrogen oxides (NO_x), ozone (O_3), sulphur dioxide (SO_2) and particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$) constitute major air pollutants (Rao et al., 2018). The problem of air pollution is most prevalent in cities that witness emissions from a variety of sources. The pollutants tend to concentrate in the cities as the high-rise buildings prevent the air pollutants' dispersion. The problem tends to be basically consistent with large cities in low- and middle-income group countries. The World Health Organization (WHO) has listed Karachi, New Delhi, Beijing, Lima and Cairo as some of the world's most polluted cities. But the problem has now extended its domain to some of the most populated cities in developed nations like Los Angeles, California (NGS, 2011).

Most often the air pollutants from the local or regional sources affect human health, but some atmospheric conditions make the pollutants travel across boundaries up to long distances and affect people elsewhere. Therefore, local, regional and global actions are needed to mitigate the cross-boundary transportation and solve it at local sites only.

3.2 Sources of air pollution

Based on its source, air pollution can be divided into indoor and outdoor air pollution.

Indoor air pollution: It consists of pollutants released from substances such as kerosene, wood and coal used for cooking and heating the house; radon released naturally from earth's surface; wall paint; construction materials; insulation materials. Further, air conditioners create a dampness and the place becomes favourable for the growth of moulds that could spread with air and can act as allergens that can trigger asthma (Leung, 2015).

Outdoor air pollution: It consists of air pollutants contributed by burning of fossil fuels by power plants, automobiles, nonroad equipment, burning and incineration of municipal and agricultural wastes and industrial facilities (Leung, 2015).

The outdoor and indoor air pollutants altogether kill about 7 million people each year worldwide, where South-East Asia and the Western Pacific Regions account for largest health burden due to air pollution (WHO, 2016). Table 17.1 gives an account of the major air pollution episodes attributed to anthropogenic activities. In the southwestern United States, wildfire, heat events and dry periods can place an extra burden on air quality standards even as efforts are undertaken to reduce emissions.

3.3 Air pollutants and health effects

Among developing economy, India and China contributes majority of the air pollution related deaths. In India, air pollution accounts for 0.65 million deaths per year and in China, it is more than the combined mortality from AIDS, malaria and tuberculosis (Lelieveld et al., 2015). People suffer from different health effects due to air pollution depending upon their existing health condition, exposure duration (short-term and long-term effects), exposure concentration and type of pollutants (Table 17.2). Those with underlying health conditions (lung disease, diabetes, cardiovascular diseases (CVD), asthma and cancer), children and elderly, and low socioeconomic group are at greater risk on account of their weak immune system (Singh et al., 2019). Air pollution may also induce diabetes, autism and could cause lower IQ (Guo et al., 2018). The coarse particulate matter (PM_{10}, particles < 10 microns in diameter) causes irritation in nasal passages and upper respiratory tract. Fine particulate matter ($PM_{2.5}$, particles < 2.5 microns in diameter; ultrafine particles) can penetrate deep into the lungs and blood that leads to heart attacks and strokes, asthma and bronchitis, and is responsible for several premature deaths and can interfere with brain development in children (Lelieveld et al., 2015). Based on the duration of exposure, health effects can be categorized into:

3.3.1 Short-term effects

In short-term health effects, people may suffer from pneumonia or bronchitis. Other harmful health effects include irritation in eyes, nose, throat and skin; headaches; dizziness and nausea (NGS, 2011).

TABLE 17.1 Episodes of major urban air pollution in the world.

Episode	Composition	Causes
Acid Rain	Precipitation of pH below 5.2 due to presence of strong acids, sulphuric acid and nitric acid formed by atmospheric reaction of sulphur dioxide (SO_2) and nitrogen oxides (NO_x; the combination of NO and NO_2) with water. (Casiday and Frey, 1998)	After World War II, Europe and eastern North America showed large increase in consumption of fossil fuels emitting huge amounts of sulphur dioxide and nitrogen oxide
Great Smog of London (1952) (Sulphurous smog)	A combination of cold weather with anticyclone and windless conditions mixed with airborne pollutants (mostly SO_2) coming from coal formed a thick layer of smog over London (Laskin, 2006)	To keep themselves warm during cold weather Londoners burnt more coal of relatively low-grade sulphurous variety that increased the amount of sulphur dioxide in the smoke and also large number of coal-fired power stations in greater London area contributed to deadly smog (ApSimon, 2005)
Los Angeles Smog 1943 (Photochemical smog)	The major component was ozone (O_3). Emission of nitrogen oxides from vehicular exhausts and gaseous hydrocarbons from cars and oil refineries in presence of sunlight formed ozone and photochemical smog (Gardner, 2018)	City built for cars during wartime led Los Angeles to become the largest car market and the unprecedented emission from vehicles and factories led to the deadly Los Angeles Smog (Jacobs and Kelly, 2008)
Malaysian Haze 2005	The haze was dominated by fine particles in which secondary inorganic aerosols (SIA, such as SO_4^{2-} and NH_4^{+}) and organic substances (such as levoglucosan, LG) were dominant (Latif et al., 2018)	The practice of slash and burn for farming and peat fires from Indonesia were major causes (Latif et al., 2018)

3.3.2 *Long-term effects*

Long-term health effects may cause cardiorespiratory disorder such as lung cancer, emphysema and chronic obstructive pulmonary disorder (COPD). It may also affect vital body organs such as brain, kidney, liver and may also cause birth defects (NGS, 2011).

3.4 Pathway of air pollution effect

Air pollutants are composed of chemical particles that may take several other forms such as solids, liquids or gases. These oxidants at low doses may mediate physiological effects, while in high doses mediate toxicity (Xia et al., 2009). The other hypothesis suggests the role of redox-active mediators, for example, reactive oxygen species (ROS) and reactive nitrogen species are site-specific mediators of cell signalling and prime regulators of the inflammatory response, where both interact in a multifaceted manner (Daiber et al., 2017). There is a possibility that the pollutants may damage endogenous redox signalling and/or activation of endogenous ROS sources that may result in enhanced responses. Factors such as size, shape, structure, surface reactivity, solubility, biopersistence and 'leachable' components may affect particle toxicity (Nel et al., 2006). For example, the smaller sized particles tend to have larger surface-to-mass ratio and possess large reactive components and therefore can easily penetrate lower respiratory airways and induce toxicity (Oberdörster 2012; Oberdorster et al., 1994). Ultrafine particles like metal ions, polycyclic aromatic hydrocarbons (PAHs) produced from the burning of fossil fuel (coal, oil, gasoline), trash, wood, charcoal-broiled meat and tobacco possess reactive components on their surface that possibly mediate systemic effects (Oberdorster and Utell, 2002). The studies show that organic carbon and sulphates are known to have strong associations with the CVD (Maynard et al., 2007). The strength of impact lies in the duration, concentration and toxicity of the exposure pollutant, and susceptibility of the exposed subjects. On entering the human body, pollution particles can be sequestrated, distributed intracellularly and systemically transmitted to others (Simkhovich et al., 2008). They can also activate the autonomic nervous system and produce adverse effects (Calderon-Garciduenas et al., 2008). Pollutants can enter from the olfactory nerve to the olfactory bulb and to central nervous system and may induce inflammation (Rao et al., 2018).

3.5 Urbanization and anthropogenic air pollution

The reform policies of the 1990s opened the path for rapid expansion and urbanization. Increasing urban population, expanding urban land and private vehicles, and increasing economic growth have undoubtedly posed a great threat to the environment. However, since the urbanization pattern and magnitude are not consistent, therefore it can have a variable effect on environment over changing time and variable emission sources at different stages (Kelly and Zhu, 2016). Densely populated cities experience a very high pollution load, which is responsible for a high morbidity and mortality burden. Serious efforts to improve air quality has led to better air quality in cities of North America, Europe and Latin America but situation is worse in developing nations like India and China. The primary and secondary gaseous and particulate pollutants take part in heterogeneous reactions in the atmosphere thus forming complex air pollution mixtures. Air pollution has become a life-threatening challenge disturbing overall earth systems' stability, ecosystems and human health, and is a potential driver for global climate change (Rockström et al., 2009). Furthermore, as the long-term air pollution data are limited, its spatial and temporal effects remain largely unknown.

The air temperature plays an important role in accelerating chemical reactions. It was seen that variable air temperature and vegetation regulate the production of biogenic volatile organic compounds (BVOCs), a precursor of ground-level O_3 (Guenther et al., 2006). The photolysis reaction rates are accelerated by high air temperatures enhancing the production of tropospheric O_3, secondary inorganic aerosols (e.g., nitrate, sulphate and ammonium aerosols) and secondary organic aerosols (SOAs) (Aw and Kleeman, 2003). The land surface roughness helps in pollutant deposition which increases pollutant concentrations over the land surface that may affect regional meteorology in urban regions (Kalnay and Cai, 2003). However, the evidence of impact of land surface changes on regional air quality is sparsely available and limited to ozone (Zhang et al., 2019). In one such study, Chen et al. (2018) showed that alternation in urban land surfaces was responsible for increases in lower air surface temperature and PBL (Planetary Boundary Layer) height, that has caused increases in surface O_3 concentrations but decreases (16.6 μgm^3) in concentrations of $PM_{2.5}$.

In another study, the increasing temperature, PBL height, reduced wind speed and increasing daytime ozone together contributed by urbanization is equivalent to increase in emissions of around 20% (Yu et al., 2012). One major study gap found in past studies was that previous studies could not find any robust driving process that could describe the interaction between land surface change, air pollution and meteorology. Further, they assumed that urban properties remain homogenous throughout the city. Therefore, the urbanization brings a multifaceted problem associated with unplanned growth, deteriorating air quality and changing meteorology (Bai et al., 2017). Scientific research and controlling policies implemented so far suggest that an integrated and comprehensive solution is required, which integrates urban planning, clean energy, energy efficiency and innovation in transportation.

4. UHI, air pollution and human health nexus in the era of climate change

Urbanization is known to drive the problems of UHI and air pollution, which are most prominently visible in cities. Further, UHI and air pollution are known to drive one another. UHI effect increases the energy demand and consumption particularly during summer, when temperatures rise. The use of different electric appliances to keep the rooms cool and methods of conventional energy generation to meet the increased energy demand cause increase in greenhouse gas emissions (EPA, 2008). The spatial temperature difference between cities and suburban areas creates intensive heat islands causing local Hadley type of circulation (Rao et al., 2014). This causes the rising air from the city centre to move towards suburban areas following temperature gradient areas and again move to city interiors. This recirculation process causes elevated inversion and inhibits dispersion of air pollutants upward in urban areas (Oke, 1974, 1977). The greenhouse gases and particulate pollutants absorbs some parts of the long-wavelength infrared radiation emitted from the earth's surface and reradiate it back to the earth's surface that warms the ambient air and enhances low level stability and higher pollutant concentrations. The ambient pollutants now will generate heat island effect and will alter the structure of vertical temperature profile that will hinder the pollutant dispersion (Patterson, 1969). The potential greenhouse gases include carbon dioxide (CO_2), methane(CH_4), nitrous oxide (NOx) and fluorinated gases that have their source as natural and artificial both. All of them are found in high concentration in urban areas (Li et al., 2017). Apart from air pollution and the greenhouse effect, UHI significantly contributed to warming in the 20th century (Estrada et al., 2017). It was found responsible for the warming of about 0.6°C between 1950 and 2015. The researchers anticipated that UHI can further contribute to 2°C to warming in some highly populated cities by 2050 (Estrada et al., 2017). What makes the situation worse is that climate change has brought new challenges to mankind that is threatening to its own existence. Climate change is said to be responsible for high atmospheric temperature; long, severe and frequent heat waves and deadly cold spells; frequent floods, droughts and cyclones. Urban population is augmenting the effect of climate change by contributing to air pollution and UHI effect. This complex nexus of climate change-air pollution-UHI driven by urbanization would prove devastating to human health as discussed in the above sections (Heaviside et al., 2016)

5. Policy recommendations

With 68% of the population about to reside in urban regions in future, urbanization and its impacts are inevitable (UNITED NATIONS, 2018). In this scenario taking the route of mitigation and adaptation is the only way out (Mall et al., 2019). The rapid urban population growth has led to more energy consumption, and increased household utility and vehicles emission. Despite climate change presenting increasing challenges to meet air quality standards, policy and action to mitigate these impacts have been surprisingly absent. Certain measures, including urban design and infrastructure improvements, adequate provision for green spaces, adaptation and mitigation action at multiple policy levels, can strengthen urban reliance and reduce the impact from UHI effect and air quality.

5.1 Urban design and infrastructure

Transitioning towards sustainable urban infrastructure in urban planning and design are at the core of mitigation and adaptation strategies to address UHI impact (Table 17.3). The urban configuration is instrumental in increasing UHI Intensity and has a key role in mitigating the impact of UHI. Yue et al. (2019) studied the urban configuration of 36 cities across China and found that the small built-up patches had lower UHI intensity as compared to large built-up areas. Buildings account for 40% of all energy consumption, globally accounting for substantial carbon dioxide emission in the environment leaving a significant footprint on urban ecology (Ürge-Vorsatz et al., 2007, Ching et al., 2019). Optimizing building structure and orientation using materials having low thermal conductivity can enable reduction in solar radiation, improved ventilation, efficient energy consumption, waste heat emissions and reduction in thermal discomfort. Green buildings offer a solution to UHI mitigation. Shin et al. (2017) reported that Leadership in Energy and Environmental Design (LEED) certified green buildings have the potential to bring down the UHI intensity by 0.26−0.48°C. A major share of mitigation and adaptation can help to increase the surface albedo and water retention that in turn increase thermal emissivity and reduce surface temperature. Adopting these can significantly lower the impact of UHI (Table 17.3).

5.2 Green cover and water body rejuvenation

Urban constructions require land which is acquired by encroaching the water bodies, forest cover and agricultural lands and disrupting the ecological balance (Zhao et al., 2017). Increasing impervious surface and shrinking traditional water reservoirs alter the natural hydrological cycle making urban flood a common disaster along with impairing the groundwater recharge in these areas (McGrane, 2016). Increasing the green cover and rejuvenating the water bodies improve the heat dissipation and water recharge. Green roofs and rooftop and vertical gardens increase the surface albedo and latent heat flux in the urban area and add to the greenery in the urban region (Sanchez and Reames, 2019). Rainwater harvesting, vegetated rooftops, tree plantation, infiltration and bioretention systems are some of the ways to tap the excess runoff, hold the peak flows, remove the contamination and

TABLE 17.2 The list of most common air pollutants, their sources and related health effects.

Pollutant	Sources and health effects of air pollutants
Particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$)	**Sources:** Combustion of diesel and petrol in automobile engines, combustion of coal, heavy oil and biomass for energy production in households and factories, combustion process in industrial and manufacturing processes (construction and building materials, mining, ceramic and bricks, and smelting).
	Effect: $PM_{2.5}$ and PM_{10} can easily enter lungs and irritate the respiratory tract. Fine ($PM_{2.5}$) and ultrafine particles ($PM_{1.0}$) can penetrate bloodstream and may cause inflammation of heart and lung.
Nitrogen oxides (NO, NO_2)	**Sources:** Theses gases are primarily contributed by automobiles, power generation and industry.
	Effects: The gas causes irritation of airways and exacerbates chronic symptoms like asthma and bronchitis and increases the risk of cardiac disorder, increased respiratory infections and reduced lung function.
Carbon monoxide (CO)	**Sources:** Dominantly contributed by automobile exhaust and burning of fossil fuels.
	Effects: This gas is known to have more binding affinity with haemoglobin and can interfere with the oxygen uptake in blood. A reduction in oxygen supply can severely affect brain, heart and other vital organs.
Black carbon (BC)	**Sources:** Black carbon are short-lived climate pollutants emitted from burning of fossil fuel (especially diesel, wood, coal and others).
	Effects: Black carbon is associated with heart attack and stroke on exposure to long periods. It may cause hypertension, chronic obstructive pulmonary disease (COPD) or cancer and may trigger bronchitis and asthma
Ozone (O_3)	**Source:** Tropospheric ozone is a short-lived secondary pollutant, contributed indirectly by combustion of fossil fuels. NOx; volatile organic compounds (VOCs) emitted by automobiles, industries and chemical factories; and methane released by waste, fossil fuel and agricultural industry reacts in sunlight to form O_3.
	Effect: It acts as a respiratory irritant. Short-term exposure to ozone can cause chest pain, coughing and throat irritation, while long-term exposure can cause reduced lung function, asthma and COPD, causing damaging impact on immune activation.
Sulphur dioxide (SO_2)	**Source:** SO_2 is released by burning of fossil fuels containing sulphur from coal, metallurgical process and mineral ores smelting, ship engines, and heavy diesel equipment.
	Effect: Sulphur dioxide is known to cause irritation in eye, may aggravate asthma and bronchitis, lung inflammation and increase the risk of respiratory infections and cardiovascular disorder.

Source: Modified from Landrigan et al., 2018; WHO, 2019. Ambient Air Pollution: Pollutants. Air Pollution. World Health Organization. Accessed at: https://www.who.int/airpollution/ambient/pollutants/en/.

sediment load from the stormwater and augment infiltration in urban areas (McGrane, 2016). These measures not only mitigate the impact of UHI but also make up for the loss in ecosystem services such as stormwater management, restoring the biodiversity and carbon sequestration and contributing to the aesthetic beauty of the region.

TABLE 17.3 UHI mitigation and adaptation techniques and their local and global effects.

UHI Mitigation and adaptation measures	Building-based measures	Community-based measures	Local effects	Global effects
Green infrastructure	**1.** Green building **2.** Green roofs **3.** Vertical gardens	**1.** Reflective surfaces **2.** Cool pavements **3.** Green pathways	**1.** Regulation of ambient temperature profile **2.** Increase in evapotranspiration **3.** Improved energy exchanges	**1.** Increase in carbon sequestration **2.** Reduced greenhouse gas emission **3.** Improved microclimate
Sustainable urban planning	**1.** Green building **2.** Green roofs **3.** Vertical gardens	**1.** Less dense urban configuration **2.** Permeable pavements **3.** Efficient public transport **4.** Green spaces/Urban parks **5.** Land-use monitoring and management	**1.** Reduced UHI intensity **2.** Storm water management **3.** Improved convection for pollutant dispersion **4.** Improved public health	**1.** Increased resilience towards extreme weather events such as heat waves and urban floods. **2.** Improved air quality **3.** Health risk reduction
Heat mitigation system	**1.** Building orientation change for solar exposure **2.** Use of low thermal conductivity materials **3.** Use of reflective surfaces **4.** Installing energy efficient systems	**1.** Urban greening **2.** Osmotic pool **3.** Regulating ponds	**1.** Reduction in anthropogenic heat emissions **2.** Reduction in heat-related morbidity and mortality **3.** Reduced energy demands	**1.** Reduced greenhouse gas emission **2.** Health risk reduction

5.3 Air quality mitigation and adaptation strategies

The synergy of UHI and anthropogenic emissions in urban areas pose a great risk to the health of its inhabitants. An extensive network of monitoring stations, emission inventories serve as the first step to assess the air quality of the region and formulate appropriate measures to be implemented. Air quality modelling, wind profile study and application of plume dispersion modelling techniques help in identifying regions which are the most suitable for industrial setup and have minimum impact on the health of residents. Stringent monitoring on the use of vehicle-based emission control devices, avoiding the use of transport for short distances and promoting the use of public transport can reduce ground-level emission and also congestion on the roads (Harlan and Ruddell, 2011). Using clean and renewable energy-based fuels curtails the emission, lowers the pollutant load, reduces the temperature and helps in creating a cleaner environment. Making the urban landscape greener by including green roofs, green walls, parks, hedges, etc., leads to dilution of pollution by promoting dispersion and higher deposition of pollutants especially particulate matter on the vegetation. Also, trees act as barrier between source and receptor, causing turbulence by disrupting the streamline flow of plumes. Modelling the distribution of trees in high emitting pockets of urban areas is a mitigation measure to be adopted during urban landscape designing stage (Hewitt et al., 2019).

6. Conclusion

As the episodes of extreme weather events, air pollution and related health effects are becoming more intense, frequent, it is indeed mandatory to strengthen the adaptive capacity of the cities. Given the current climate scenario and complexity of the urban environment, adaptation strategies need to cover the entire cycle from capacity building of citizens against the possible hazard in the first place to immediate response to extreme events. Effective communication between the stakeholders and active participation of masses in the decision-making are a must to track the tipping point for development trajectories of the urban region. However, economic disparity, lack of good governance, lack of resources and lack of political will and preparedness are some of the challenges faced by middle and low-income countries which ironically are also witnessing rampant urbanization. The problem of urban heat island, anthropogenic air pollution and urban climate change have attracted global attention as global initiatives to promote climate actions at the city level have been taken up rapidly in recent decades. The Urban Climate Change Research Network is one such international collaborative decision support system to provide insight into climate-based actions and policies for urban administration. Such approaches are needed to put a strong foot forward in combating the climate-air-ecological threat posed by urbanization across the globe.

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