Climate Mitigation and Adaptation Concerns in Urban Areas

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Urban areas continue to be the center of action for many countries due to their contribution to economic development. Many urban areas, through the urbanization process, have become vulnerable to climate risk, thereby making risk mitigation and adaptation essential components in urban planning. Climate change is highly attributed to anthropogenic activities, and this makes population growth in urban areas a factor of global warming. The numerous problems and vulnerabilities associated with the urbanization process place urban areas at the center of climate adaptation and mitigation. Massive efforts have been made by urban areas and cities in general to mitigate and adapt to climate change. As reported, many of the world's urbanized areas have agreed on protocols that address climate change and push for urban actions that reduce greenhouse gas emissions and climate risks. Urban areas and cities' mitigation and adaptation actions to climate risks are, thus, essential towards the reduction of vulnerabilities.

Keywords: urban areas ; climate change ; mitigation ; adaptation

1. Introduction

Urban areas have long been the preferred place for human settlement [1]. This is due to the benefits and functions that serve and enable culture, learning, information, and industry [2][3]. Urban centers or cities in general go beyond human and resource concentration. People continue to settle in urban centers, and today, about half (54%) of the world's population lives in urban areas [4][5]. This is projected to increase to about 70% by the middle of the century [4]. Urban centers are articulate and facilitate greater functions of socio-economic activities that attract a lot of people [6].

The increasing concentration of people in urban areas has resulted in the transformation of agricultural lands into residential and industrial purposes [7][8]. There is, thus, unequal development of trade, housing, and tourism [9][10]. People's willingness to live in urban areas has resulted in migration and the continuous expansion of urban areas [5][11][12][13]. Through urbanization, many urban areas of the world have experienced massive growth with respect to population and economic development [13][14]. Urbanization is, thus, considered an essential process that offers numerous opportunities and serves as a catalyst for economic growth in urban areas [14]. Despite the numerous opportunities associated with urbanization, it results in some negative impacts and has received criticism in many studies (e.g., Wang et al. [15], Zhang et al. [16]). As people continue to live in urban centers, urban spaces expand, resulting in many socio-economic and environmental problems [15][17].

As urban areas continue to battle with the problems of urbanization, they are also challenged by the negative impacts of climate change [18][19]. This has made many urban areas of the world vulnerable [18][20][21]. For example, rising climate risks and atmospheric pollution negatively affect urban areas and increase urban vulnerabilities [22][23]. While several threats arise from the climate–atmosphere interactions, it is crucial to stress the negative impacts posed to human health, especially considering the critical role of health in socio-economic transformation [24]. Several studies have stressed the negative human health impacts and related vulnerabilities. For instance, Knol et al. [25] reported a medium to high relationship among short-term ultrafine particle exposure, mortality and morbidity, and increased cardiac and lung disease in Europe. Baccini et al. [26] highlighted the dire effects of increasing summer temperatures on people's health in fifteen European cities. Kan et al. [22] informed researchers about the mounting effects of extreme weather events and air pollution on mortality, infectious diseases, and water quality in China. Petkova et al. [27] also highlighted how heat-related death (deaths per one thousand population) increased in Philadelphia, New York City, and Boston between 1985–2006. Additionally, Lehtomäki et al. [28] showed that the death rate caused by particulate matter ($PM_{2.5}$) and ozone (O_3) was highest in Denmark and lowest in Iceland among the Nordic countries. Similarly, Peters and Schneider [29] explained how the combined consequences of heat, air pollution, age, and socio-economic and health conditions cause cardiovascular diseases and the need to consider disease prevention. The rise in the negative impacts of climate change and the potential health effects and vulnerabilities, especially in urban areas, needs attention [30][31][32]. Attention in this regard is on the right path considering the already existing negative impacts associated with the urbanization process and climate change [15].

Recent climate change is highly attributed to anthropogenic activities, and this makes population growth in urban areas a factor of global warming [14][33]. The numerous problems and vulnerabilities associated with the urbanization process place urban areas at the center of climate adaptation and mitigation [18][34]. Massive efforts have been made by urban areas and cities in general to mitigate and adapt to climate change [35][36]. As reported by Mi et al. [34], many of the world's urbanized areas have agreed on protocols that address climate change and push for urban actions that reduce greenhouse gas emissions and climate risks. Urban areas and cities' mitigation and adaptation actions to climate risks are, thus, essential towards the reduction of vulnerabilities [37].

Several studies have revealed the complementary and interrelated nature of adaptation and mitigation [38][39]. As reiterated by Landauer et al. [38], whereas adaptation reduces urban areas' sensitivity to climate risks, mitigation lessens their exposure. Conversely, Jones et al. [40] indicated differing views on the interrelatedness of adaptation and mitigation and, thus, suggested their separate treatment, especially considering the diversity of urban scale and policy design. Notwithstanding, adaptation and mitigation policies are essential to the continuous development of urban areas, and their combination offers enormous benefits, increases synergies, and minimizes conflicts [41]. As emphasized by Grafakos et al. [42], urban areas and cities recently have given attention to both adaptation and mitigation policies in planning. Several research studies (e.g., Seto et al. [13], de Oliveira and Doll [43], Gao et al. [44]) have stressed the co-benefits of adaptation and mitigation plans for urban areas.

Climate risks in urban areas were initially given less attention by climate change researchers and institutions as much attention was given to ecosystems and agriculture [45]. However, in recent times, urban areas have become the center of climate risk mitigation and adaptation, considering the socio-economic and human health vulnerabilities [13][18][34][35]. With urbanization and population growth recognized as a greater driver of global warming [14][33], it is imperative to understand how urban areas and urbanization have been treated by the climate change community, especially by the Intergovernmental Panel on Climate Change (IPCC) in their Assessment Reports (henceforth ARs).

The IPCC, established in 1988 under the auspices of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), is responsible for providing consistent scientific assessment on climate change, its consequences and potential future hazards, as well as adaptation and mitigation options (https://www.ipcc.ch/ accessed on 2 January 2022). The IPCC has delivered six ARs since 1988: the First (FAR) in 1990, which stressed the essence of climate change as a challenge with global effects and the need for world collaboration; the Second (SAR) in 1995, delivered essential materials for policymakers close to the approval of the 1997 Kyoto Protocol; the Third (TAR) in 2001, also drew attention to the impacts of climate change and the need for adaptation; the Fourth (AR4) in 2007, further based on the approval of the Kyoto Protocol and aimed at limiting warming at 2 °C above the late 19th century temperatures, and the Fifth (AR5) completed between 2013 and 2014, offered scientific contributions to the Paris Agreement. The Sixth (AR6), which is the current report, is expected to be completed by the second half of 2022 (although some sections are already released) and seeks to deliver three special reports: Global Warming of 1.5 °C (SR1.5), Special Report on Climate Change and Land (SRCCL), and Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) (https://www.ipcc.ch/about/history/ accessed on 2 January 2022).

As policymakers, academic and scientific communities, and other stakeholders await the release of the full and complete AR6, it is worthwhile to understand the impact of the first five ARs on academic concerns. With urban areas at the forefront of climate change adaptation and mitigation [13][18][34], and urbanization regarded as a major contributor to global warming [14][33], it is critical to comprehend the implications of IPCC ARs on the issue of climate risk mitigation and adaptation in urban areas. It is interesting to note that amongst the five IPCC ARs, only the AR5 dedicated a chapter to urbanization (captured under chapter 8: Urban Areas) [46]. The AR6 also recognizes climate-related problems of urbanization. It is, thus, important to understand how research advances after the delivery of each of the IPCC's ARs. The geographical distribution and prominence and the main topics reached will help understand which regions of the world are represented and cared for by IPCC ARs.

2. Socio-Economic

The studies revealing the socio-economic impacts of climate issues in urban areas showed varied outcomes. Most studies raised problems relating to climate impacts on agriculture, food security, poverty, and the adaptive capacity of urban areas. For instance, Salleh [47] stressed the impacts of climate change on agriculture and urban commerce in Malaysia and the developing countries of Southeast Asia, and its effects on poverty and food security. Salleh [47] suggested the need for better adaptation plans to prevent national and international conflicts in the region. Similarly, Ruiz-Alvarez et al. [48] underlined the variations in monthly and annual precipitation and their negative effects on agriculture in Aguascalientes, Mexico. To better adapt to this situation, Ruiz-Alvarez et al. [48] advocated the need to store water during high humid precipitation months for use in the dry season. Likewise, Singh et al. [49] stated that decreased freshwater access will have a surging effect on worldwide food security, livelihood, and widespread migration. Singh et al. [49] recommended increased measures for water preservation and wastewater recycling for improved adaptation. On the contrary, Ye et al. [50] projected an increase in food crop yield from 2030−2050 in China and indicated an increase in food supply in China. Nonetheless, Ye et al. [50] warned of the growing Chinese population as a counter-element to the projected increase in food supply and called for significant policy alternatives to address this issue. Again, Zhao et al. [51] found low and high adaptive capacity to climate problems in the inland and eastern coastal urban agglomerations, respectively, in China. Zhao et al. [51] proposed both adaptation and mitigation measures such as the expansion of infrastructure and funding for improved adaptive capacity in the underdeveloped regions and the regular monitoring of climate change impacts in the developed areas of China. Additionally, Wilder et al. [52] noted that climate change adaptation at international (U.S.A.–Mexico) borders is conservatively seen as difficult, despite the possible improved resilience in regionalization of adaptive responses. The researchers suggested specific adaptation plans such as improved social learning and co-creation of climate knowledge [52]. Additionally, Khan et al. [53] reported the vulnerable conditions of farmers in urban Punjab, Pakistan. To adapt to this situation, Khan et al. [53] suggested the enabling of climate-smart adaptation initiatives for urban farmers through the execution of useful policies and investment strategies.

Other studies emphasized the concerns about the impact of urbanization, urban housing, and city planning. Norman [54] saw the challenges associated with urbanization in Australia and proposed seven principles (see Norman [54] for more details), that should support intergovernmental accord on urban coastal planning. Moreover, Xie et al. [55] emphasized that the Shanghai metropolitan areas in China have the highest rates of increase in annual and seasonal average surface air temperature, ranging from 0.23 ℃ to 0.50 ℃ per decade due to urbanization. Likewise, Marelle et al. [56] stressed that urbanization increased the frequency and intensity of extreme urban precipitation in the megacities of Paris, Tokyo, Shanghai, and New York. To mitigate this, Marelle et al. [56] advocated the recognition of urbanization effects in urban planning assessments to make cities more resilient to extreme precipitation. In furtherance to this, Wilkinson [57] found changes in environmental building elements in Melbourne, Australia, and emphasized the need for policymakers to monitor building owners' integration of environmental elements into their stock to enhance sustainability. Moreover, Rosatto et al. [58] informed researchers about the usefulness of green roofs in regulating the thermal change of buildings in the autonomous city of Buenos Aires, Argentina, and specifically advocated for their use in controlling thermal change of buildings. Equally, Kousis et al. [59] established the potency of resin-based pavement binder made with waste bio-oils in urban noise reduction and explicitly suggested its global exploration in the urban pavement market.

3. Air Quality

The studies on air quality reflecting the impacts of IPCC ARs on the concerns of risk mitigation and adaptation in urban areas focused on pollution from both outdoor and indoor sources in cities. For instance, Garg et al. [60] found the electric power generation division of India to be the highest contributor of sulfur dioxide (SO_2) emissions, while the power and transport divisions likewise lead in nitrogen oxide (NO_x) emissions. Garg et al. [60] suggested mitigation elasticity to officials for efficient mitigation in India. Sthel et al. [61], in their laboratory experiment, found that ethanol production in Brazil generates pollutant gases like N_2O, SO_2, and NO_x, and advised better mitigation measures in that regard. Again, Campbell et al. [62], in their analysis on the impacts of transport sector emissions on future U.S. air quality under climate change reported widespread decreases in future concentrations of NO_X, SO_2, volatile organic compounds (VOCs), carbon monoxide (CO), ammonia (NH_3), and particulate matter with a diameter of microns (μm) less than or equal to 2.5 ($PM_{2.5}$) due to decreasing on-road vehicle emissions in urban areas. Notwithstanding, Campbell et al. [62] indicated an increase in 8 h ozone (O_3) in the U.S.A. and advised on the appropriate mitigation measures. Additionally, at the European level, San José et al. [63] found that by the year 2100, O_3 concentrations will decrease over most parts of Europe due to changes in temperature and precipitation, except Greece, Bulgaria, and Romania, and in the city of Milan, Italy, and advised on the need for the right mitigation measures. Moreover, Xie et al. [64] established that biogenic VOC and soil NO_X emissions over the Yangtze River Delta (YRD) area of China in 2008 were 657 Gigagrams (Gg) of carbon and 19.1 Gg of nitrogen, correspondingly. Xie et al. [64] indicated a potential increase in these emissions by 25% and 11.5% in 2050, in that order. In the same study, the researchers found an increase in surface O_3 of 5 to 15 parts per billion (ppb) in the northern areas and a decrease of −5 to −15 ppb in the southern areas of the YRD. Similarly, Lam [65] highlighted the potential increase in $P.M_{2.5}$ and O_3 in the Pearl River Delta region of China in 2050 under the representative concentration pathway (RCP 8.5).

In their analysis on the impact of urban growth on air quality in Indian cities, Misra et al. [66] found that above the central portion of a city, concentrations of $PM_{2.5}$ emissions are mostly contributed by residential areas, brick kilns, and industries.

4. Sea Level Rise/Flooding

Several other studies confirmed sea level rise and flood risks in urban areas. On sea level rise, Bhuiyan and Dutta [67] informed people about increased salinity intrusion into the Gorai River in Bangladesh and advocated for the appropriate adaptation plans. Wong et al. [68] stressed that regionally, megacities in Africa, South, Southeast, and East Asia, and the Small Island States have the highest vulnerabilities to sea level rise, which requires adaptation. Wang et al. [69] revealed the potential impacts of rising tides on residential buildings in Australia and informed the need for adaptation. In Abadie's analysis of sea level damage risk in the world's 120 major coastal megacities, the researcher reported potential greater damage for Guangzhou, China and New Orleans, U.S.A., and emphasized the need for potential huge adaptation assets in these countries [70]. Additionally, Mycoo et al. [71] emphasized the vulnerable state of Greater Bridgetown, Barbados, due to sea level rise and revealed the significance of human adaptation and the safety of precious coastal assets.

On flood risk, Moeslund et al. [72] talked about the possible flooding in Aarhus, Denmark, in the event of extreme weather phenomena and suggested the incorporation of appropriate flood models equally to those in their study on potential city planning. Mortsch [73] revealed the flooding challenges in downtown London, Ontario, Canada, and recommended increased adaptation in that regard. Le Cozannet et al. [74] reported the probabilistic marine flooding in the urban Mediterranean basin in Lyon, France, and recommended the consideration of a change-centered global sensitivity analysis of potential marine flooding. Additionally, Cheng et al. [75] showed the effectiveness of the detention of increasing flood hazards in the Charles River watershed in Boston, U.S.A., and suggested the importance of creating more detention areas integrated with soil preservation in watershed development. Further, Samu and Kentel [76] stated that the greater part of Zimbabwe has low to medium (2.3% likelihood) flood incidence and highlighted the need for the execution of proper mitigation measures. Martínez-Gomariz et al. [77] highlighted the effects of pluvial flood risk in Badalona, Spain, and stressed the need for a comprehensive adaptation plan. Moreover, Abadie et al. [78] analyzed potential coastal flood risk damage in 136 cities and found the highest potential damage in Guangzhou, China; Mumbai, India, and New Orleans, U.S.A. Abadie et al. [78] recommended the need to encompass the likelihood of high-end scenarios into coastal urban adaptation development for potential sea level rise and flood risk.

5. Extreme Temperatures

In extreme temperatures, many studies emphasize heat stress and thermal comfort. For instance, Lee and Levermore [79] reported an increase in mean surface temperature and its effect on heat and cold in the cities of Seoul and Ulsan, South Korea, and indicated the need for improved mitigation. Similarly, O'Neill et al. [80] stressed the excessive heat events in 285 communities in the U.S.A. Although mitigation measures are in place, O'Neill et al. [80] suggested the need for more collaboration and economic resources to assist widespread mitigation actions. Again, Adachi et al. [81] revealed the present and potential increased urban heat island (UHI) in Tokyo, Japan, and called for increased mitigation measures against UHI for the city. Additionally, Tromeur et al. [82] described the energy needs for residential buildings and comfort (heat) in 10 French cities and indicated their susceptibility. For improved mitigation, Tromeur et al. [82] suggested the need for city managers to think about green space spots, push polluting actions beyond the city, and lower car traffic for riders. McPhee et al. [83] informed people about the potential heat events in Santiago, Chile, due to increasing temperatures and decreasing precipitation and recommended the need for effective adaptation plans. Additionally, Shevchenko et al. [84] underlined the heat wave episodes in Lugansk and Henichesk, Ukraine, and highlighted the need for adaptation. Further, Cinar [85] revealed the increased UHI in Fethiye, Turkey, due to a rise in night-time temperatures. The researcher suggested the need to consider street alignment of buildings and the dimensions of public and green areas in city management and design [85]. Hamdi et al. [86] found no significant change and increased warming in annual mean UHI intensity and nocturnal UHI, respectively, in the cities of Brussels (Belgium) and Paris (France), and advised appropriate adaptation plans. In furtherance to this, Alves et al. [87] showed the residential thermal discomfort situation in São Paulo, Brazil, and recommended an improved adaptation plan in that regard. Equally, Invidiata and Ghisi [88] indicated the potential increase in residential energy demand of buildings in the cities of Curitiba, Florianópolis, and Belém, Brazil, and recommended the utilization of passive design plans in buildings. Li et al. [89] emphasized the potential for higher temperatures and severe heat waves in Toronto, Ontario, Canada, and showed how their study can help policymakers realize potential temperature changes in Ontario. In proposing specific mitigation measures against heat due to increasing urban temperatures in Bari, Italy, Lassandro et al. [90] specifically suggested the use of green roofs, water jects, and cooling resources. Furthermore, Kotharkar et al. [91] discovered significant variation in temperature regime and heat stress within Nagpur, India, and demonstrated how their research can provide heat response planning and mitigation plans to the area.

6. Health

Several studies stressed the negative health impacts (mortality, morbidity, and general human health) in urban areas due to increasing temperatures and air pollution. For instance, Knol et al. [25] reported that 14 European technocrats ranked a medium-to-high association between increased short-term ultrafine particle exposure and mortality, and morbidity for cardiac and lung diseases. The researchers recommended the need to consider ultrafine particles in potential health risk assessment [25]. Muthers et al. [92] informed people about the potential rise in heat-associated mortality of about 129% in the city of Vienna, Austria, if no adaptation plan is taken. In the analysis of the effect of heat on mortality in 15 European cities, Baccini et al. [26] found that heat-related mortality for summer went from zero (0) in Dublin, Ireland to 423 in Paris, France. Baccini et al. [26] further indicated the potential increase in summer temperatures and their effect on the health of the people in Europe, and emphasized the need for improved mitigation. Similarly, Ostro et al. [93] reported increased premature deaths in California, U.S.A., and recommended the increased use of air conditioners as a mitigation measure for heat risk. Likewise, Petkova et al. [27] showed that heat-associated mortality per thousand population increased in Philadelphia, New York City, and Boston, respectively, from 1985 to 2006. Petkova et al. [27] highlighted the significant contributions of their study in developing measures that can reduce potential heat effects. Again, Kim et al. [94] revealed the projected increased mortalities in Seoul, Daegu, Gwangju, Busan, Incheon, and Daejeon, South Korea, and stressed effective measures that can cause significant health improvement and decrease heat-associated mortality. Additionally, Rasmussen et al. [95] highlighted the increased ragweed species in the European countries of Denmark, France, Germany, and Russia by the year 2100, and showed how this intersects with heavily inhabited cities like Paris and St. Petersburg. Rasmussen et al. [95] suggested the need for preventive measures to limit ragweed seed spread and the application of inter-country management measures for increased mitigation of potential health risk. Chen et al. [96] further informed people about the potential increase in surface O_3 and associated mortality in China and underlined the need for mitigation measures. Additionally, Estoque et al. [97] assessed heat health risk in 139 cities in the Philippines and reported high heat health risk in the Manila metropolitan area. The researchers indicated how their research can assist in risk reporting and improve knowledge of city-scale health risks.

7. Water Supply/Drought

Most studies raised concerns about the impact of climate issues relating to water supply and demand, water use and management, and drought. For example, Gober et al. [98] reported that current per capita water use in Phoenix, Arizona, can be maintained in the absence of unmanageable groundwater use. For improved mitigation against drought disasters, Galvão et al. [99] stated that rainwater catchment structures are used in the urban areas in Brazil and Japan to increase water source and use. Again, Wilson and Weng [100] reported water quality (phosphorus concentration) issues in the Des Plaines River watershed in Chicago, Illinois, U.S.A. during late winter and early spring. The researchers underlined the importance of their study in contributing to the reduction of negative effect on surface water quality and improved mitigation [100]. Moreover, Jacinto et al. [101] informed people about the potential reduction in water use in Portugal until 2100 and recommended a proper adaptation plan. Additionally, Huang et al. [102] found variations in water resources and potential drying trends and their effects on water resources in Chinese cities. Huang et al. [102] suggested the need to address water resource challenges and adapt to the impacts of climate change. Ougougdal et al. [103] reported increased water demand and related water scarcity problems in Ourika, Morocco, and called for an appropriate adaptation plan. Alike, Alkhawaga et al. [104] underlined the potential water security condition in Kafr El Sheikh city, Egypt, and recommended the need for frequent evaluation of water security features for Egyptian cities.

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