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A systematic review of the health co-benefits of urban climate change adaptation

Ayyoob Sharifi [a,b], Minal Pathak [c,*], Chaitali Joshi [c,d], Bao-Jie He [e,f]

[a] Graduate School of Humanities and Social Sciences & Network for Education and Research on Peace and Sustainability (NERPS), Hiroshima University, Japan
[b] Graduate School of Advanced Science and Engineering, Hiroshima University, Japan
[c] Global Centre for Environment and Energy, Ahmedabad University, Commerce Six Roads, Navrangpura, Ahmedabad, Gujarat 380009, India
[d] Department of Architecture, The Maharaja Sayajirao University of Baroda, Pratapgunj, Vadodara, Gujarat 390002, India
[e] School of Architecture and Urban Planning, Chongqing University, Chongqing, 400045, China
[f] Key Laboratory of New Technology for Construction of Cities in Mountain Area, Ministry of Education, Chongqing University, Chongqing, 400045, China

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ABSTRACT

The recent and projected upward trends in the frequency and intensity of climate-induced events in cities have enhanced the focus on adaptation. In addition to enhancing the capacity of cities to prepare for and absorb risks, adaptation measures provide multiple co-benefits. However, health co-benefits are among the least explored. These are now seen as increasingly important with the renewed focus on public health since the COVID-19 pandemic. This study reviews literature focused on the health co-benefits of urban climate change adaptation measures. Health co-benefits of seven different categories of adaptation measures are discussed. Results showed that existing evidence is mainly related to some categories such as critical infrastructure, nature-based solutions, and urban planning and design measures. Other adaptation categories like early warning systems; policy, management & governance, including local adaptation policies; and measures and strategies related to 'knowledge, perceptions & behavior' that mainly involve people's understanding and individual responses to climate change, are relatively underexplored. Moreover, it was discussed that some adaptation measures may result in health trade-offs and these needs to be further studied. Overall, through identifying health co-benefits, results of this review can make a strong case for further promotion of climate change adaptation in cities.

1. Introduction

Cities are now on the crossroads of multiple crises; of an unexpected pandemic and deepening climate emergency. With cities having to address multiple issues, an understanding of adaptation measures could help identify and prioritize actions in cities. According to the Intergovernmental Panel on Climate Change, adaptation in human systems refers to "the process of adjustment to actual or expected climate and its effects", in order to moderate harm or exploit beneficial opportunities (IPCC, 2018). Climate change adaptation and dealing with challenges of meeting demands for infrastructure, health, and wellbeing goals for citizens are now priorities for many cities. The co-benefits framing offers an approach for policymakers to think of a solution-oriented approach that can integrate diverse concerns. In literature, co-benefits are generally seen as benefits that might be additional to the global health gains from mitigation (Ganten et al., 2010). Similarly, Cheng and Berry (2013) identify health co-benefits as "advantages outside of the scope of the original health outcomes targeted to be improved". This paper refers to the IPCC definition where co-benefits are "the positive effects that a policy or measure aimed at one objective might have on other objective, irrespective of the net effect on social welfare" (Mayrhofer & Gupta, 2016, IPCC, 2014).

Increasingly, the impacts of climate change become more evident as global emissions of Greenhouse Gases continue to rise. This is evidenced by the upward trends in the annual frequency of climate events such as floods, droughts, severe storms, and heat waves, and their associated human and economic losses in recent decades (Hoeppe, 2016; Smith & Katz, 2013).

Cities as compared to rural areas have many positive impacts on people like higher employment, and better access to health and

* Corresponding author at: Global Centre for Energy and Environment, Ahmedabad University, GICT Building, Central Campus, Navrangpura, Ahmedabad 380009, Gujarat, India.
E-mail addresses: sharifi@hiroshima-u.ac.jp (A. Sharifi), minal.pathak@ahduni.edu.in (M. Pathak).

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education facilities. However, people living in cities are also affected by potential health risks due to overcrowded living conditions, inadequate sanitation, poor quality of water, contaminated food, traffic congestion, noise and air pollution and poor, and inadequate housing facilities. The COVID-19 pandemic has further amplified the risks at the intersection of health and climate in cities (Sharifi and Khavarian-Garmsir, 2020). Given the future rate of urbanization and projected risks from climate and their impacts on human health (Bai et al., 2012), this study is focused on urban areas.

The annual direct losses to disasters in cities are estimated to be more than USD 300 billion and, in the absence of proper adaptation plans, this may cross USD 400 billion by 2030 (WB, 2016). A large proportion of these costs are health related (Limaye et al., 2019). While there is a lack of global estimates of the health-related costs, past events indicate that they can exceed billions of dollars (Holmes et al., 2016; Knowlton et al., 2011).

Climate change adaptation measures are critical to minimize economic losses associated with climate-related health risks (Limaye et al., 2020). For instance, estimations for Skopje, Macedonia show that adaptation interventions can reduce the estimated annual cost of heat-related mortality by more than 30% (Floater et al., 2014). However, while health co-benefits of climate change adaptation are acknowledged, they are among the least studied co-benefits of adaptation measures (Sharifi, 2021). There are a few studies that mention health co-benefits of some adaptation measures (Harlan & Ruddell, 2011; Younger et al., 2008). Despite this, there is still a lack of review articles that provide a more comprehensive account of the health co-benefits of adaptation in cities. Better knowledge of these co-benefits is needed as urbanization trends are increasing globally and, particularly, in developing countries. This may create additional challenges as urbanization may result in issues such as degraded ecosystems services, intensified air pollution, reduced physical activity, and increased inequalities; thereby, increasing vulnerability to health-related impacts of climate change (Holmes et al., 2016; Smith & Levermore, 2008). Adopting well-designed adaptation strategies is argued to significantly reduce the health-related impacts of climate-induced events in cities (Hondula et al., 2014). Through providing a clear understanding of co-benefits, this study would help cities prioritize adaptation actions that can address multiple goals and potentially gain a better buy-in from stakeholders. In this regard, better knowledge of health co-benefits can inform planners and decision makers of the desirable and effective adaptation measures that should be taken. Health co-benefits of seven categories of adaptation measures are addressed in this paper, namely infrastructure including critical and health infrastructure, nature-based solutions, housing and building design, urban planning and design, early warning systems, policy and management and governance, and knowledge, perception and behaviour. Depending on the adaptation measure, different health co-benefits such as reduced cardiovascular and respiratory diseases, decreased heat stress, reduced exposure to food and water-borne diseases, and enhanced mental health can be achieved. Various methods/strategies are listed in this paper, adoption of which would result in health co-benefits such as improved stormwater management (critical infrastructure) and enhanced equity and access (health infrastructure) by collaborative approaches and monitoring in informal settlements. Implementation of nature-based solutions would help in improving thermal comfort, reduced pollution, reduced climatic risks like floods and heat waves. Naturally ventilated and passive design strategies can contribute to enhancing Indoor Air Quality and Indoor thermal comfort. Strategies aiming at reducing urban heat island effect and increasing albedo effect would reduce heat stresses and decrease cardiovascular risks. Compact urban development and combined passive design measures at urban planning and design level would substantially help in achieving adaptation targets. Early Warning systems would reduce social and economic losses. Policy, management and governance help in mainstreaming future plans and policies and identifying and institutionalizing structures that can help best help in implementing plans and policies. Knowledge, perception and behaviour could be accelerated by engaging stakeholders at every stage and improving individuals' perception and awareness. All these together can bring huge positive health benefits.

An earlier study by Sharifi (2021) details co-benefits and synergies between adaptation and mitigation measures but does not focus on health co-benefits of adaptation. A few other studies discuss co-benefits of individual adaptation actions (Gronlund & Berrocal, 2020; Shen et al., 2020; Valois et al., 2020). To our knowledge, there are no comprehensive studies which provide recent evidence of the health co-benefits of climate change adaptation in cities.

Against this background, the main objective of this paper is to provide a better understanding of the health co-benefits of urban climate change adaptation measures by reviewing literature across different urban sectors. The paper is structured as follows. Methods for literature search and selection and content analysis are presented in the next section. Review results are presented and discussed in Section 3. Section 4 provides more discussions and Section 5 concludes the paper by summarizing the findings and providing some recommendations.

2. Materials and methods

The flowchart of procedures taken to select relevant studies to be included in this review is shown in Fig. 1. For literature selection, we have followed the "preferred reporting items for systematic reviews and meta-analyses" framework proposed by Moher et al. (2009). The framework has been adopted by thousands of researchers over the past decade and allows selecting related literature in a systematic way. We first developed a broad-based search string that includes terms related to adaptation, health, climate change, and cities (see the Appendix). The initial search for literature was conducted on November 11, 2019 and returned 616 articles. In addition, 68 articles were added to the database by searching in Google Scholar and screening the cited references of the originally retrieved articles. Titles and abstracts of all articles were screened to select those related to the health co-benefits of adaptation measures. The screening criteria were as follows: specific focus on urban areas (i.e., focusing on one or multiple urban scales, ranging from building to region), focus on at least one adaptation measure/action, and consideration of health/well-being implications of the adaptation measure(s). Articles related to climate risks or impacts but not focused on health co-benefits were excluded. Full texts of the remaining 257 articles were carefully read to extract information related to health co-benefits. While reading the full texts, 12 more articles were excluded as they did not include details related to health co-benefits. It is worth noting that many related papers may have been published since our original search in 2019. While we have not included those systematically in this study, we activated the alert function of Web of Science (WoS) to receive regular notifications of newly published articles and integrate their insights. We believe this selection procedure has allowed us to include as many relevant papers as possible in the review. We acknowledge that some other related papers may exist that have not been identified through our approach. However, we argue that the number of papers reviewed is large enough to extract patterns and adding more papers would probably not affect the results reported in the paper.

An information extraction sheet was developed in Microsoft Excel to collect evidence on different items such as the geographic focus of the study, the type of adaptation measure(s) studied, the health co-benefits, and potential health trade-offs. Upon completing the Excel sheet, information synthesis was conducted manually using an inductive content-analysis method (Mayring, 2014). As discussed by Moldavska & Welo, (2017), when existing knowledge on a topic is fragmented and there are no previous systematic reviews, inductive content analysis is a desirable method. It allows extracting insights from the literature more comprehensively and without preconceived bias (in case of our study this means without previous assumptions regarding the adaptation

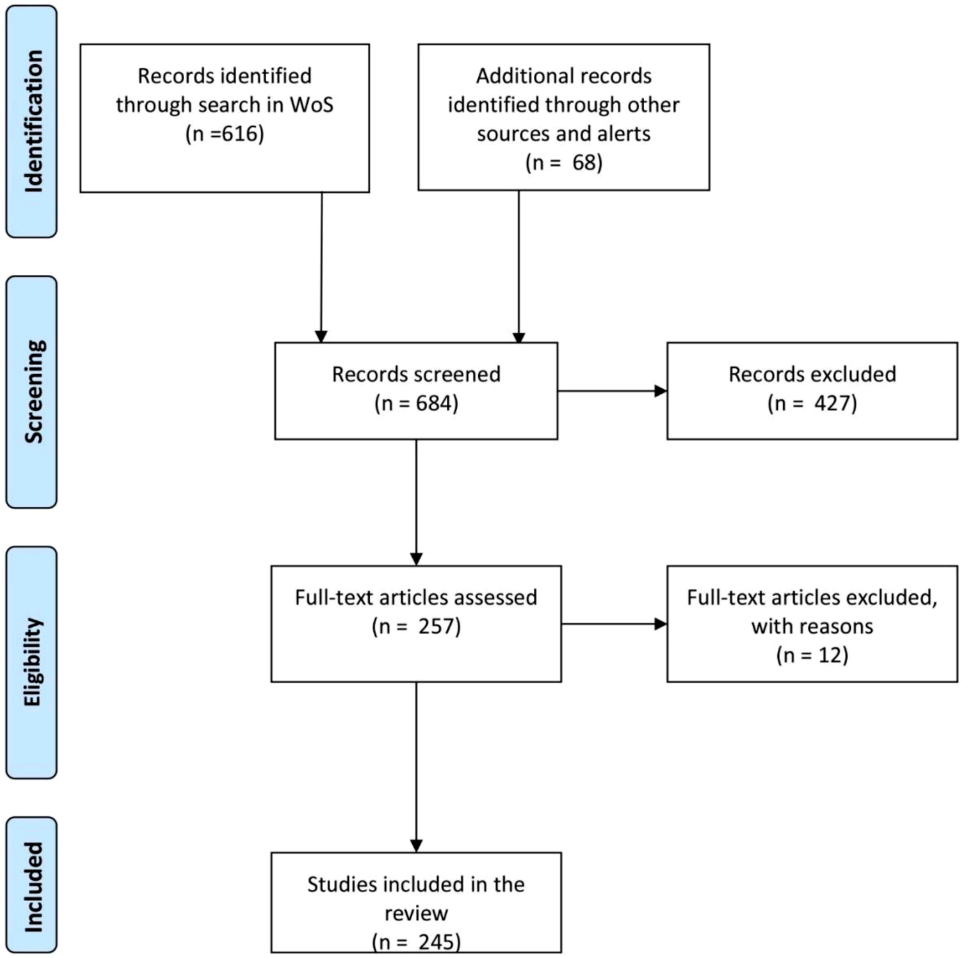

Fig. 1. Procedures for literature search and selection - adapted from Moher et al. (2009).

measure categories and their health co-benefits). Despite these benefits, inductive content analysis is a time-consuming process due to the lack of previous standards and categorization (Moldavska & Welo, 2017). Also, as is the case for all qualitative approaches, this process involves certain levels of subjectivity. Regarding the specific procedures for inductive content analysis, when checking information collected from the first paper, the listed adaptation measures were divided into several categories depending on their focus. While reading collected information of the next paper, it was checked if the discussed measures can be classified under existing categories or should be classified as distinct ones. In other words, new categories of adaptation measures were only developed if the discussed measures could not be subsumed to one of the previously identified categories. This process continued until all information in the Excel sheet was checked. At the end, there were seven categories of adaptation measures, namely, infrastructure, nature-based solutions, housing and building design, urban planning and design, early warning systems and monitoring, policy and management, and knowledge and perceptions. The infrastructure category refers to infrastructure supporting operations of different sectors such as transport, water, sewerage, sanitation, energy, and health. Nature-based solutions include a wide range of measures aimed at protecting and restoring natural ecosystems in urban areas. Among other things, these include development of parks and urban forests and integration of green roofs and facades. Housing and building design measures are aimed at providing indoor thermal comfort through using either passive design techniques or mechanical air conditioning systems. A wide range of urban planning and design measures exist that shape the form and structure of cities. In the context of this study, these include density, configuration and orientation of street canyons, shading, and increasing surface albedo. Early warning systems refer to systems developed to collect and process data, monitor trends, and disseminate information in a timely manner to facilitate effective communication of risks and threats. This is likely to enhance preparation and absorption capacities. Policy, management, and governance entail a wide range of measures incorporated into municipal and sectoral plans to identify risks and their impacts and develop and implement proper mitigation and adaptation plans to deal with them. Finally, knowledge, perceptions, and behavior refer to measures aimed at increasing risk awareness of people and promoting behavioral changes that strengthen their abilities to absorb and adapt to risks.

3. Results

Out of 245 papers included in study, 105 papers verify the evidence of positive impact of adaptation strategies, 91 papers confirm health as the primary co-benefit and 48 papers highlights health as a secondary co-benefit. Most of these studies relied on observations while a small number of studies were based on modeling. About a dozen studies included a global sample of cities while a number of these were individual city case-studies.

These co-benefits of the seven identified categories of urban climate adaptation measures are described in the following sub-sections. A summary of the main results of the review including the main results and the key gaps according to the studies that have been analyzed can be found in Table 1 at the end of this section.

Table 1
Summary of adaptation measures, benefits, trade-offs and major gaps.

Adaptation measures}		*Majoradaptationbenefits*	*Majorhealthco − benefits*	*Majorhealthtrade − offs*	*Majorgaps*
Infrastructure	Critical infrastructure	- Enhancing capacity cope with/ absorb risk	- Reducing inequalities - Improved physical activity - Reduced respiratory effects - wellbeing benefits		- Quantified estimates of the health contributions - Analysis of differential health impacts on informal settlements and vulnerable groups
	Health infrastructure	- Improving resilience of vulnerable groups - Enhanced capacity to absorb a wide range of risks	- Short- and long-term benefits for physical and mental health - Reducing exposure to food- and water-borne diseases		
Nature-based solutions	Urban greenery	- UHI mitigation - Flood control - Reducing water stress	- Ecosystem services (clean air, clean water) - Reduced heat stress - Mental health benefits - Reduced cardiovascular diseases	- Spread of vector-borne or zoonotic diseases - Pollen allergies	- Empirical evidence on the direct health impacts of the solutions - Estimates of the cumulative health co-benefits of multiple solutions
	Other nature-based solutions		- Reducing exposure to water-borne diseases - Mental health benefits - Ecosystem services (clean air, clean water) - Reduced heat stress		
Housing and building design		- Adaptation to extreme heat and cold - Improving adaptive capacity of vulnerable groups	- Reducing morbidity and mortality rates due to indoor pollution - Enhanced indoor thermal comfort	- Passive measures such as natural ventilation may cause trade-offs in polluted contexts - Sick building syndrome	- Sufficiency of passive design measures for providing thermal comfort under future scenarios - Combined effects of multiple measures
Urban planning and design		- Avoiding risk-prone areas	- Improved physical activity and reduce	- Possibility of higher exposure to pollution and	- Knowledge on the optimal levels of density, mixed

(*continued on next page*)

Table 1 (*continued*)

Adaptation measures}	*Majoradaptationbenefits*	*Majorhealthco − benefits*	*Majorhealthtrade − offs*	*Majorgaps*
	- Ecosystem protection - Reduced energy and water consumption	obesity and cardiovascular diseases - Reduced stress and fatigue - Improved mental health - Ecosystem protection	UHI effect in compact cities - Possibility of more stress in compact cities	use, connectivity, etc. - Combined effects of multiple measures
Early warning systems	- Better preparation capacity to absorb various types of shocks - Enhanced risk awareness	- Reduce mortality and morbidity - Reduce hospital admission		- Integration and effective communication of health co-benefits in early warning systems
Policy, management, and governance	- Enhanced planning and absorption capacities	- Better inclusion of the needs and priorities of different groups		- A database of different measures and their benefits - Implementation of health-focused adaptation measures - Knowledge on differential impacts of the interventions
Knowledge, perceptions, and behavior	- Enhanced awareness leads to better adaptation	- Better capacity to avoid unhealthy conditions	- Potential health risks from air conditioning overuse	- Understanding people’s awareness and perceptions

3.1. Infrastructure

Infrastructure is a key intervention area for adaptation (Lee & Kim, 2018). The aspects of infrastructure that are important for climate change adaptation can be broadly divided into three categories: i) Critical infrastructure that relates to the built environment including transport, water, sewerage, sanitation, and energy, and ii) Health infrastructure., and iii) Nature-based solutions. This section covers the first two categories while nature-based solutions are addressed in Section 3.2.

3.1.1. Critical infrastructure

Adequate and good quality physical infrastructure including transportation systems and infrastructure, sewerage and stormwater and electricity infrastructure in urban areas is essential for climate change adaptation. In addition to enhancing adaptation to direct and indirect climate impacts, investments in infrastructure holds priority for three reasons: i) Physical infrastructure lasts for decades impacting long-term urban resilience (Ürge-Vorsatz et al., 2018), ii) Infrastructure and access to services enhance public health and wellbeing especially in developing countries, and iii) Inadequate infrastructure can amplify climate impacts and exacerbate existing inequalities. For instance, a study of 22 capital cities in China showed nearly half of the cities had vulnerable infrastructures and would find it extremely challenging to adapt to future climate change under RCP 4.5 and RCP 8.5 resulting in economic losses (Deng et al., 2020).

Stormwater infrastructure becomes particularly important in settlements close to waterways or denser settlements, where populations adds pressure on aging or inadequate stormwater infrastructure, increasing the challenges with flood management (Serrao-Neumann et al., 2014). Adequate and good quality sanitation and stormwater infrastructure prevents water logging and provides health co-benefits from reduced outbreak of diseases. In developing countries, increasing growth will pose additional challenges in future, and investments are urgently needed to maintain the services that enhance wellbeing of citizens. For example, Reckien (2014) show that in India, investments in health and water infrastructure and management would have the highest potential to reduce impacts across income groups, particularly the low-income residents.

3.1.2. Health infrastructure in the context of climate change and COVID-19

The intersections of climate change and health are particularly complex. In 2015, the Lancet Commission on Health and Climate Change, emphasized that climate change could significantly threaten public health benefits gained in the past few decades and investments in health infrastructure on the other hand presented ‘the greatest opportunity of the 21st century’ (Watts, Amann, Ayeb-Karlsson, Belesova, & Bouley, 2018). Climate risks threaten health infrastructures in cities in many ways- for example from increased mortality and hospital admissions during heatwaves and extreme events, increased disease outbreaks post extreme rainfall events, and increase in water- and food-borne diseases from a changing climate. Especially post COVID, concerns of adequacy of health infrastructure to cope with these multifarious challenges have deepened (Fox et al., 2019). COVID-19 resulted in massive health impacts from mortality, severe short- and long-term impacts on physical health, and impacts on mental wellbeing. While these impacts are witnessed in cities across geographic regions and development status, the vulnerability of the urban poor, minority communities or communities of color has been highlighted due to their pre-existing social, economic, and infrastructural constraints. Future plans should ensure that solutions are built on the foundation of equity and environmental justice, so these do not end up exacerbating existing inequalities. Proposed solutions include collaborative decision making, involving local stakeholders in plan making processes, better coordination with the local governments, and enhancing the data and monitoring in informal settlements (Wilkinson, 2020).

COVID-19 has also initiated discussions in literature around compounded impacts and adaptation to both climate change and pandemics. For example, disruptions in power supply to hospitals from extreme events during pandemics or the increased vulnerability of populations to pandemics when combined with poor air quality after bushfires can result in multiple and cascading impacts on communities (Phillips et al., 2020). The Global Commission on Adaptation calls for an investment of $1•8 trillion globally upto 2030 and identifies investments in climate-resilient infrastructure among the top areas for new investments (Herrero & Thornton, 2020; Saghir et al., 2020). Strengthening health infrastructure would require going beyond strong emergency preparedness systems towards a long-term adaptation strategy including good governance and accountability (Milner et al., 2021; Phillips et al., 2020). A starting step would be making efforts towards improving the database of public health policies and their impacts on the local populations. Such a database would include identifying areas and communities that are more vulnerable and developing strategies that include and specifically incorporate resilience of these communities. Recent studies are highlighting the importance of robust public health infrastructure including improving resilience of public hospitals in cities (Aghapour et al., 2019; Sheehan et al., 2020). Expansion of health infrastructure could possibly result in trade-offs such as from reduced public funding for other climate adaptation projects however there is limited evidence in literature so far.

3.2. Nature-based solutions

The reviewed literature covers various solutions ranging from the individual building scale (e.g., green roofs), to neighborhood scale (neighborhood parks, bicycle lanes), to city-wide networks of green and blue spaces. The following subsections discuss co-benefits associated with two major categories: urban greenery and other types of nature-based solutions.

3.2.1. Urban greenery

These include measures such as urban nature protection, increasing the share of urban greenery (e.g., urban trees, parks, and gardens), and creation of connected networks of parks and green spaces. These measures enhance climate change adaptation by, among other things, improving thermal comfort through regulating microclimatic conditions, mitigating urban flooding through stormwater management, and overcoming water stress by facilitating groundwater recharge (Sharifi, 2021). Health and well-being co-benefits of such measures can be divided into three major categories: thermal comfort benefits that minimize health issues caused by heat stress; health benefits associated with reduced air, water and noise pollution; and mental/physical health benefits. Cooling benefits of urban greenery is well evidenced in the literature (Belcakova et al., 2019; Martinez et al., 2019; Sharifi, 2021; Toparlar et al., 2015; Zolch et al., 2019). In particular, the utility of urban greenery for mitigating the Urban Heat Island (UHI) effect is emphasized (Brown et al., 2018). There is ample evidence suggesting that urban greenery alleviates negative health impacts by reducing heat exposure, particularly heat burdens on vulnerable social groups such as elderly (Arifwidodo & Chandrasiri, 2020; Baldwin et al., 2020). For instance, examining impacts of various factors such as land use type, urban green coverage (vegetation index, tree cover, urban garden), built environment typology, and socio-economic factors on heat-related mortality in London, Murage et al. (2020) found that areas with higher level of green coverage exhibit lower temperatures, and urban green coverage has the greatest mitigation effect on heat-related mortality (Murage et al., 2020). Similarly, evidence from Boston, MA indicates that greater density of street trees decreases the odds of indoor and outdoor heat-related mortality on hot and humid days (Williams et al., 2020).

Pollution mitigation benefits of urban greening are extensively discussed in the literature (Brown et al., 2018; Chiabai et al., 2018). It is argued that through absorption of pollutants such as Ozone and particulate matter, urban greenery can reduce their ground-level concentration, thereby contributing to the reduction of mortality rates and respiratory diseases (Jaafari et al., 2020; Knight et al., 2016). In Sao Paulo, Brazil, for instance, conservation and promotion of urban green spaces is demonstrated to be an effective strategy for management of urban air pollution (Siqueira-Gay et al., 2017). Similar results have been reported in a study conducted in Tehran, the most polluted city of Iran (Jaafari et al., 2020). A modeling study in Lisbon, Portugal shows that air quality is better in areas near streams and green spaces. Also, analysis of 107 parks in the city demonstrates that significant air quality improvements can be achieved by increasing area and vegetation density of green spaces (Matos et al., 2019). This study and other research conducted in Almada, Portugal (Jaafari et al., 2020; Vieira et al., 2018) stress that not all green spaces provide identical air quality improvements and factors such type and composition matter. In Almada it was found that urban greenery featuring more complex structures (e.g., trees) and less management (i.e., pruning, irrigation, etc.) is more effective for air quality improvement than green spaces with less complex structures and more management requirements (e.g., lawns) (Vieira et al., 2018).

In addition to benefits accrued from cooling, urban greening contributes to physical/mental health and well-being of urban residents (Belcakova et al., 2019; Kondo et al., 2018; Mytton et al., 2012). Presence of green space is argued to foster additional physical activities among residents (Mytton et al., 2012; Wang et al., 2019). In addition, proximity and access to green spaces may improve mental/psychological state of citizens (Belcakova et al., 2019; Nutsford et al., 2013). These, in turn, contribute to reducing health risks. A survey of urban residents in seven Korean metropolitan cities showed that risk of diseases such as cardiovascular disease, coronary heart disease, acute myocardial infarction, total stroke, and ischemic stroke is lower among inhabitants of areas with higher urban green space coverage (Seo et al., 2019). In Auckland, New Zealand, access to green space was found to contribute to treatment of Anxiety/mood disorder (Nutsford et al., 2013). Similarly, results from three Australian cities demonstrated that exposure to higher rates of tree canopy or grass helps alleviate anxiety and psychological distress (Astell-Burt & Feng, 2019).

3.2.2. *Other types of nature-based solutions*

In addition to the previous category that entails generic efforts to increase urban greenery and promote nature protection, a wide range of other solutions exist that facilitate adaptation and also provide health co-benefits. These include elements such as green roofs, green walls, bioswales, green bike lines, etc. (Wu et al., 2018). Also, elements such as lakes, urban streams, wetlands, and other types of water bodies are important (Wu et al., 2018). In much the same way as green spaces do, these measures contribute to climate change adaptation by regulating stormwater runoff and urban microclimate (Sharifi, 2021). A combination of various climate-induced events such as floods and hot weather can increase the likelihood of water-borne diseases. Climate-induced heavy rainfalls may lead to the overflow of combined sewer or leakage of water-borne pathogens from agricultural lands. These, in turn, may contaminate drinking water reservoirs and/or increase the risk of direct and/or indirect exposure to contaminated floodwater (Semenza, 2020). Accordingly, through stormwater management and flood prevention, nature-based solutions can reduce the risk of water-borne diseases (Levy et al., 2016; Zinia and McShane, 2018). nature-based solutions such as sustainable drainage systems are also argued to enhance perceptions of health and wellbeing among residents (Charlesworth, 2010). Furthermore, microclimate regulation benefits of such measures contribute to air purification and reduce health-related issues caused by heat stress and the UHI effect (Li and Bou-Zeid, 2013; Pitman et al., 2015; Wu et al., 2018; Zardo et al., 2017; Zinia & McShane, 2018). Also, increasing residents' interactions with nature-based solutions is beneficial for mental health and stress reduction. Not only proximity to nature contributes to mental health, but nature-based solutions may also promote social interactions among community members that can be conducive to stress reduction (Andreucci et al., 2019). Some groups such as elderly are argued to gain more benefits. These, for instance, include lower mortality, reduced risk of cardiovascular diseases, and slower decline in walking and cognitive abilities (Andreucci et al., 2019). However, despite all these potential benefits, unlike the case of green spaces, there is a lack of empirical evidence on the direct health impacts of urban nature-based solutions (Nieuwenhuijsen, 2021; Venkataramanan et al., 2019). A longitudinal analysis of the health impacts of urban waterway regeneration in Scotland showed that it is effective in decreasing the annual mortality rates. The largest reduction rates were observed in the waterway's 500 m buffer zone (Tieges et al., 2020).

Despite potential benefits, nature-based solutions may also induce health risks through hosting infectious pathogens and contributing to the spread of vector-borne or zoonotic diseases (Lõhmus & Balbus, 2015; Medlock & Vaux, 2015). Such concerns have been particularly discussed following the emergence of the COVID-19 pandemic. For instance, lakes, wetlands, and other water bodies may increase the presence of and mosquitoes and lead to harmful algal blooms. Additionally, a connected network of green elements may increase the spread risk of infectious diseases through the movement and presence of rats and ticks. Furthermore, some vegetation species may increase pollen concentrations and cause problems for allergic people (Lõhmus & Balbus, 2015). It is, therefore, critical to take appropriate measures to minimize such risks and trade-offs. This may, for instance, be achieved through regular maintenance measures to impede the creation of desirable habitats for mosquitoes and rodents or prevent the growth of pathogens. Also, careful selection of vegetation species and optimal design of buffer zones to reduce direct exposure could be effective for minimizing potential risks (Lõhmus & Balbus, 2015; Medlock & Vaux, 2015).

3.3. *Housing and building design*

Various building-based climate change adaptation measures are mentioned in the literature. These measures can generally be divided into two categories: passive building design measures, and conventional air conditioning systems (Sharifi, 2021). These measures contribute to maintaining indoor thermal comfort, thereby improving adaptation to weather extremes such as extreme heat and cold (Sharifi, 2021; Shen et al., 2020). In turn, maintaining thermal comfort contributes to creating a healthier indoor environment for inhabitants and reducing morbidity and mortality rates (Sujanova et al., 2019; Taylor et al., 2018). A study from the West Midlands region, UK shows that the UHI effect and summertime heat exposure are major contributors to mortality in the region. Results of the study showed that, depending on weather conditions, installing external shutters, as a simple passive design measure, may decrease mortality associated with heat stress by 30-60%. Further, coupling this measure with building retrofit may reduce the heat-related mortality by 52% (Taylor et al., 2018).

A wide range of passive measures such as natural ventilation, improved thermal mass and application of phase change materials, solar shading, night cooling, optimal orientation, nocturnal radiation, thermal insulation, and geothermal can be used to not only improve indoor thermal comfort, but also enhance indoor air quality that is important to mitigate the risk of respiratory and cardiovascular diseases (Bambrick et al., 2011; Holmes et al., 2016; Mavrogianni et al., 2015; Samuel et al., 2013). Such measures are particularly beneficial to vulnerable groups such as urban poor, those with underlying chronic diseases, or elderly that may not afford mechanical cooling and/or be more vulnerable to heat stress (Bambrick et al., 2011; Mavrogianni et al., 2015). In addition, passive measures such as natural ventilation can contribute to mitigating indoor air pollution that can have significant impacts on occupants' health (Hoskins, 2003; Samuel et al., 2013). Effectiveness of passive measures has been discussed in many studies. Focusing on social housing in Central London, Mavrogianni et al. (2015) found that measures such as natural ventilation, night cooling, and shading can contribute to reducing the risk of overheating. Effectiveness of natural ventilation has also been demonstrated for Chinese cities (Tong et al., 2016). Depending on various factors such as local weather and air quality (that can affect the desirability of natural ventilation), natural ventilation can be an effective measure to provide thermal comfort and reduce cooling energy demand by 8–78% (Tong et al., 2016). Overall, natural ventilation and passive measures can contribute to enhancing indoor thermal comfort and reducing long-term exposure to air-conditioned environments that can lead to sick building syndrome and cause several health-related issues. For instance, evidence from China shows that it can cause human discomfort and have negative impacts on nervous, digestive, and respiratory systems (Cao et al., 2012).

It is worth noting that passive measures alone may be insufficient for achieving indoor thermal comfort in some contexts or under future climate scenarios (Botti & Ramos, 2017; Mavrogianni et al., 2015). For instance, a simulation study in New York City shows that while a combination of different passive measures such as improved thermal mass, natural ventilation, and solar shading can ensure thermal comfort under temperature scenarios for 2030s and 2050s, they may not be enough to overcome heat stress in 2080s, and mechanical cooling will be needed (Botti & Ramos, 2017). Similarly, simulations for Central London showed that projected future increase in ambient temperature may reduce effectiveness of passive measures (Mavrogianni et al., 2015). Also, in some contexts with high rates of air pollution, applying passive measures such as natural ventilation may result in health trade-offs. As a case in point, a modeling study shows that although retrofitting 10% of office buildings in California to replace mechanical ventilation with natural ventilation can reduce the number of employees experiencing sick building syndrome by 22,000–56,000, it may increase their exposure to ozone and particulate matter. As a result, health costs may increase by \$130–\$207 million. This is much higher than the healthcare cost reductions associated with reductions in the number of occupants experiencing sick building symptoms (estimated between 4.3\$ - 11.5\$ million) (Dutton et al., 2013). Possible impacts of air pollution on the desirability of natural ventilation have also been discussed for Chinese cities (Tong et al., 2016). Therefore, under some conditions, mechanical air conditioning should also be used to maintain a healthy indoor environment (Y et al., 2019). It is, of course, critical to improve air conditioning techniques to enhance their efficiency and minimize potential health issues that may emerge due to long periods of exposure to mechanical air conditioning (Cao et al., 2012; Sharifi, 2021).

Different actions such as updating building codes to integrate sustainability principles, providing legal basis or incentives for promoting building retrofit, or adopting green building programs and policies can be taken to increase the extent of integration of these adaptive measures into building envelopes (He, 2019).

3.4. Urban planning and design

Literature on urban climate change highlights multiple adaptation benefits that can be achieved though urban planning and design measures. These measures can be divided into two major categories: measures related to compact urban development, and passive urban design measures.

Climate-compatible and compact urban development is characterized by a combination of measures such as proper levels of density, land use mix, connectivity, and accessibility (Hoymann & Goetzke, 2016; Sharifi, 2021). Multiple adaptation benefits are linked with these measures. Compactness contributes to avoiding development on risk-prone areas, thereby minimizing exposure to hazards such as flooding and wildfire (Hoymann & Goetzke, 2016; Sharifi, 2019a). Furthermore, through limiting and regulating horizontal urban growth, compact urban development prevents encroachment on valuable natural assets such as wetlands and forests that are important for provision of ecosystem services such as stormwater management and microclimate regulation that enhance adaptation capacities (Burley et al., 2012; Sharifi, 2021). There is also evidence indicating that water and energy consumptions are lower in compact cities, and this enhances adaptation to potential water and energy shocks that may increase in both frequency and intensity due to climatic changes (Sharifi & Yamagata, 2016; Yang & Goodrich, 2014).

Mixed evidence has been reported in the literature regarding health-related impacts of compact urban development. As for positive impacts, compactness is argued to enhance physical activity; reduce stress, sleep disorders, and fatigue associated with long commutes; and improves mental health by providing more opportunities for socialization (Hansson et al., 2011; Ihlebæk et al., 2020). For instance, survey results from Sweden show that long commuting is associated with higher stress and sleep disturbance (Hansson et al., 2011). Similar findings have been reported in other countries such as Austria (Gottholmseder et al., 2009), the US (Walsleben et al., 1999), and Norway (Ihlebæk et al., 2020). For instance, evidence from Oslo, Norway shows that suburbanites may experience more stress due to long commutes (Ihlebæk et al., 2020). Further, compact cities that feature optimal levels of mixed use, connectivity, safe and walkable streets, job-housing proximity, safe infrastructure for cycling, and accessible public transportation offer more opportunities for physical activity through walking and/or active transportation (Beenackers et al., 2018; Cheng & Berry, 2013; Giles-Corti et al., 2016; Ihlebæk et al., 2020; Kim & Yoo, 2019; Stevenson et al., 2016; Sarigiannis et al., 2017). This contributes to reducing obesity, diabetes, and cardiovascular and respiratory diseases (Cheng & Berry, 2013; Stevenson et al., 2016). For example, inner-city residents in Oslo have more daily physical activity as they use active modes such as walking and biking for commuting. On the contrary, suburbanites spend more time on long commutes that leads to more stressful experiences and also leave them with limited time for daily physical activity (Ihlebæk et al., 2020). Several other studies have highlighted the effectiveness of compact urban development for encouraging physical activity (Griffin et al., 2013; Sarkar & Webster, 2017; Wang et al., 2016). In addition to health benefits related to physical activity, studies from different countries show that residents in compact cities with attractive open and public spaces and walkable streets may have more opportunities for socialization that may contribute to mental health (Giles-Corti et al., 2016; Ihlebæk et al., 2020; Kim & Yoo, 2019; Mouratidis, 2018; Sharifi & Murayama, 2013; Thompson & Kent, 2014). Finally, there are studies demonstrating that compact metropolitan areas experience fewer extreme heat events compared to sprawled areas (Dulal, 2017; Stone et al., 2010).

However, there is also evidence showing that residents in compact areas are more exposed to air and noise pollution that may lead to poor health outcomes (Beenackers et al., 2018; Ihlebæk et al., 2020). Also, lack of adequate green and open spaces in compact cities may limit opportunities for outdoor exercise and recreation and result in higher perceived urban stress (Beenackers et al., 2018; Hartig et al., 2014; Ihlebæk et al., 2020). In addition, high density and limited open/green spaces may intensify the urban heat island effect and increase heat-related mortality and morbidity (Stevenson et al., 2016). These negative effects can be mitigated by taking efforts to minimize air pollution, reduce reliance on private car, enhance public transportation infrastructure, increase land use mix, and improve walkability through appropriate street network design (Hankey & Marshall, 2017; Kim & Yoo, 2019; Stevenson et al., 2016).

As mentioned above, some measures such as increasing density may intensify heat stress and cause associated health issues. In addition to some already discussed measures such as increasing the ratio of open and green spaces, other passive urban design measures such as optimal configuration and orientation of street canyons, appropriate shading, and increasing surface albedo can be used to avoid heat-related health impacts. Street orientation along with other factors such as the depth of the street canyon can influence the outdoor thermal comfort through impacts on the wind patterns and the amount of solar radiation into the canyon. Consequently, this may affect the level of thermal comfort of pedestrians and their resilience to heat stress (Shafaghat et al., 2016; Sharifi, 2019b). There is, however, no optimal orientation applicable to all contexts due to differences in local climatic conditions. For instance, in the temperate climate of De Bilt, The Netherlands, research shows that the North-South orientation allows receiving certain amounts of solar radiation throughout the year and is desirable for providing outdoor thermal comfort in autumn, winter, and spring (van Esch et al., 2012). However, in summer, the research shows that East-West direction is more desirable. Therefore, during summertime proper shading may be needed to avoid heat-related health issues. Shading can be achieved using different methods, but using trees is more desirable as they can provide other co-benefits too (Zolch et al., 2019). Similar results have also been reported for Thessaloniki, Greece that features humid subtropical climate in the summer (Chatzidimitriou & Yannas, 2017). In, Tel Aviv, Israel, however, the North-South direction was found to be more desirable under different conditions (Balslev et al., 2015). Overall, optimal configurations should be determined after careful consideration of the local context (Shafaghat et al., 2016).

Increasing albedo of urban surfaces such as roofs and pavements is another measure that can provide cooling benefits and contribute to outdoor thermal comfort (Falasca et al., 2019; Smith & Levermore, 2008; Taleghani, 2018). This could be achieved through different measures such as using materials with high solar reflectivity and increasing the share of unsealed surfaces and green spaces (Claessens et al., 2014). For instance, a study in the campus of the Sapienza University of Rome examined effectiveness of different designed configurations and found that increasing albedo (cool roofs and pavements) combined with increasing vegetation provides the best solution (Salata et al., 2017). Advantages of using high-albedo materials, in combination with other mitigation measures, in cities facing heat stress have also been highlighted in other studies, indicating their benefits for public health (Falasca et al., 2019; Taleghani, 2018). In Louisville, Kentucky, it was found that such combinations may decrease heat-related mortality by more than 20 percent (Stone et al., 2019). Another study showed that a combination of high albedo with other environmental measures can significantly reduce the relative odds of death within and outside home (Williams et al., 2020). Such quantitative estimations for other cities would also be helpful in communicating the health benefits of combined passive design measures.

3.5. Early warning systems (EWS) and monitoring

Interventions towards monitoring, evaluation and warning systems involve establishing warning systems for climate events such as heat, precipitation or floods and enhancing monitoring for disasters and climate events. Early warning systems can prevent mortality, reduce morbidity, avert economic losses, and enhance urban resilience (Cools et al., 2016). Early warning systems bridge the linkages between disaster risk reduction and climate change adaptation (Banwell et al., 2018).

Literature shows that presence of early warning systems contributes to reducing deaths and hospital admissions and the benefits outweigh the costs of operating the system (Toloo et al., 2013). Early warning systems accompanied with implementation of heat action plans in Indian cities have shown success in preventing mortality (Pathak & Mahadevia, 2018), reducing heat-related health impacts, enhancing public awareness, and improving capacity of local government (Singh et al., 2021). Heat action plans often involve interventions that enhance thermal comfort by, for example, identifying and developing cooler community spaces, providing public access to drinking water, etc. (Guardaro et al., 2020)

When early warning systems are combined with planned sheltering ahead for evacuations in case of extreme events, these can deliver health benefits and minimize the negative impacts of emergency sheltering during extreme weather (Wu et al., 2019). In China, implementation of early warning systems for flash floods has saved several thousand lives (Liu et al., 2018) and averted economic losses from avoided damage to infrastructure. EWSs for emergency response to floods have resulted in greater understanding of climate risk at the city level (Bhat et al., 2013), and triggered response from all stakeholders in managing flood events (Cools et al., 2016).

Adaptation planning is not a linear process. Effective policy and investment decisions for adaptation hinge on a robust understanding of local climate, its interaction with urban processes and projections for the future (WRCP, 2019). In order to integrate health benefits of adaptation actions, cities would require continuous monitoring of climate variables and public health data to understand the impacts from extreme events. For example, high quality granular data on short- and long-term health impacts of extreme weather events can be an important area for risk mapping and adaptation planning. In addition, easily-understood information about the benefits of adaptation actions needs to be incorporated into decision tools to mitigate mortality and illness occurring during hot weather. These could include web-based programs that illustrate effective methods for including heat health in comprehensive local-level adaptation planning; information on costs and benefits of several activities; maps showing zones of high potential heat exposure and vulnerable populations in a local area; and public awareness materials and training for implementing preventive activities (O'Neill et al., 2009).

Results from cities with successful resilience plans show that a robust urban health system, disease surveillance and health information system were critical factors for long term sustainability (Desai et al., 2016). Surat city in India has adopted a system of disease monitoring that includes regular information about water quality and disease outbreaks (Bhat et al., 2013). This helps local government identify the areas at risk and focus interventions specific to the vulnerable areas.

The role of information and monitoring became particularly critical during the COVID pandemic in 2020 (Sharifi, Khavarian-Garmsir, & Kummitha, 2021). Initial results post COVID have shown that monitoring of wastewater can serve as an early-warning system and an important information tool for city officials to better respond to public health risks (Sharifi & Khavarian-Garmsir, 2020). While there are several examples in literature, early warning systems by themselves can achieve limited success. For these to sustain and deliver long-term adaptation and health benefits, EWS and regular monitoring need to be integrated within the overall adaptation process.

3.6. Policy, management & governance

Planning and governance for climate events at the local level entails identifying key climate risks for the city and their health impacts, organizing existing plans and projects to incorporate these impacts, mainstreaming these into future plans and policies, and identifying institutions and governance structures that can best implement plans and policies. These can range from city-level plans such as urban resilience plans, water management, flood protection, or individual projects that address a specific component, for example sanitation. While several cities have successfully initiated local climate plans (Grafakos et al., 2020), these do not necessarily integrate public health. A review of literature showed that climate change responses were promising in areas of assessment (monitoring, diagnosis of health and vulnerability assessment), showed mix results on policies, and were relatively weak on assurance including communication, workforce development, and evaluation (Fox et al., 2019). There is already a gap between the adaptation plan and its implementation (Lee & Kim, 2018) and with the existing challenges, incorporating public health would pose further coordination challenges.

Literature identifies a number of governance and institutional challenges in implementing adaptation plans and integrating co-benefits. A key challenge is around the traditional siloed approach to urban

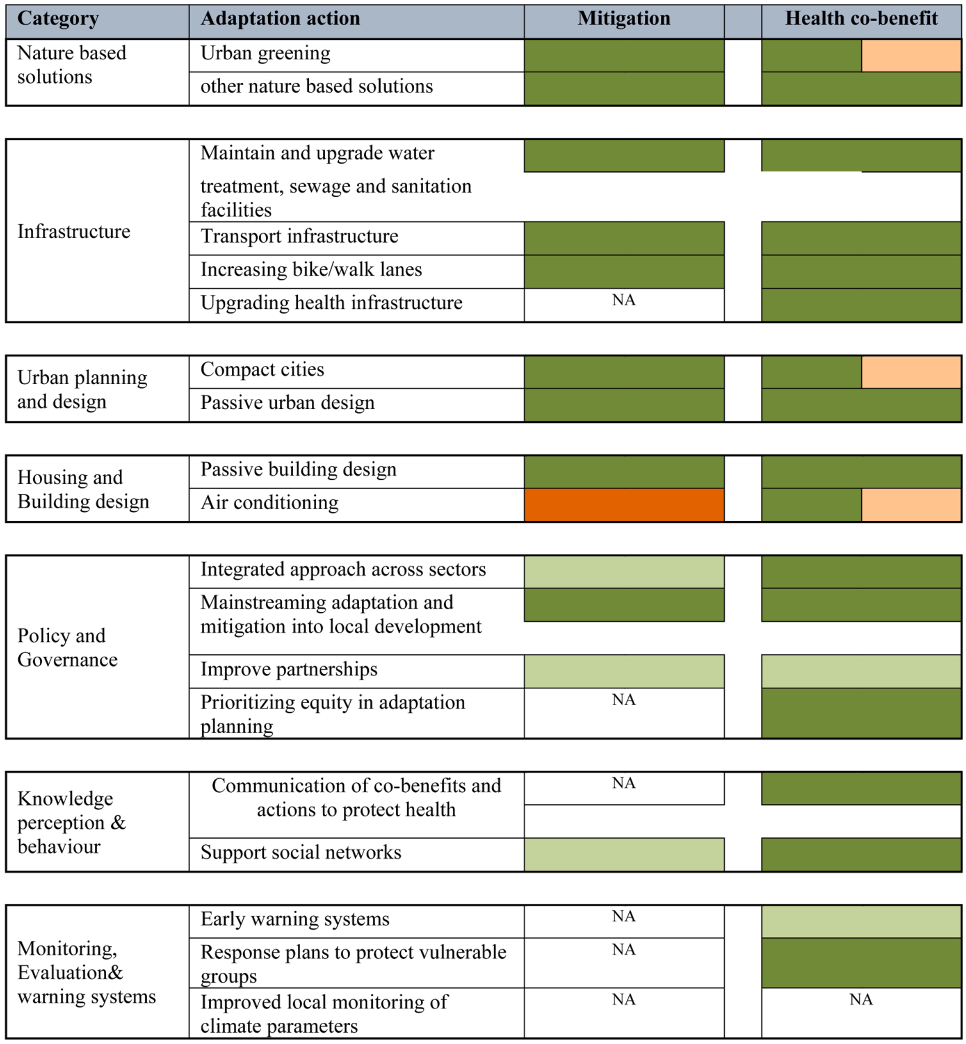

Fig. 2. Major adaptation measures and their potential linkages to health and mitigation. Shades of green represent co-benefits while orange represent trade-offs. The intensity of colors represent the confidence attached to the finding. This is indicated by evidence from studies and agreement among authors. A darker color would indicate more confidence in the association. Blank boxes indicate insufficient knowledge/evidence.

planning and management in cities relying on a single project or sector. Such a piecemeal approach results in a missed opportunity to integrate co-benefits.

Climate planning is often not the local government's mandate (Nana et al., 2019), and roles and responsibilities of actors and institutions are ambiguous. For example, sometimes, health departments and actors are not adequately incorporated in local and national climate change plans (Sheehan et al., 2017). Also, there is little awareness among policy-makers regarding the opportunities that co-benefits present (Rashidi et al., 2019).

Surat city established a unique institution set up to address the health impacts from climate change. The success of its resilience plan was also facilitated by robust health and climate monitoring, strong partnerships between the government and private sector and engaging academic institutions and stakeholders to facilitate cross-learning (Desai et al., 2016). In this case, the success was a result of the development and strengthening of a local network involving multiple actors, a decentralized system that allowed for flexibility, a high degree of trust among its members and its efforts to build legitimacy and stability (Puppim de Oliveira and Doll, 2016).

The COVID-19 pandemic has highlighted inequality in cities. Literature on urban adaptation has emphasized prioritizing equity in adaptation plans, policies and financing. Equitable adaptation delivers economic and social benefits and delivers better health outcomes (Pelling & Garschagen, 2019). There is a gap in understanding the distribution of co-benefits, particularly in public health. For example, even when adaptation actions are seen to deliver health co-benefits, it is not clear if these reach the most vulnerable populations. Better social outcomes can be generated by framing and identifying synergies between adaptation actions and urban development, especially strategic interventions targeted at urban poor. Such interventions also deliver better partnerships between local stakeholders, decision makers and external funding agencies (Chu, 2016). However, adaptation actions can cause trade-offs or adverse outcomes either by acts of commission, where adaptation projects result in adverse impacts or acts of omission where the poor are excluded from policies and plans (Anguelovski et al., 2016). Such trade-offs may relate to exclusion, displacement, or those relating to conflicts with other stakeholders. Adopting the concept of wellbeing for climate change mitigation and adaptation planning can help better recognition of co-benefits and trade-offs of these actions across different groups and ensure that benefits accrue to all especially the most disadvantaged (Thomas et al., 2014).

3.7. *Knowledge, perceptions & behavior*

The success and up-scaling of adaptation and its associated benefits depends on people's acceptability of these interventions. Potential for co-benefits in cities is much higher as citizens are able to experience these in their daily lives (Floater et al., 2016). The benefits of valuation approaches and their communication have been widely supported in literature. Communicating the planned interventions clearly leads to greater buy-in and enhances procedural equity. There is often inadequate communication of co-benefits from the project implementers prior to implementation resulting in a limited awareness of benefits among local community, especially the intended beneficiaries (Rahman & Mori, 2020).

There is a strong consensus that engaging stakeholders earlier and regularly in the planning stages allows for a better understanding of project impacts and an earlier identification of trade-offs for different groups (Giordano et al., 2020; Pagano et al., 2019). A study on flood risk reduction in Thailand showed that it was important to engage stakeholders and consider identifying more local co-benefits while implementing decisions around flood management (Alves et al., 2018). A collaborative process for designing and implementing nature-based solutions has been strongly highlighted in literature (Frantzeskaki, 2019; Raymond et al., 2017). For example, a survey of four global cities for co-benefits of nature-based solutions showed stakeholders perceived governance drivers, leaders and strategies differently, indicating the variation among national, regional and local priorities (O'Donnell et al., 2021). Much of this communication also depends on the process of consultation including the documents and quality of maps provided, tools, skills of the interviewer, and how well these are communicated and understood by the stakeholders (Olazabal et al., 2018).

Raymond et al. (2017) identify a seven-stage process for integrating co-benefits of nature based solutions into policies and actions: 1) Identification of the problem or opportunity 2) Selection and assessment of actions; 3) design of implementation processes; 4) implementation; 5) engagement of stakeholders and communication of co-benefits; 6) transferring and upscaling; and 7) monitoring and evaluation of co-benefits.

People's behavior is influenced by the knowledge they have and the information they receive. There is a gap in understanding people's awareness and perception around climate risks and their adaptive capacities (Mashi et al., 2020). Public responses are strongly influenced by the context including the local socio-economic and cultural factors and the type of information they receive. For instance, people who experienced health impacts due to heat adopted a range of personal adaptation options ranging from drinking water, showering or bathing, eating cold foods, using outdoor areas or cooler public places, and avoiding direct sun exposure (Bélanger et al., 2015). People also tended to change behavior when receiving weather information through the media or the internet (ibid).

People's perception is strongly influenced by social and cultural factors and evidence shows that actions that improve social capital can benefit mental health (Cheng & Berry, 2013). During the pandemic, amidst massive behavior changes adapting to lockdown situations, people's awareness and appreciation for natural environment has increased making a strong case for public support in incorporating nature in recovery plans (Rousseau & Deschacht, 2020). This could inspire behavioral changes towards transformational solutions that address climate change and public health such as a one-health approach across sectors, shift to plant-based diets and protecting natural ecosystems (McNeely, 2021).

4. Discussion

As summarized in Fig. 2, measures related to these adaptation categories can provide different levels of health co-benefits. Critical infrastructure enables better service delivery, which directly improves the health and wellbeing of citizens. This is particularly the case if infrastructure is developed considering the needs and priorities of different societal groups. Nature-based solutions provide multiple health co-benefits such as enhancement of ecosystem services (e.g., clean air and water), reducing heat stress, and improving mental health. Similarly, urban planning and design measures that promote walkability and ensure outdoor thermal comfort can provide multiple benefits through enhancing physical activity, improving air quality, and creating environments conducive to mental health and wellbeing. Appropriate design measures at the building level are also essential as they can contribute to human health by enhancing indoor air quality and thermal comfort.

Early warning systems for climate change events can improve wellbeing and reduce mortality, risk of disease or adverse health impacts. The benefits from heat warning systems on reducing heat-related deaths and illnesses have also been reported in other studies (Harlan & Ruddel, 2011). Mainstreaming these into urban planning and integrating public health institutions will be key to mainstream health co-benefits in cities. There is limited understanding among policymakers and the conventional siloed approach to urban planning and development does not lend itself easily to such integration. Strong governance and institutional frameworks that allow for an integrated approach to adaptation planning can deliver better health outcomes. This needs to be achieved through collaborative approaches and cross-learning between departments and across cities.

One prominent finding is that health co-benefits of some adaptation measures such as those related to infrastructure, nature-based solutions, urban planning and design, and housing and building design have received relatively more attention in the literature. In contrast, limited evidence has been reported on other measures. Particularly, there is very limited quantitative evidence on the health co-benefits of adaptation measures associated with early warning systems, policy and governance, and knowledge and behavior. This could possibly be because these measures are a little more dispersed compared to more focused sectoral actions and therefore it is difficult to establish direct attribution of health benefits to these interventions.

Many of the studies included in this paper report co-benefits qualitatively. Identifying co-benefits, and especially the economic benefits associated with the actions makes a clearer case for implementing adaptation actions. However, researchers and policymakers have always found it challenging to capture benefits associated with health and wellbeing due to their dispersed nature, temporality (as benefits accrue later), and the difficulty of putting an economic value on these. There is a need to develop methods to better understand costs and benefits in quantitative terms in order to aid decision makers in prioritizing actions.

Unless designed and implemented appropriately, some of the measures such as those related to nature-based solutions and urban planning/design may result in health trade-offs (Sharifi, 2020). Trade-offs related to air-conditioning and poor design of green spaces has been documented in past studies (Cheng & Berry, 2013). However, health trade-offs from adaptation interventions are comparatively less documented. Further research is needed to better understand such potential trade-offs and develop strategies to minimize them.

5. Conclusions

Increasing trends of climate change impacts have been observed in the past few decades and future projections indicate further increase in the frequency and intensity of climate-induced threats. This signifies the importance of climate change adaptation efforts. Such efforts are likely to offer multiple socio-economic and environmental co-benefits that have been well-studied in the literature (Sharifi, 2021). The health co-benefits, however, have receive limited attention despite the increasing understanding of the potential health-related impacts of climate change. This paper contributed to filling this gap by reviewing health co-benefits of urban adaptation measures. Seven different categories of urban adaptation measures were identified, and their health co-benefits were discussed. These are related to critical infrastructure, nature-based solutions, housing and building design, urban planning and design, early warning systems, policy and governance, and knowledge and behavior.

Findings from this paper provide insights to local policymakers on prioritizing urban policies and actions in the short-, medium-, and long-term. For example, early warning systems including heat warnings, flood warnings etc. can help deliver immediate benefits. Other interventions such as provision of stormwater infrastructure and public transportation infrastructure need to be aligned with the ongoing urban development plans. While all measures discussed in this review provide some types of health co-benefits and, ideally, all of them should be integrated in urban (re-) development plans, this may not be feasible in each city considering the resource limitations. Therefore, local decisionmakers may need to prioritize those measures that are likely to offer higher benefits. In that case, measures related to infrastructure, nature-based solution, and planning and design could be prioritized as evidence reported in the literature shows that they can also provide co-benefits for climate change mitigation. Several of the measures discussed here could possibly be included in national guidelines and codes so these may be upscaled within the region. An integrated infrastructure development strategy could deliver multiple benefits for adaptation and health. The success of these plans depends on strong governance and institutions. The findings from this paper highlight the need for bringing in health departments into climate change decision making processes.

The measures included in this study would deliver co-benefits. However, the extent would depend on the context. For example, health co-benefits for a given city would depend upon various factors such as the local climatic drivers, local geography, resilience preparedness, socio-economic condition, and the state of infrastructure. More regional studies would help identify adaptation strategies suitable to different typologies of cities. Future research could further focus on documenting trade-offs and how these might differentially affect the more vulnerable populations and what actions might be helpful in reducing these trade-offs.

The study brings together evidence from multiple studies to show that most adaptation actions lend themselves to positive health outcomes. Given the ongoing and multiple challenges of an intensifying climate and the COVID pandemic, the paper makes a strong case for including health co-benefits as a key outcome for climate change action in cities.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

TS= (("adapt*") AND (“climate change*” OR “climatic change*” OR “global warming”) AND ("health*" OR "wellbeing" OR "Well-being") AND (“city” OR “Urban*” OR “cities” OR "built environment"))

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