Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Review

The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management

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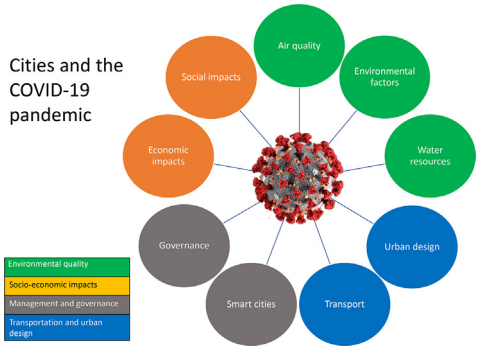
HIGHLIGHTS

- Literature on the impacts of COVID-19 on cities is reviewed.
- Evidence related to four thematic areas is synthesized.
- Existing evidence is mainly related to air quality and environmental factors.
- Significant improvements in air and water quality have been observed.
- Poor, marginalized, and vulnerable groups are disproportionately affected by the impacts of COVID-19.

GRAPHICAL ABSTRACT



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ABSTRACT

Since the early days of the COVID-19 crisis the scientific community has constantly been striving to shed light on various issues such as the mechanisms driving the spread of the virus, its environmental and socio-economic impacts, and necessary recovery and adaptation plans and policies. Given the high concentration of population and economic activities in cities, they are often hotspots of COVID-19 infections. Accordingly, many researchers are struggling to explore the dynamics of the pandemic in urban areas to understand impacts of COVID-19 on cities. In this study we seek to provide an overview of COVID-19 research related to cities by reviewing literature published during the first eight months after the first confirmed cases were reported in Wuhan, China. The main aims are to understand impacts of the pandemic on cities and to highlight major lessons that can be learned for post-COVID urban planning and design. Results show that, in terms of thematic focus, early research on the impacts of COVID-19 on cities is mainly related to four major themes, namely, (1) environmental quality, (2) socio-economic impacts, (3) management and governance, and (4) transportation and urban design. While this indicates a diverse research agenda, the first theme that covers issues related to air quality, meteorological parameters, and water quality is dominant, and the others are still relatively underexplored. Improvements in air and water quality in cities during lockdown periods highlight the significant environmental impacts of anthropogenic activities and provide a wake-up call to adopt environmentally friendly development pathways. The paper also provides other recommendations related to the socio-economic factors, urban management and governance, and transportation and urban design that can be used for post-COVID urban planning and design. Overall, existing knowledge shows that the COVID-19 crisis entails an excellent opportunity for planners and policy makers to take transformative actions towards creating cities that are more just, resilient, and sustainable.

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Contents

1. Introduction

Cities are home to most of the world population and are centers of economic growth and innovation. However, the high concentration of people and activities in cities make them vulnerable to various stressors such as natural and man-made disasters. Understanding this, over the past few decades, a vast body of research has been published on the impacts of a wide range of disasters on cities, and necessary planning, recovery, and adaptation measures that need to be taken to deal with those disasters (Sharifi, 2020). However, while this is not the first time in the human history that pandemics affect cities, limited literature related to cities and pandemics existed before the emergence of the COVID-19 pandemic (Matthew and McDonald, 2006). Urban research related to previous pandemics is mainly focused on issues such as inequalities that make poor and marginalized groups more vulnerable to pandemics (Wade, 2020). The recent pandemic has brought to the fore the issue of urban vulnerability to pandemics and has resurrected interest in this topic. As various forces such as climate change and human encroachment into natural wildlife habitats may increase the frequency of pandemics in the future, better knowledge of the underlying patterns and dynamics of pandemics, their effects on cities, and necessary preparation, response, and adaptation measures is needed (Connolly et al., 2020a). In this regard, the recent pandemic offers an unprecedented opportunity to understand how cities might be affected by pandemics and what actions are needed to minimize the impacts and enhance urban pandemic resilience.

The first confirmed cases of the Coronavirus disease 2019 (COVID-19) were identified in late 2019 in Wuhan, Hubei Province, China. Since then, it has become a fully-fledged pandemic that has rapidly swept through many countries (Lu et al., 2020). As many parts of the world continue to struggle with the COVID-19 crisis, researchers are constantly working to understand the underlying patterns of the pandemic and shed more light on its unanswered aspects. This is evidenced by the substantial number of scientific articles published during the past few months. In fact, as of September 10, 2020, searching for the term 'COVID-19' in Scopus returns 43,071 articles, and this trend is expected to continue in the coming months.

As expected, a large share of this research is focused on medical issues related to the diagnosis and treatment of the disease (Harapan et al., 2020). However, since the early days of the pandemic, impacts of the pandemic on cities and the way they respond to it have also received significant attention. In fact, the pandemic has brought to the fore the old debate on the potential vulnerabilities of cities to pandemics and infectious diseases (Matthew and McDonald, 2006). As a result, over the past few months, a large body of research has been published on various issues related to COVID-19 and cities. This warrants a literature review to highlight existing knowledge and gaps. Despite this, no such review still exists. Against this backdrop, the main aims of this study are to understand impacts of the pandemic on cities and to highlight major lessons that can be learned for post-COVID urban planning. For this purpose, the early literature published on this topic is reviewed. The issues exposed by the pandemic and recommendations provided to deal with them can inform city planners and policy makers of measures that need to be taken to develop cities that are more resilient to pandemics.

2. Materials and methods

2.1. Literature selection

The objects of this study are relevant papers indexed in Scopus, a widely used database for archiving scientific articles. Another commonly used database is the Web of Science. However, Scopus was used for its broader coverage. Also, the search string was intentionally designed broad to provide reasonable coverage of the diverse research that exists on cities and their planning, design, and management. The search string is as follows:

TITLE-ABS-KEY ((“covid*” OR “coronavirus”) AND (“urban” OR “cities” OR “urban planning” OR “urban design” OR “urban studies” OR “city”))

An initial search in Scopus on June 17, 2020 returned 1190 articles. A brief screening revealed that many articles are not related to planning, design, and management of cities. These were mainly articles that include the term “city” in the abstract to refer to either Wuhan as the epicenter of the pandemic or other cities across the world where efforts related to other disciplines (e.g., medical experiments) have been taken. Therefore, we used the filtering function of Scopus to exclude papers not related to planning, design, and management (including environmental management) of cities. Accordingly, papers focused on disciplines such as pharmaceutical sciences, nursing, medicine, and psychology were excluded. At the end of this stage, 167 articles remained in the database. After checking the abstracts of these articles to ensure their relevance, 27 more articles were excluded. While checking the abstracts, we also assigned each paper to different categories depending

on their thematic focus. At the end of this stage, the categorization was refined by merging similar themes (for instance, categories related to different types of pollution were combined into the 'air quality' category). The final thematic categorization is shown in Table 1. It should be noted that during the process, we also enabled the notification function of Scopus to receive weekly publication updates and add newly published papers to the database if necessary. Overall, 7 additional papers were added to the database using this option.

2.2. Procedures for literature analysis

The selected papers were reviewed in detail to extract the necessary information for the analyses presented in the following section. Specifically, to analyze the contents of the selected papers, an excel sheet was designed with selected papers on the rows, and columns for collecting data on a wide range of items and issues, including geographic focus, sectoral focus, socio-economic and environmental factors, impacts, and key lessons. The review was conducted in three steps. First, each co-author reviewed a number of papers and collected the necessary data (Step 1). Following this, the lead author checked the collected data, divided the articles into several themes based on commonalities, and coded the data (Step 1). At the final stage, the authors double checked the reviewed articles to ensure accuracy of the collected and coded data (Step 3). This data was then used for writing up the review.

3. Results and discussions

Before discussing the review results, a brief overview of the thematic categories is provided here. As Table 1 shows, research on COVID-19 and cities can be classified into four major themes, namely, (1) environmental quality, (2) socio-economic impacts, (3) management and governance, and (4) transportation and urban design However, these themes are not addressed in a balanced manner, and existing knowledge is mainly related to a the environmental quality theme that covers sub-themes such as air quality impacts, environmental factors affecting the airborne transmission of the virus, and impacts on the urban water cycle. Some possible explanations for the dominance of these themes will be provided in the remainder of this paper. The dominance of these themes can also be observed from the outputs of term (keyword) co-occurrence analysis obtained from VOSviewer that is a software tool for text mining and bibliometric analysis of scientific papers (Fig. 1). It is obvious that air quality and environmental factors are dominant, but there are also other key terms, such as smart cities and density that belong to the other themes. Considering the close connections between social and economic impacts, in this review they are presented as the theme titled 'socio-economic impacts'. Similarly, the other two major themes are consisted of sub-themes that are closely related. Smart cities are believed to contribute to management and governance of cities and form the third major theme titled, 'management and governance'. Finally, the last theme covers issues related to transportation and urban design.

Table 1
Major thematic areas discussed in the literature.

Thematic category		Count	%
Environmental quality	Air quality impacts of lock-downs	36	24
	Effects of environmental factors and meteorological conditions	19	13
	Impacts on urban water cycle	8	5
Socio-economic impacts	Social impacts and social factors for improved response and adaptation	18	12
	Economic impacts	9	6
Management and governance	Governance mechanisms	12	8
	Smart cities and smart solutions and their contribution to response and recovery	14	10
Transportation and urban design	Issues related to urban mobility and transportation	15	10
	Urban design issues	8	5
Overarching issues		8	5

3.1. Environmental quality

3.1.1. Air quality

In response to the pandemic, partial and total lockdowns were enforced in many parts of the world. These lockdowns provided an unprecedented opportunity to test how major transportation policy interventions and reforms in production patterns may contribute to enhancing urban air quality (Kerimray et al., 2020). Evidence related to cities from at least 20 countries has been reported in the reviewed literature, with most studies focusing on Chinese cities. Impacts of lockdown measures on various pollutants such as $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, and O_3 have mainly been explored based on a comparisons of concentration levels during the lockdown period with either pre-lockdown concentration levels or those from the corresponding periods in the previous years.

Results show that in most cases, travel restrictions have significantly reduced NO_2 and CO that are pollutants directly associated with the transportation sector (Baldasano, 2020; Dantas et al., 2020; Saadat et al., 2020). For instance, in March 2020, on average, hourly observations of NO_2 concentration in Madrid and Barcelona showed, respectively, 62% and 50% reductions compared with the 2019 data. Such reductions, however, have not been reported for American cities such as Memphis and New York (Jia et al., 2020; Zangari et al., 2020). This may indicate that traffic emission contributions to air pollution are small in those cities (Jia et al., 2020). In contrast, significant reductions reported for Brazilian, Chinese, Indian, and South Asian cities indicate that greening the transportation sector can provide major air quality benefits (Dantas et al., 2020; Filonchyk et al., 2020; Sharma et al., 2020; Kanniah et al., 2020). Results reported for other pollutants such as $PM_{2.5}$ and PM_{10} are more mixed. Overall, while significant reductions have been observed in some Chinese cities (Bao and Zhang, 2020), evidence shows that reductions in PM concentration are less significant (Menut et al., 2020; Berman and Ebisu, 2020). This is explained by the fact that in some contexts non-transportation sources such as residential heating, food industries, and biomass burning are major contributors to aerosol concentrations (Menut et al., 2020; Berman and Ebisu, 2020). For instance, in some Western European cities, reduction in PM concentration is less significant due to the fact that residential heating is a major contributor to PM concentrations (Menut et al., 2020). There is even some evidence suggesting that PM concentrations have increased during the lockdown period. For instance, in some parts of Northeast China, this occurred due to an increase in domestic heating, as well as, increase in industrial activities in the peripheral areas to compensate for the shutdown of production activities in major population centers (Nichol et al., 2020). PM concentration may also increase due to the long-range transport of particles from neighboring industrial or agricultural areas, as shown in studies from Brazil and Morocco (Dantas et al., 2020; Otmani et al., 2020). This shows that policy measures to reduce traffic-related pollution are not enough to address air quality issues, and other sectors should also be considered (Nichol et al., 2020). For instance, major actions regarding agricultural burning or finding optimal sites for industrial activities are needed.

Regarding Ozone (O_3) concentrations, significant increases have been reported in the reviewed studies. This has mainly been attributed to lower titration of O_3 by NO due to significant reductions in NOx concentration levels (Sicard et al., 2020). It is, however, argued that further research is needed to better understand the underlying reaction mechanisms and the effects of other meteorological factors (Lian et al., 2020). Therefore, policymakers should be aware that measures designed for reducing some pollutants such as NO_2 and PM may increase secondary pollutants such as O_3 and cause other health problems.

Another important issue related to air quality is that, according to the early evidence, reducing air pollution can contribute to controlling the

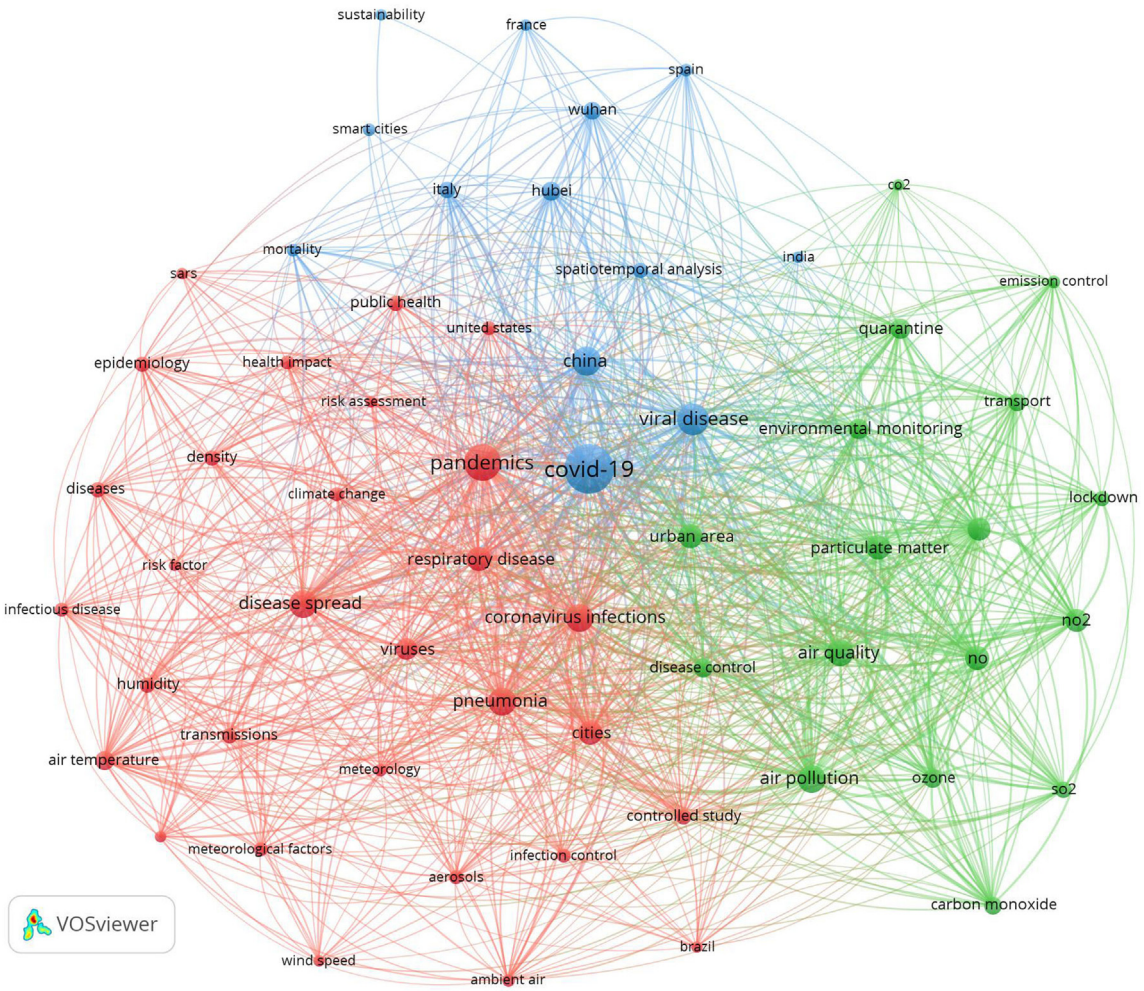

Fig. 1. Term co-occurrence map.

spread of the pandemic and increase coping capacity of the infected individuals. In fact, several studies have found strong associations between COVID-19 transmission/mortality and high levels of air pollution (Xu et al., 2020; Yao et al., 2020; Coccia, 2020a). For instance, studies from different Italian regions show higher spread rates in northern regions that are characterized by higher levels of air pollution (Cartenì et al., 2020; Conticini et al., 2020). In addition, long-term exposure to pollution can indirectly increase vulnerability to COVID-19 by affecting the respiratory system (Berman and Ebisu, 2020; Conticini et al., 2020). Therefore, improving air quality can contribute to addressing issues related to COVID-19 and other pandemics, both in the short and long term.

Overall, results imply that, depending on the context-specific conditions and sources of pollution, major benefits can be achieved by greening the transportation system and eliminating pollution from heavy industries (Bao and Zhang, 2020). However, as evidence related to the increased level of Ozone concentration shows, the secondary impacts of such measures should also be considered, and this should be further studied in future research. In addition, further research is needed to better understand the role of meteorological conditions that have mainly been overlooked in the reviewed papers. This is important because, for instance, a modeling study in India showed that while $PM_{2.5}$ levels decreased during the recent lockdown, under unfavorable meteorological conditions, they could indeed increase (Sharma et al., 2020). Another important finding is that enhancing air quality can reduce transmission rates and improve coping capacity of citizens. This is, however, not yet well-explored and warrants further research.

3.1.2. Environmental factors

Characteristics of the ambient environment can influence the transmission dynamics by affecting the survival of the virus on contaminated surfaces and/or its airborne diffusion (Zoran et al., 2020a). Impacts of different environmental and meteorological parameters such as temperature, humidity, wind speed, and pollution levels have been studied in the literature. As this paper is focused on the city scale, only results related to the outdoor environment will be discussed. Reported evidence is from countries such as China, Italy, the US, Brazil, Iran, Norway, and Turkey that feature different climatic conditions. Accordingly, due to context-specificities, and the number and complexity of parameters involved, results reported regarding the influence of environmental factors on COVID-19 are not uniform across different cities and regions.

Conflicting results have been reported on the influence of temperature. Some studies from China, Brazil, and Italy argue that lower temperatures are more favorable for the transmission of the virus. For instance, using the number of confirmed cases obtained from the data repository at Johns Hopkins University Center for Systems Science and Engineering (CSSE) and meteorological data obtained from the ground-based monitoring network of the World Meteorological Organization (WMO) global telecommunications system, Lin et al. (2020) found a negative and exponential relationship between transmission rate and temperature in a study of 20 provinces/municipalities across China. In areas below 0 °C, rapidly increased rates of transmission were observed (Lin et al., 2020). Similar results about the higher rates of infection in lower temperatures have been reported in other studies of provincial capital regions and

provincial capital cities of China (Liu et al., 2020; Shi et al., 2020; Qi et al., 2020). In the latter, data on COVID cases was obtained from Health Commissions of the cities and meteorological data from Shanghai Meteorological Bureau and Data Center of Ministry of Ecology. Elsewhere, in subtropical cities of Brazil, Prata et al. (2020) examined association between COVID-19 data (obtained from the Ministry of Health) and meteorological data (obtained from the National Institute of Meteorology) and found that each 1 °C increase in the temperature is associated with −4.8951% decrease in the cumulative daily number of confirmed COVID-19 cases. Also, an analysis using temperature data obtained from the Weather Underground website and global confirmed cases obtained from the CSSE indicates that most of the cases (~60%) have occurred in areas with temperatures ranging between 5 °C and 15 °C (Huang et al., 2020). In Italy, study of different regions, based on data obtained from the Ministry of Health and ilmeteo.it, shows lower rates of transmission in warmer regions (Cartenì et al., 2020).

Contrary to these findings, several studies argue that there is either no correlation between temperature and COVID-19 confirmed cases, or temperature raise can even increase the rate of transmission. For instance, analysis of Iranian cities with different climatic conditions (using data from the Ministry of Health and Medical Education and Iran Meteorological Organization) showed that the spread rate of COVID-19 has a low sensibility to the ambient temperature variations (Jahangiri et al., 2020). Further, evidence from Milan (based on the daily average pollutants data obtained from https://aqicn.org, and data on daily new cases collected from https://www.worldometers.info and https://www.statista.com/statistics.), and Oslo (using COVID data from the Norwegian public health institute database and weather data from the Norwegian Meteorological institute), show a positive correlation between COVID-19 and temperature (Menebo, 2020; Zoran et al., 2020b). In Oslo, COVID-19 was negatively correlated with precipitation. This may indicate that warm and sunny days increase the risk of transmission by reducing the level of compliance with the 'stay-home' rules (Menebo, 2020). In line with these results, an analysis of 122 Chinese cities (using data obtained from the National Meteorological Information Center and official health commission websites) shows that, with a threshold of 3 °C, there is a positive linear relationship between temperature and the number of COVID-19 cases, and the relationship becomes flat beyond that threshold (Xie and Zhu, 2020).Significant correlation between temperature average and the spread of COVID-19 was also found in a study on Jakarta, Indonesia (Tosepu et al., 2020). Overall, more research is needed to better understand how temperature is related to COVID-19. Based on the results, however, it cannot be stated that temperature rise can contribute to containing the virus. This is supported by the fact that countries such as Iran have experienced the second wave of the pandemic despite entering the warm season. Therefore, social distancing and other protection measures should continuously be promoted in urban areas.

Regarding humidity, there is relatively good consensus in the reviewed literature that drier air favors the transmission of the virus (Xu et al., 2020; Yao et al., 2020; Liu et al., 2020; Qi et al., 2020; Zoran et al., 2020b). This is likely because in humid conditions, airborne transmission of virus droplets is limited as they are more likely to drop down (Xu et al., 2020; Yao et al., 2020; Zoran et al., 2020b). It should, however, be mentioned that some studies did not find significant relationship between humidity and transmission of the virus. For instance, after controlling for the effect of population density, the effect of humidity was not significant in a study of 20 Chinese municipalities (Lin et al., 2020). Future research may reveal further insights into the relationship between humidity and COVID-19 transmission.

As for other environmental parameters such as wind speed, existing evidence is limited and inconclusive. While analysis of data from nine Turkish cities, based on data obtained from the Ministry of Health and the Weather Underground website, showed that wind speed is positively associated with COVID-19 infections (Şahin, 2020), in a study of 20 Chinese cities no significant relationship was observed (Lin et al., 2020), and in Italian cities, correlations were negative (Coccia, 2020a; Zoran et al., 2020b). In the latter, low wind speed was often coupled with high levels of air pollution (PM_{10} and O_3). It is likely that these pollutants become carriers of the virus, and calm air increases the risk of transmission by allowing them to stay in the air for a more extended period. This, again, highlights the significance of reducing air pollution in cities.

Overall, apart from humidity that is found to be negatively correlated with COVID-19 transmission rate, evidence on the association between environmental parameters and COVID-19 transmission dynamics is inconclusive and considerable contextual variations exist. While some studies have found higher transmission rates in lower temperatures, others have not reported any significant relationships. Similarly, mixed evidence has been reported on the association between wind speed and transmission rates. Understanding how environmental factors influence survival and diffusion of COVID-19 can help urban policymakers design more appropriate protection and response measures (e.g., context-sensitive social distancing and quarantine). For this purpose, more context-specific research is needed. It is also essential to explore transmission dynamics in indoor environments in the future research.

3.1.3. Urban water cycle

Three major issues related to the impacts and implications of the pandemic for management of urban water cycle have been discussed in the literature: first, improvements observed in the quality of water resources; second, concerns regarding the possibility of increased water pollution caused by drugs used for treatment of COVID-19 patients; and third, the need for enhanced wastewater treatment to reduce the likelihood of COVID-19 transmission through fecal matter.

Similar to positive environmental impacts related to air quality, several studies have reported improvements in surface and groundwater quality during lockdown periods. Overall, lockdowns have improved water quality by reducing contamination of upstream and downstream water sources. Due to reduced anthropogenic activities, headwaters that are often located far from cities are less affected by non-point pollution sources such as NO_2, SO_2, and NH_3. In addition, downstream water resources are also less contaminated by point sources such as industrial units and non-point sources such as vehicular traffic (Hallema et al., 2020). This is a reminder of the scale of detrimental impacts of unregulated human activities on the environment. For instance, following the lockdown, tourism activities in Venice came to a halt, resulting in a dramatic decrease of the vessel traffic and associated pollution and sediment concentration in the lagoon of Venice. In combination with other factors (e.g., significant decrease of wastewater discharge due to the city population being halved, and reduced rainwater runoff from tributaries because of reduced precipitation during the pandemic), this has led to significant water transparency improvements in the lagoon and city canals, as shown by the comparison of satellite images (Sentinel-2 imagery) taken before and during the lockdown (Braga et al., 2020). Elsewhere, analysis of groundwater samples in Tuticorin, India showed that lockdown measures and associated reductions in agricultural and industrial activities have reduced chemical and bacterial pollutants in the groundwater. These findings can be used by policy makers to identify the sources of pollution and take actions to improve water quality. For example, designing appropriate laws and regulations to minimize negative agricultural, industrial, and traffic impacts on water resources should be prioritized in the Post-COVID era (Hallema et al., 2020).

Despite these water quality improvements, there are some concerns that drugs used for treatment of COVID-19 patients may pollute freshwater resources. For instance, in South Africa, the antiretrovirals (ARVs) used for treatment of HIV have polluted freshwaters due to the failure of wastewater treatment plants to properly remove them from wastewater. Based on this, it is argued that possible use of ARVs for treatment of COVID-19 patients and their release into wastewater may further intensify the pollution problem (Horn et al., 2020). This indicates the importance of taking effective wastewater treatment measures.

As coronavirus can spread through fecal-oral routes, proper management of urban water cycle is also critical for containing the spread of the virus (Naddeo and Liu, 2020). Sufficient disinfection of water plants and wastewater treatment plants and measures such as the prevention of sewage leakage into freshwater resources are essential to reduce human exposure to the virus (Naddeo and Liu, 2020). However, these are challenging tasks in many densely populated areas such as India, where there is a lack of sewage treatment facilities. As COVID-19 can remain for several days in the sewage, this can undermine lockdown and 'stay home' measures aimed at flattening the curve. Therefore, in addition to measures that need to be taken to prevent water pollution at the point source, it is necessary to provide resources to enable onsite water and wastewater treatment by households (Bhowmick et al., 2020).

The presence of COVID-19 and other viruses in the sewage system also provides an opportunity to gain information about the infection hotspots and efficacy of control and spread patterns through regular wastewater testing. In fact, in addition to providing information on patterns and intensities that can be used to develop targeted and data-driven lockdown measures, regular testing of wastewater data can function as an early-warning system that allows local decision makers to respond proactively to potential public health threats and prevent their spread. Initial efforts to commercialize such ideas have already been taken (e.g., see https://www.biobot.io/).

Overall, the pandemic has exposed the significant anthropogenic impacts on water resources and has contributed to better identifying the sources of water pollution. Urban planners and policy makers should use this opportunity to take actions such as designing proper regulations to reduce detrimental human impacts on water resources. Furthermore, given the presence of the virus in the sewage system, real-time monitoring should be used to identify hotspots, predict diffusion patterns, and take effective response measures. Also, measures should be taken to ensure that drugs used for treatment of the patients will not lead to water resource pollution.

3.2. Socio-economic impacts

3.2.1. Social impacts

The social consequences of the pandemic have been discussed in the context of developing as well as developed countries. The focus is mainly on negative impacts, but there are also studies discussing positive social activities driven by the crisis. Most studies have focused on issues caused by the long-standing structural inequalities that can be observed in many societies. Historically, pandemics have hit minorities and people at the bottom of the socioeconomic spectrum disproportionately (Wade, 2020; Duggal, 2020). They often suffer more from pre-existing conditions due to more exposure to risks, economic difficulties, and limited access to services (Wade, 2020). The rapid spread of COVID-19 has exposed some of these old problems and inequalities in a new light (Kihato and Landau, 2020). For instance, recent data from New York City shows that the mortality rate of the Black and Latino people is twice that of the Whites (Wade, 2020). This is partly because minority groups have limited access to medical care during pandemics (Wade, 2020). In addition to minorities, COVID-19 has hit other vulnerable groups such as urban poor harder. In many parts of the Global South, rapid and non-uniform urban development has resulted in conditions where a large share of the urban population lives in slums with poor living and sanitary conditions (Biswas, 2020). A combination of factors such as very high density, inadequate access to basic infrastructure services, and precarious livelihoods makes it difficult, if not impossible, to contain the spread of COVID-19 in slums through promoting social distancing and quarantine measures (Wasdani and Prasad, 2020). These issues have already been evidenced across many cities in Asia, Africa, and South America. For instance, per capita floor area for the poorest 60% of city dwellers in India is 72 sq. ft. that is even below the recommended floor area for prisoners; the conditions are even worse for slum dwellers (Biswas, 2020). This and other inequality issues make it difficult to socially distance, thereby undermining the effectiveness of 'homestay' orders for containing the spread of the virus (Mishra et al., 2020). Similar issues have also been discussed in the context of some African and Brazilian cities (Kihato and Landau, 2020; de Oliveira and de Aguiar Arantes, 2020). Conditions in slums and informal developments are further exacerbated by the lack of access to medical care (e.g., hospital beds) and basic services such as clean water to comply with hand washing recommendations (Biswas, 2020; de Oliveira and de Aguiar Arantes, 2020). Additionally, precarious economic conditions, and the fact that many communities (e.g., in Sub-Saharan Africa) depend on close social interactions for their livelihood make adherence to 'stay home' orders challenging (Kihato and Landau, 2020; Finn and Kobayashi, 2020). Accordingly, there are concerns that inequalities may not only make containment challenging, but also result in further diffusion of the virus. Therefore, social distancing policies should not be implemented in isolation from economic support mechanisms. These examples also clearly show how inequality and inequitable access to services can put the entire city at risk. While historical experience shows that previous pandemics such as the 1918 flu pandemic have also revealed the socioeconomic fault lines, they have resulted in limited post-pandemic actions towards reducing inequalities and addressing the needs of minorities and poor groups. It is hoped that more efforts towards solving these issues through more inclusive planning will be made in the post COVID era (Wade, 2020; Jon, 2020). Overcoming inequality challenges can also enhance resilience to other threats such as climate change impacts that tend to affect vulnerable groups disproportionately.

Increase in the occurrence rate of social tensions is another issue that has been discussed in several papers. For instance, pandemics have caused social tensions between migrant groups and host communities in China and Hong Kong (Castillo and Amoah, 2020; Zhang, 2020). Experiences such as being stigmatized have significantly affected freedom of movement of migrant communities and have caused problems for their mental health (Castillo and Amoah, 2020; Zhang, 2020). Such tensions have also been observed in the past. For instance, explaining how in response to the 1918 flue, racial residential segregation was formalized in South Africa, Finn and Kobayashi (2020) warn that in some contexts social distancing and other measures applied in response to COVID-19 have led to racist sentiments. Therefore, it is critical to ensure that COVID-19 response and control measures do not result in human right abuse, racism, classicism, and pro-rich governance (Kihato and Landau, 2020; Finn and Kobayashi, 2020).

The pandemic has also exposed issues regarding the diminishing sense of community in some cities. Biswas (2020) argues that limited attention to 'stay home' orders in Indian cities is partly due to the increase in self-centric behaviors. Such behaviors have also been reported elsewhere. As the pandemic ravaged through North American cities, some rich urbanites from high-density cities fled to their vacation homes located in the territories of indigenous people. In fact, instead of staying at their permanent homes, these rich urbanites have ignored the border closure policies of indigenous groups by deciding to quarantine in their second homes (Leonard, 2020). This lack of sense of community is likely to make response and recovery processes more challenging. In contrast, in places, such as Ho Chi Minh City, where residents have shown strong sense of community, significant success stories have been reported (Thoi, 2020).

While reported evidence is mainly on the negative impacts, some successful cases of social innovation and collaboration have also been discussed. For instance, in Naples, Italy efforts have been made, through volunteering programs, to get people involved in local practices that contribute to meeting local food demands and also strengthen social ties during the pandemic (Cattivelli and Rusciano, 2020). Similarly, in response to the pandemic, social movements and community-driven activities have been developed to deal with social inequalities and address issues related to the right to housing in Lisbon, Portugal (Mendes, 2020). These movements have strengthened the sense of solidarity and mutual support, and have achieved some success in

suspending evictions and mortgage payments. They have also provided opportunities for enhancing social engagement towards improving the right to housing. Such civil society interventions are effective in creating networks of mutual support that may in the long run transform power relations and further pressure policy makers to deal with social inequalities (Mendes, 2020).

Overall, the pandemic has once again exposed inequalities and social fault lines that exist in many societies and make it challenging to prepare for, response to, and recover from pandemics. Accordingly, reducing inequalities is critical for enhancing coping and response capacities of cities. This should also be coupled with measured aimed at improving sense of community to prevent social tensions and improve the capacity of community-driven initiatives that are vital for responding to and recovery from risks and pandemics.

3.2.2. Economic impacts

The long-term economic shutdowns due to the COVID-19 pandemic have had very negative impacts on urban economy. The consequences are complex and occur in various ways and on a wide range of scales. Although research on this topic is currently underway, early findings imply that the outbreak has had a significant influence on city tax revenues, citizens' income, tourism and hospitality, small- and medium-sized businesses, urban food supply chain, and migrant workers. Besides, a growing line of research has dealt with the uneven and unequal social and spatial distribution of the effects of the pandemic.

An expected finding is that cities that don't have a diverse economic structure are more vulnerable. For instance, Krzysztofik et al. (2020) explained the pattern of COVID-19 cases in Poland concerning "urban shrinkage, trans-industrialism, hard coal mining, and polycentricity". They noted that "mining municipalities, those with large care centers, and shrinking cities" are the most vulnerable ones. Also, unprecedented global travel restrictions and 'stay home' measures have created unprecedented challenges for cities relying on tourism. Globally, such cities have been particularly hit hard economically (de Oliveira and de Aguiar Arantes, 2020; Earl and Vietnam, 2020). Rutynskyi and Kushniruk (2020) estimated that the pandemic caused a 40 to 60% fall in the number of tourists in Lviv, Ukraine. They projected that the financial losses associated with 1–1.5 million decline in the number of tourists would be about 80 to 135 million Euros. Accordingly, they predicted that, in an optimistic scenario, the share of tourism in the 2020 city budget would decrease by two-thirds compared to the previous year. In another study, Napierała et al. (2020) indicated that the impact of COVID-19 on the urban hotel market is negative and geographically differentiated. They pointed out that the largest Polish cities, which often host international tourists, are more affected by the outbreak than the smaller ones, which often host domestic tourists. Accordingly, they believe that the recovery of the hotel industry in the more internationalized urban destinations is much more complicated and depends on solving the issue at the continental and global scales. Therefore, the future model of hotel development in these cities should be changed based on the principles of sustainable development.

While impacts are context specific, some social groups have been disproportionately affected. For instance, Qian and Fan (2020) rejected the view that the global epidemic is a systematic "disadvantage that limits the economic activity of almost everyone, regardless of socioeconomic status or geographic location". They suggested that factors such as education, family income, Communist Party membership, and state-sector employment are important factors determining people's vulnerability to the financial troubles related to COVID-19 in China. They concluded that not only COVID-19 may have exacerbated pre-existing social disparities, but also has created new forms of inequalities, posing economic burdens for people living in epicenters, infected individuals, and families with COVID-19 patients. Similar arguments have been made by Creţan and Light (2020) and Krzysztofik et al. (2020) in Romania and Poland, respectively. They argued that it is more likely for the poorest people and most marginalized regions to experience broader social and economic damages due to the pandemic. Migrant workers are another vulnerable group that have been disproportionately affected (Creţan and Light, 2020). Predicting a period of recession and rising unemployment in both Western and Eastern European countries, Creţan and Light (2020) pointed out that transnational employment opportunities may be dramatically reduced in Western Europe, while the recession may cause more Romanians to pursue work in other EU countries, and may also result in greater dependence among those who stay in the country on remittances sent by the migrant workers. Overall, since some societal sections such as poor and marginalized groups are hit harder by the pandemic, they should receive special attention when designing and implementing post-pandemic recovery programs (Qian and Fan, 2020). These findings are in line with those reported in Section 3.4.

Another group of studies have discussed that the global pandemic has exposed the extreme vulnerability of cities and called for reconsidering the way urban tourism, food, and environment systems are developed and governed. The need for better self-sufficiency and a paradigm shift towards more diverse economic structures is particularly emphasized. Gössling et al. (2020) considered this crisis as an opportunity to reflect on the existing mass tourism policies and redefine tourism development pathways. They called for transformations in global tourism policies to make them consistent with sustainable development goals. The supply chain and its transformation has also received considerable attention (Batty, 2020). For instance, Pulighe and Lupia (2020) demonstrated that transportation restrictions and border closures induced by COVID-19 have disrupted food supply chains in cities. This has provided additional momentum to urban farming movements aiming to increase urban self-sufficiency by growing local food. It is expected that, more attention will be paid to local supply chains in the post-COVID era (Batty, 2020).

Overall, the pandemic has declined the tax base of many cities, reducing their ability to implement urban development plans. As cities are expected to experience significant financial deficits, they may need to prioritize investments and postpone or cancel some plans that may deem less important (e.g., environmental and cultural) (Kunzmann, 2020). This may, however, also encourage engagement in collaboration networks of cities (Kunzmann, 2020). It is, however, too early to tell what the exact scale of economic losses in cities will be, and how they will respond to and adapt to those losses. Some initial response actions such as provision of stimulus economic plans and allowing tax deferral, have been made that their effectiveness remains to be seen. There are also arguments regarding the possible long-term economic benefits of lockdowns (e.g., due to reduced air pollution) that should be further explored in the future research (Bherwani et al., 2020).

3.3. Management and governance

3.3.1. Governance

As urbanization trends continue to increase globally, the significance of city-level governance for addressing societal challenges is increasingly recognized. Evidence reported in the literature indicates that integrated urban governance strategies that involve long-term visioning, pre-event planning, adequate investment in primary healthcare systems, early warning, and coordination of activities of different sectors and stakeholders are more conducive to timely and effective response mechanisms to pandemics and disease outbreaks in cities (Duggal, 2020; Thoi, 2020; Shammi et al., 2020). Integrated urban governance has enabled some cities to successfully prevent the spread of the virus by being able to rapidly detect infected individuals through increased testing and improved surveillance, and timely lockdown and social distancing actions (Duggal, 2020; Earl and Vietnam, 2020). Such actions have often involved providing economic and social support (Duggal, 2020). For instance, in Vietnam, which is widely lauded for its success in flattening the curve, local governments provided economic support to poor, disadvantaged, and vulnerable groups (Thoi, 2020).

Generally, long-term visioning and appropriate plans for mitigation, absorption, recovery, and adaptation, are key factors determining urban resilience to any disruptive events, including pandemics (Santos et al., 2020). These allow cities to learn from past experiences and proactively design strategies to minimize the impacts of future disruptive events. In this regard, in countries such as Singapore, Taiwan, and South Korea cities have made great achievements by developing emergency plans and applying lessons learned from the SARS and H1N1 pandemics (Duggal, 2020). Also, the case of Setubal municipality in Portugal shows how immediately activating the Municipal Emergency Plan (MEP) has enabled timely response (Santos et al., 2020). In contrast, absence of proactive planning and emergency plans in Bangladesh, has made it difficult for cities to effectively respond to the crisis. They have failed to enhance the capacity of the healthcare system, analyze the situation, assess the risk, and take required measures in a timely manner by coordinating the actions of multiple actors and sectors (Shammi et al., 2020).

Coordination of different actors and sectors is critical to avoid confusions/conflicts and ensure effective and efficient use of limited resources. Indeed, fragmented governance, characterized by different priorities, and conflicts between different levels of governance over limited resources is blamed for the limited success in containing the spread of virus in some contexts such as the US and Australia. Such conflicts are partially attributed to the limited local independence and high reliance on the central government for coordinating actions (Connolly et al., 2020a; Steele, 2020). In fact, while top-down management through multi-level governance systems is essential for coordinating activities, some level of local leadership is needed for taking nimble and timely actions. In Australia, issues related to fragmented urban governance have been exposed by the outbreak of COVID-19. In response to the pandemic, different levels of the Australian government took initiatives to reduce the impacts and contain the spread of the virus. However, their actions were not coordinated, and their priorities were different. For instance, the Commonwealth was focused on reducing the economic impacts and designing economic stimulus plans to revive the economy. At the same time, the State Governments were mainly trying to reduce the pressure on hospitals and ensure safety of teachers and students through enforcing lockdown measures. These different priorities have caused confusion and undermined the effectiveness of city-level actions. This is further exacerbated by the fact that city-level governance is not well recognized in the constitution and cities have limited financial resources, making them dependent on Commonwealth and State Governments. This results in the lack of integrated urban governance as urban management is strongly shaped by "siloed State agencies which are themselves in turn, heavily influenced by large private sector interests". Therefore, more integrated governance at the city level, enabled by long-term community vision, strong leadership, and stakeholder participation is needed (Steele, 2020). Successes attributable to such integrated approaches have been reported in China and Vietnam, where top-down and state-centric measures to coordinate activities across different cities and provinces have been coupled with certain levels of bottom-up and community-based activities at the city level. Such combined approaches have facilitated timely actions to prevent the diffusion of the virus and reduce the socioeconomic impacts of the pandemic. Based on this, there are some arguments about the possibility of more state involvement in urban governance in the post-COVID era (Hesse and Rafferty, 2020). It should, however, be mentioned that two important factors have contributed to the success of this combined model. One is the high level of trust in government and its initiatives, the absence of which may make it difficult to achieve pre-determined objectives (Thoi, 2020; Earl and Vietnam, 2020). The other important factor is having mechanisms in place to engage citizens in the initiatives. For instance, in successful cases such as the Setubal municipality (Portugal) and Ho Chi Minh City (Vietnam) engagement of community-based organizations has made significant contributions to local governments regarding information dissemination, provision of economic and social support to vulnerable groups, sanitizing public spaces, and implementing social distancing and 'stay home' measures (Thoi, 2020; Santos et al., 2020). Strengthening Non-Governmental Organizations (NGOs) and community-based initiatives may also be critical when state-centric initiative are lacking or fail to respond properly. For instance, Duggal (2020) argues that community-driven activities such as distributing meals and other basic needs has contributed to preventing catastrophic starvation during the lockdown in India. Overall, community engagement is recommended as it can contribute to designing better informed emergency plans and also enhance their implementation prospects (Wilkinson et al., 2020).

Other governance-related issues such as the need to better consider urban-rural linkages in urban governance and the desirability of strengthening global networks of cities that can facilitate experience sharing and mutual support have also been noted in the literature (Kunzmann, 2020; Connolly et al., 2020b; Acuto, 2020; Rich, 2020). Regarding urban-rural relationships, it is needed to ensure that they are not exploitative and do not undermine the capacity of rural areas to deal with adverse events (Rich, 2020). As for global collaboration, it is argued that the declined tax base of cities may encourage engagement in collaboration networks of cities (Kunzmann, 2020). The existing experience of networks such as C40 Cities and the 100 Resilient Cities may provide good insights in this regard (Acuto, 2020).

Overall, literature shows that top-down and multi-level governance approaches should be combined with strong, democratic, and integrated city-level governance to enable effective and nimble response to pandemics. Such integrated approaches facilitate developing appropriate long-term development visions and emergency plans, help avoid sectoral conflicts, and maximize benefits that can be accrued from stakeholder engagement. As will be discussed in the following section, smart city solutions can contribute to promoting integrated urban management.

3.3.2. Smart cities

Long before the pandemic, there was increasing interest and major advances in using smart solutions, enabled by Information and Communication Technologies (ICTs) and big data analytics, for enhancing efficiency and efficacy of urban operations and improving quality of life (Chen et al., 2020). Unfolding amid these rapid advances, COVID-19 has provided a good opportunity to test the ability of smart solutions to solve major societal issues (Kummitha, 2020). It has also provided additional momentum for smart city development, as evidenced by the increased reliance on teleworking, telemedicine, surveillance systems, and online commerce and education (Kunzmann, 2020). It is, therefore, argued that COVID-19 is likely to boost smart city movements (Kunzmann, 2020).

The early evidence reported in the literature shows that various smart technologies have been repurposed to among other things, inform appropriate response measures, minimize human-to-human contact, identify infected individuals, predict diffusion patterns, and facilitate quarantine measures. Real-time monitoring and big data analytics are critical for effective adaptive response to disruptive events. Major achievements can be made by fusing IoT sensors, smart city systems, and machine learning techniques as the experience of Newcastle, UK shows. For several years, the city has used an Urban Observatory to collect and store real-time data on various metrics, including vehicular traffic, pedestrian movement, and air quality. In response to the COVID-19 crisis, the live data feeds of the platform were re-purposed to develop a data dashboard that informed local authorities of changes in societal behaviors and allowed them to make data-driven and evidence-based adaptive decisions. For instance, it immediately revealed abnormal changes in mobility and activity patterns that required attention, and also enabled data exchange between different stakeholders in a timely manner (James et al., 2020). Cases of utilizing smart technologies for minimizing human-to-human contact in service delivery have also been reported. These include China-based initiatives such as using drones for autonomous delivery of medical and

commercial supplies during the lockdown (Chen et al., 2020), or clinical care and computed tomography scanning enabled by Artificial Intelligence (AI) to protect healthcare workers from direct contact with patients (Chen et al., 2020). These have also provided other benefits such as improving efficiency and speed.

Smart solutions have also been widely used to identify infected individuals and take appropriate containment measures. Depending on the social and political contexts, three different approaches related to these functions can be distinguished: 'techno-driven', 'human-driven' and 'combined' (Kummitha, 2020). In his analysis, Kummitha (2020) shows that while Chinese approach is 'techno-driven', Western democracies have adopted a 'human-driven' approach. In the techno-driven approach, smart technologies are used in a top-down manner to contain the pandemic by disciplining citizens and controlling the free flow of information (Kummitha, 2020). For instance, China has deployed a 'color-coded ranking' program enabled by smart phone applications to control movement of residents. The program operates based on recent health information recorded for an individual and his/her relatives (Chen et al., 2020). Similarly, in India the 'Quarantine Watch' smart phone application has been introduced to track adherence to self-quarantine rules. Individuals have used the application to self-report their status by uploading geo-tagged selfies that can be checked by the system using facial recognition technologies (Datta, 2020). In contrast, the human-driven approach has focused on controlling the pandemic by informing and educating citizens and enabling two-way communication between citizens and the government. This has been more common in Western democracies (Kunzmann, 2020; Kummitha, 2020). The techno-driven approach, however, has demonstrated more success in containing the spread of the virus, deploying the technologies ubiquitously, preventing the spread of misinformation, and coordinating actions of different cities and actors (that is essential for achieving integrated urban management as was mentioned in the previous section). Yet, it has raised serious concerns regarding privacy protection, transparency, and information reliability. It is argued that this lack of transparency and initial efforts to conceal information may have played a significant role in the initial spread of the virus. There are also concerns that authoritarian regimes may take advantage of the situation to reinforce power relations (Kummitha, 2020). The human-driven approach is argued to be more useful for empowering citizens to solve other existing and emerging socioeconomic and environmental issues. Overall, it seems a combination of both approaches is needed so that smart solutions can be deployed in a manner that contributes to containing the pandemic, deals with privacy concerns, facilitates and optimizes coordination and information sharing, and controls the spread of misinformation (Kummitha, 2020). One such combined approach has been implemented in South Korea, which is highly lauded for its success in controlling the pandemic. Instead of total lockdown that has major socioeconomic ramifications, South Korea has, since the early stages of the pandemic, applied extensive surveillance based on anonymized spatio-temporal mapping, using smart technologies including debit/credit card transaction data, mobile phone data, and CCTV data, to trace the mobility of patients. This method has been used to communicate the conditions properly and transparently with citizens to help avoid public panic and also prevent the spread of fake news. A similar approach has also been taken in the Czech Republic (Won Sonn and Lee, 2020; Kouřil and Ferenčuhová, 2020). Won Sonn and Lee (2020) argue that under critical circumstances caused by pandemics one needs to choose between extensive surveillance of a small percentage of the population or blanket lockdown that undermines mobility freedom and has major economic ramifications. It is argued that if the urgency of the situation and the purposes of the surveillance are properly communicated with citizens and they are assured that the collected data will be used for communal benefit, privacy concerns can be mitigated (Kunzmann, 2020; Won Sonn and Lee, 2020). Also it is believed that younger generation is less concerned about privacy, as demonstrated by their willingness to reveal their privacy on social media (Won Sonn and Lee, 2020). Another concern raised about smart solutions is their accessibility and affordability. Accordingly, better fulfillment of smart city objectives requires taking actions to avoid digital divide (Aguliera and Nightengale-Lee, 2020).

Overall, the pandemic has boosted interest in smart city development by demonstrating the multiple benefits of smart solutions in terms of identifying infected individuals, predicting diffusion dynamics, minimizing human-to-human contact, and enabling enforcement and tracking of social distancing and quarantine rules. These have contributed to designing effective response and recovery measures. Regarding the implementation, while techno-driven approaches have been more successful, there are concerns about their implications in terms of privacy and enforcement of power relations. Therefore, a combination of techno-driven and human-driven approaches is necessary to not only overcome such concerns, but also enhance adaptation to future events by raising citizen awareness.

3.4. Transportation and urban design

3.4.1. Transportation

Generally, population movement and transportation infrastructure that increase inter- and intra- urban connectivity, are considered as key factors contributing to the spread of infectious diseases, and their role in previous diseases outbreaks (e.g., Ebola) has already been documented (Connolly et al., 2020b). This is also confirmed in a study on the association between mobility patterns and the spread of the virus across different Italian regions. Results show that the number of daily certified cases of COVID-19 infections is strongly linked with the trips made 21 days before (note that this finding shows that the 14 day quarantine period set in many places, based on incubation-based approaches, may not be accurate) (Cartenì et al., 2020). There are also other modeling studies confirming the significance of mobility patterns/restrictions for the spread/containment of the pandemic (Wu et al., 2020). Accordingly, in order to contain the spread of COVID-19 many local governments applied partial or complete mobility restrictions (Cartenì et al., 2020; Ai et al., 2020). Empirical evidence suggests a significant decrease in social mobility following the prevalence of COVID-19 and the adoption of travel restrictions. For example, Hadjidemetriou et al. (2020) reported 80% decline in daily trips after restrictions were introduced in the UK. Similar findings have been reported in other contexts. For instance, an overall decrease of 76% is reported in the city of Santander, Spain (Aloi et al., 2020); Bucsky (2020) indicated that the demand for transport had more than halved in Budapest, Hungary; in India, Saha et al. (2020) observed significant reductions in retail and entertainment, supermarket and pharmacy, park visits, public transportation stations, and workplace mobility (by 73.4%, 51.2%, 46.3%, 66%, and 56.7% respectively); and, in the Netherlands, de Haas et al. (2020) found that, relative to the fall of 2019, the number of trips and the distance traveled fell by 55% and 68%, respectively.

Several studies have examined the efficacy of travel restrictions in containing the spread of the virus. Results show that restrictions on human movement have limited the spread of the virus in China (Kraemer et al., 2020; Tian et al., 2020), and the UK (Hadjidemetriou et al., 2020). According to Zhang et al. (2020), the first reaction of many countries/cities to the COVID-19 outbreak was to minimize air travel from/to China, and it had effectively reduced the number of COVID-19 cases imported from China in February 2020. Wu et al. (2020) claim that the rapid spread of COVID-19 across China and the globe, in a very short span of time, was attributed to the outbreak during the Chinese New Year, the abundance of connecting flights, and Wuhan's excellent rail connectivity. Other researchers have found that COVID-19's arrival time was delayed in those Chinese cities that had fewer travelers from Wuhan (Tian et al., 2020). They emphasized, however, that suspending intra-city public transport could only reduce the number of incidents and banning travel between cities or provinces

after COVID-19 arrival was not very effective. This indicates the significance of taking timely actions.

A growing body of literature has centered on the resilience and the transmission risk of various transport modes. Zhang et al. (2020) found a substantial association between the frequency of air flights and high-speed rail services out of Wuhan and the number of infected people in the destination cities. They argue that these travel modes not only increase the risk of infection of travelers, but also play a significant role in the increase of the number of confirmed cases in the destination cities. Regarding other transport modes, in an analysis of the effects of COVID-19 on urban transport systems, Teixeira and Lopes (2020) found that New York's bike-sharing network saw a lower decrease in ridership than the subway system (71% vs. 90%) and its trips' average duration was increased from 13 min to 19 min per trip. They also found evidence indicating a modal shift to the bike-sharing from some subway users. They concluded, therefore, that the bike-sharing network has proven more resilient than the subway system. A similar argument is made by Bucsky (2020), who indicated that cycling and bike-sharing witnessed the lowest decline in demand in Budapest (23% and 2%, respectively) while the highest decline was seen by far in public transport (80%). This is a clear indication that non-motorized transportation systems are more resilient to pandemics. Investment in such systems not only contributes to containing the spread of the virus, but also can increase service accessibility and reduce pressure on overly crowded transportation systems during emergency situations (Biswas, 2020).

The reviewed literature also indicates that COVID-19 can have long-lasting and structural effects on travel behavior and people's mobility. Several studies have shown that the crisis has double-edged consequences for peoples' activities and travel behavior (Aloi et al., 2020; Bucsky, 2020; de Haas et al., 2020). The positive outcome is that the total travel is decreased, and people choose to bike and walk more. Nonetheless, as a negative side effect, the COVID-19 experience may increase negative attitudes towards public transportation and preference for individual travel modes. For instance, as discussed in Section 3.4, the pandemic has led to a boom in second home real estate. This is likely to increase investment in suburban developments, thereby increasing reliance on private vehicles (Kunzmann, 2020).

In an effort to explore the possible effects of social distancing on travel behaviors, De Vos (2020) hypothesized that social distancing, social isolation, and reduced physical activity might have a detrimental impact on well-being and health status. He suggested active travel as a way to preserve safety and well-being at acceptable rates. Budd and Ison (2020) called for adopting 'Responsible Transport' measures and policies during the post-COVID recovery period. They argued that people ought to be conscious of the effects of their travel habits on not only their own health and well-being, but also on the environment.

Overall, the early evidence on COVID-19 impacts on the transport sector highlights three major issues: first, smart mobility restrictions, based on the transmission risk of different transportation modes, is essential for containing the spread of the virus. These should involve taking early actions to restrict travel from/to high-risk cities; second, policymakers should be mindful of the possible increase in the negative attitudes towards public transport due to the crisis. It was discussed that public transport ridership had plummeted significantly in the early phases of the pandemic and people have shifted to other modes such as cycling, walking, and private vehicle use. While smart urban design strategies can contribute to meeting daily needs using neighborhood-oriented planning (that facilitates using active modes), long travel distances would still be inevitable in cities. Accordingly, to avoid further reliance on private vehicles, public transportation systems should be reformed, and actions should be taken to minimize potential health risks to regain public trust by meeting safety needs of the users. This is also essential for achieving low-carbon and inclusive urban development (de Haas et al., 2020); third, active transport modes have proved more effective in meeting mobility demands of citizens during pandemics. They can provide access to services in an affordable manner. Therefore, active transport modes should be further promoted by more investment in cycling and pedestrian infrastructure (Hadjidemetriou et al., 2020; De Vos, 2020). Of course, these efforts should be parts of broader initiatives aimed at compact urban development.

3.4.2. Urban design

While different urban form and design factors can influence the dynamics of pandemics, existing literature has mainly focused on factors related to the density, and other factors are not well explored. The COVID-19 outbreak highlighted issues related to the desirability of compact urban development. The initial hypothesis was that densely populated and well-connected areas could become hotspots for the rapid spread of the pandemic due to high levels of face-to-face interaction. However, reported evidence on the association between density and COVID-19 is contrasting and inconclusive. In their study of over 900 US metropolitan counties, Hamidi et al. (2020) did not find a strong positive correlation between COVID-19 infection and mortality rates and density. Surprisingly, compared with sprawling areas, they observed slightly lower virus-related mortality rates in high-density locations. Similarly, Boterman (2020) did not find a significant positive relationship between county density and infection rate in the Netherlands, which is generally highly urbanized and densely populated. Also, in China, Lin et al. (2020) found that the percentage of the population arrived from Wuhan, and population density are key factors that can explain the spread rate of COVID-19. However, after controlling the former variable, the linear relationship between population density and spread rate disappeared. They further explored the effect of population density and did not find high spread rates in high density metropolitan regions.

However, some studies have shown significant relationships between density and the spread of the virus. Qiu et al. (2020) investigated the impacts of specific socioeconomic and environmental characteristics on transmission rates in two early stages of the epidemic in China (first phase: January 19 to February 1, second phase: February 2 to February 29). Their study indicated that while population density did not have a significant relationship with the transmission rate of COVID-19 in the first phase, it had a significant negative effect in the second phase. They suggested that public health measures and the sharing of inter-city resources are two possible reasons for reducing social interactions and establishing a significant relationship in the second phase. In contrast, Ren et al. (2020) observed that the very high-risk zones of COVID-19 infection in Beijing and Guangzhou tend to occur in areas with larger population densities. Similarly, a study of different Italian regions shows higher transmission rates in regions with higher population densities (Cartenì et al., 2020). This is explained by the fact that social distancing is more challenging in high-density areas that feature more crowded spaces. Similar findings about the positive relationship between density and spread rates have been reported in a study of 20 Chinese provinces/municipalities (Lin et al., 2020).

The inconclusive evidence on the association between density and the COVID-19 infection rate is in line with earlier findings reported for other infectious diseases. For instance, while high-density in Monrovia and Freetown, Sierra Leone has contributed to the diffusion of Ebola, another infectious disease (SARS) was originated and spread in the low-density, peri-urban areas of China (Connolly et al., 2020b). Accordingly, density alone cannot be a predictor of the spread of infectious diseases and other factors such as the state of development, availability of prevention and response measures, the extent of adherence to sanitation and social distancing measures, and the extent of access to amenities and public health infrastructure are also important. In fact, while increased density may be a factor enabling the transmission of infectious diseases, high-density cities are often better prepared and have more access to resources necessary for timely response needed to prevent the spread of viruses (Connolly et al., 2020b). In contrast, lower-density peri-urban and suburban areas have limited access to resources

and may increase the chance of exposure to new types of viruses and diseases that can be transmitted through increased human-wildlife interactions due to human encroachment on natural ecosystems (Connolly et al., 2020b).

Connectivity and city size are other variables that are discussed in the literature. Several studies, focused on China, found that connectivity, particularly with Wuhan, is the primary factor affecting the epidemic spread in the early days of the outbreak (Lin et al., 2020; Xie and Zhu, 2020; Wu et al., 2020). Similarly, Hamidi et al. (2020) identified connectivity as a risk factor for COVID-19 in the US, and placed more emphasis on connectivity rather than density when explaining the transmission dynamics of the virus. Regarding city size, it has been found to be a key factor influencing the spread of the virus in the US cities (Stier et al., 2020). This may indicate that policymakers need to implement more aggressive protection measures in larger cities (Stier et al., 2020). However, more research is needed to better understand possible associations between city size and prevalence of infectious diseases.

Finally, while there is a lack of empirical evidence on the effects of the design of streets and open/public spaces on the dynamics of COVID-19 spread and associated response measures, there are

Table 2
Major issues revealed by the pandemics and recommendations for post-COVID planning.

Theme		Major issues revealed by the pandemic	Major recommendations/implications for post-COVID planning
Environmental quality	Air quality	- Traffic emissions are major sources of pollution in many cities - Non-traffic sources of pollution are also important in some contexts - In some contexts, COVID-19 transmission/mortality rates are strongly associated with high levels of air pollution - Long-term exposure to air pollution can increase human vulnerability to pandemics	- Greening the transportation and industry sectors can provide major air quality benefits - Measures to reduce traffic-related pollution are not enough to address air quality in all contexts - As measures designed for reducing some pollutants may increase secondary pollutants, holistic approaches to pollution mitigation are needed - Reducing air pollution can contribute to reducing transmission/mortality rates of pandemics
	Environmental factors	- Evidence on the association between temperature and COVID-19 transmission rate are inconclusive - When the wind speed is low, air pollution is likely to intensify transmission rate	- During pandemics, social distancing and other protection measures should continuously be promoted irrespective of environmental conditions - Improving air quality can contribute to addressing issues related to covid-19 and other pandemics both in short and long term
	Urban water cycle	- Unregulated human activities have resulted in the contamination of water resources in many cities - Drugs used for treatment of COVID-19 patients may pollute freshwater resources - Lack of sewage treatment facilities in poor areas undermines the effectiveness of lockdown measures	- Designing regulations to minimize negative agricultural, industrial, and traffic impacts on water resources should be prioritized - Sufficient disinfection of water plants and wastewater treatment plants and measures such as the prevention of sewage leakage into freshwater resources are essential to reduce human exposure to the virus
Socio-economic impacts	Social impacts	- COVID-19 has exposed old problems and inequalities in a new light - Inequalities make containment challenging, and may also lead to further diffusion of the virus - Enforcing social distancing and other response measures is challenging in slums	- More inclusive actions towards reducing inequalities and addressing the needs of vulnerable groups should be prioritized - Slum upgrading should be prioritized - Social distancing policies should be coupled with economic support mechanisms - Enhancing sense of community is critical for improving response and recovery capacities
	Economic impacts	- Homogeneous economic structure increases vulnerability - Marginalized groups are disproportionately affected by the economic impacts of the pandemic - Global supply chain makes cities vulnerable to disruptive events	- Diversifying urban economic structure is essential - Developing relief programs to support vulnerable and marginalized groups is necessary during pandemics - Transformation to more local supply chain that increases self-sufficiency is needed for dealing with the economic fallouts of the pandemic and similar future events
Management and governance	Governance	- Absence of proactive planning and emergency plans is a major reason for failure to respond effectively is some countries - Fragmented urban governance erodes response and adaptation capacities	- Long-term visioning and integrated urban governance enhance adaptive capacity - During pandemics, local governments should provide economic and social support to vulnerable groups - In addition to top-down initiatives, certain levels of local leadership and community engagement are critical for timely response to pandemics
	Smart cities	- Smart solutions have contributed to developing more effective and efficient response and recovery measures (e.g., identifying and isolating infected individuals, reducing human-to-human contacts in service delivery, etc.) - Techno-driven approaches have been successful in containing the virus, but have raised concerns regarding privacy protection and transparency	- Public access to real time and geo-referenced data enables better response and recovery from adverse events - Techno-driven approaches should not undermine privacy issues and be misused to reinforce power relations - Human-driven approaches are more suitable for citizen empowerment - Combined approaches are better suited for containing the pandemic, dealing with privacy concerns, facilitating coordination and information sharing, and controlling the spread of misinformation
Transportation and urban design	Transportation	- Increased transport connectivity is a risk factor that may contribute to the diffusion of infection diseases - Public transportation may increase the risk of transmission during pandemics - The pandemic may increase negative attitudes towards public transportation	- Smart mobility restrictions, based on the transmission risk of different transportation modes, is essential for containing the spread of the virus - More attention to minimizing potential public health risks of public transportation is needed - Modal shift to cycling and walking offers a unique opportunity to further promote active transportation
	Urban design	- Density alone is not a key risk factor contributing to the spread of the virus - Some cities lack appropriate levels of green and open spaces to meet outdoor exercise and recreation demands of their citizens while fulfilling social distancing requirements	- Better access to amenities and public health infrastructure make high-density areas less vulnerable to pandemics - Considering multiple other benefits of compact urban developments, planners should continue promoting them - More space should be allocated to pedestrian areas and open spaces

arguments that to facilitate effective physical distancing in the time of pandemics, cities need to allocate more space to active transport modes and open/public spaces. This may require redesigning streets to accommodate the needs of pedestrians and cyclists better and providing ample green and open spaces in order to meet the outdoor exercise and recreation demands of citizens (Honey-Rosés et al., 2020). Such reconfigurations may also provide opportunities to integrate urban greenery into cities further, thereby achieving additional health and climate adaptation co-benefits. They may also contribute to resilience against other stressors and adverse events (Sharifi, 2019c).

Overall, while the link between COVID-19 prevalence and urban design characteristics has created many debates in the media and the public, the existing literature does not specify in much detail how different design measures such as connectivity, block size, land use mix, polycentricity, etc. influence the infection and mortality rate of COVID-19 and the capacity of cities to respond to the pandemic. However, according to the early findings, planners are recommended to keep advocating compact forms of urban development rather than sprawling ones because various other merits of compact urban development are demonstrated in the literature (Connolly et al., 2020b; Hamidi et al., 2020; Sharifi, 2019a, b).

4. Summary and conclusions

In early 2020 COVID-19 ravaged many countries around the world. Everyday life in many cities have been interrupted ever since. As many parts of the world continue to struggle with the COVID-19 pandemic, the scientific community has made efforts to shed more light on its underlying dynamics. Drawing on the early evidence reported in the literature, in this study, we tried to understand major impacts on various urban sectors, identify key factors that should be considered for better preparation and response to future similar events, and highlight gaps that need to be further studied in the future research.

This review shows that early evidence is mainly related to four major themes, namely, (1) environmental quality, (2) socio-economic impacts, (3) management and governance, and (4) transportation and urban design. However, there is no balanced coverage of these themes, and issues related to the first theme are dominant. This is probably because data related to air quality and environmental impacts is more readily available, but accessing and analyzing data related to other themes may need more time.

While some common patterns can be observed, existing evidence indicates that impacts and response mechanisms differ from one context to another, and it is not always easy to provide identical recommendations that apply to different cities. However, like any other crisis, COVID-19 provides lessons that can be used to build back better. Major issues revealed by the pandemic and possible lessons/recommendations for better planning in the post-COVID era are presented in Table 2. This table provides some insights into how to handle the present and any future similar events that occur in cities. Clearly, cities need to re-evaluate their policies in different sectors. For instance, improvements in air and water quality during lockdown periods once again highlight the significant environmental impacts of anthropogenic activities and provide a wake-up call to adopt environmentally friendly development pathways. The pandemic has also exposed old socioeconomic inequalities that exist in cities. It was discussed how such inequalities could threaten public health by making it difficult to enforce protective measures such as social distancing. Obviously, overcoming such inequalities is critical and should be prioritized as cities recover from the pandemic.

The pandemic is expected to fundamentally alter how cities are managed/governed in the future. In this regard, actions taken within the next few years are important and determine whether post-COVID cities will be developed and managed in a more sustainable manner. As cities start to recover, their main priority will probably be economic development. However, it is essential to make sure that, in addition to economic development, social and environmental dimensions of sustainability will also be considered. In fact, the pandemic has provided opportunities that can be capitalized on by planners. For instance, in the transportation section (Section 3.4.1), it was discussed that public transportation has been severely affected during the pandemic, and many people have turned to private vehicles and biking/walking as safer alternatives. While increased interest in private vehicles poses threats to achieving sustainable development, the increase in the number of cyclists in many cities around the world provides a unique window of opportunity to promote cycling culture in cities further. This may turn temporary cyclists into long-term riders.

Another important issue highlighted by this study is that various urban sectors and factors can impact (and also be impacted by) the dynamics of the pandemic. This indicates the significance of developing integrated assessment and action approaches that facilitate developing better mitigation and response strategies. For instance, a recently developed index for Italian cities/regions allows developing ex-ante measures by considering various socio-economic and environmental factors such as sources of air pollution, urban ventilation, and population density (Coccia, 2020b). As it was discussed, the impacts are context-specific and there is no one-size-fits-all solution for solving the issues caused by the pandemic. Therefore, developing context-specific integrated approaches is essential for developing and implementing effective planning, response, recovery, and adaptation actions.

Regarding the limitations, it should be acknowledged that research on some themes such as urban design and environmental factors is not wholly conclusive, and considering the evolving nature of the pandemic, new and different findings may emerge in the coming months. Therefore, more reviews in the coming months are needed to not only update the findings of this initial review, but also provide insights on currently under-studied issues such as the long-term socioeconomic and environmental consequences, and the way the pandemic will transform citizen behavior and urban governance. Such reviews are particularly important because the full socioeconomic impacts of the pandemic may take some more time to appear. Future reviews should also involve analysis of the temporal evolution of the evidence related to different themes discussed in this study to explore possible lines of convergence and divergence.

In the end, it should be reiterated that this crisis highlights the need for critical reflections on the importance of cities and how they are governed. It is hoped that enlightened by the substantial impacts of the pandemic on cities, planners and local authorities will be more successful in rallying support for transformative actions towards dealing with other important threats such as climate change that are looming over cities.

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.

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