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Urban Climate Health Risks and Resilience

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Abstract: The effects of climate change health impacts on urban health care systems and vulnerable populations are a researched topic with foundations on urban risk management, urban health methodologies, and sustainable urbanization. As climate change is a dynamic and transformative global issue the gap between adaptation and mitigation efforts and urban planning relies, among other things, in the limitations of previous studies of risk management structures tailored to the existing strategy to calculate the uncertainties and predict their influence on urban systems and subsystems. Moreover, as climate and health is a well-researched issue, it is also complex as the methodologies and strategic approach to minimize health risks of climate change is intrinsically contingent to risk methodologies and policy-making processes that are efficient with support of knowledge-based information. This paper emphasis the need for focusing on urban health risk management methods that serves to identify potential opportunities, and then manage and take action to prevent adverse health effects. It also emphasizes the probability of events and their consequences, which are measurable both qualitatively and quantitatively.

Keywords: climate change; health risks; urban climate; risk health management

1. Introduction

The nexus between climate, health and urbanization Climate change is a major concern and affects our good health. Human actions are changing the global environmental systems having implications affecting our health as it depends on the stability of the environment, and the balanced functioning of the world's climate system [1,2]. Presently, we are experiencing the impact of climate change and gradually densely populated urban areas, particularly in developing countries, will face the consequences more rapidly and forcefully [3]. Nonetheless, there are several climate health risk factors affecting the urban poor population. These issues will compound existing vulnerabilities, increase poverty levels, and affect the urban poor with more severity because these dwellers live in vulnerable conditions such as crowded living situations, lack of access to basic services, including health care and safe housing structures [4].

2. Materials and Methods

In pursuing these complex issues, research was conducted using the case study method to explore climate change health impacts on the urban poor in megacities. The research looked at practical and theoretical cases, differentiated by geographic, demographic, and socioeconomic factors. The literature referred to in this narrative review was found on Google Scholar, PubMed and books related to climate, health, urban poor, and urbanization from scholars. The literature search was performed using combinations of keywords including 'climate change', 'human health', 'health', 'urban poor', 'megacities', 'urbanization', urban climate risk management', and 'climate health risks'. Only peer-reviewed, English language articles published between 2000 and 2023 were shortlisted the literature search.

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3. Results

A changing climate can alter the pattern of diseases, mortality, human settlements, food, water, and sanitation. Air quality will adversely affect health and safety and present a risk for all-cause mortality as well as specific diseases. Some of those specific diseases outcomes are stroke, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, pneumonia, and cataract in household air pollution [5,6]. These health outcomes translate into health risks exacerbated among those who are heat-sensitive will increase. The vulnerabilities of the urban poor will be intensified by heat fatalities due to poor air circulation in overcrowded precarious households and lack of access to air conditioning [7]. Climate change creates an increase in frequency of severe climatic events and these effects generate hazardous sanitary events known as health risks. Moreover, as changing patterns in temperature, precipitations and other extreme events increases the geographic range of diseases, they may influence transmission of many diseases, including water-related illnesses, such as diarrhea, and vector-borne infections, including malaria. Malnutrition is another factor that is highly considered as it has far-reaching effects on how food is produced and may have health impacts from increasing rates of malnutrition [8,9]. Flooding affects roads, telecommunication networks, and power supplies and housing communities, destroying essential infrastructure that supports the urban system. Heavy rains will force storm water discharge systems to empty waste and lead to a build-up of debris in outdoor drains, which often clogs the underlying pipes. Another issue is the rising sea levels impacting coastal megacities and its population, which consequently will result in salination of freshwater supplies, loss of productive land, and a change in coastal dwelling mosquitoes' breeding [10–12]. Concentration and range of pollen is also affected by higher temperatures exacerbating asthma related health impacts [13]. A global increase in the distribution and incidence of infectious diseases is projected. The lifecycles of pathogens and the animals that carry and transmit them are influenced by these climatic changes that affect land use and land cover. Malaria and other vector-transmitted diseases get most of the attention from climate-change scientists and health professionals. The intertwined between climate change and malaria is related to the temperature and rainfall that are key parameters of climate change with fluctuations in temperature influencing the spread of the disease by affecting its rate of transmission. The latitudinal, altitudinal, seasonal, and inter-annual connection between climate change and disease, along with historical and experimental evidence, leads to the conclusion that climate, in addition to other causes, significantly influences infectious diseases in a nonlinear fashion [14,15].

Climate change will alter the patterns and spread of malaria transmission. Rainfall affects malaria, acting not only on persistent bodies of water, but also on physical and biochemical characteristics of aquatic environments. Heavy rains and flooding are known to cause major malaria outbreaks in semiarid or arid lowlands; at the same time, spatial, and temporal variations in rainfall determine the nature and scale of malaria transmission in highland areas [16]. Furthermore, Chagas disease is one of the most significant climate-sensitive vector-borne diseases in South America, and it is spreading throughout the continent. The globalization of the disease through climate change as well as other factors, such as migration (it can be increased by climate change impacts in certain regions), blood transfusion, and so forth, is a concern for developed countries, and these aspects are modifying and accelerating the transmission rate and distribution of the disease [17,18]. The relation between Chagas disease and temperature change has been studied almost since the beginning of the disease's parasitological, clinical, and epidemiological description. Direct impacts such as thermal stress, floods, and storms; and direct impacts such as borne-vector diseases, waterborne pathogens, water quality, air quality, and food availability and quality are concerns for urban populations. The socioeconomic situations of the urban residents as well as the environmental conditions of the city are important factors that amplify the impacts of climate change on a population's health [19].

Another factor to assess the vulnerability of populations is the existing city's adaptation and mitigation strategies and the viability of the institutions, technology in place, and risk management planning to be implemented when the city's leaders need to act upon the situation [20]. Although little work has happened to lessen climate change impacts on public health and its propagation into the urban ecosystem, the awareness of risk management has been emphasized considerably in the

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government and the private sector. The devastating consequences for densely populated cities of large-scale disasters such as Hurricane Sandy, which had overwhelming impacts in October 2012 affecting 24 states, including the entire eastern seaboard from Florida to Maine, with particularly severe damage in New Jersey and New York, presents a challenge to public policy if meaningful actions are not taken into consideration [21,22]. Climate change impacts on health is a "global shock" that allows for a unique outline of risks. These types of global shocks stream a series of risks that grow to be active threats because they extend its effects across global systems. These threats expand along the urban ecosystem arising in health, environmental, social, or financial risks.

3.1. Health Impacts and Urbanization

According to the latest United Nations report between 2007 and 2050, the urban areas of the developing world are expected to absorb an additional 3.1 billion people while the overall population will grow by just 2.5 billion people [23]. Urbanization is dynamic and transformative and in developing countries, unplanned expansion of housing projects exposes a greater number of urban residents to climate change health risks. The health impacts will depend on the geographic region, susceptibility of populations, socio-economic conditions throughout the different class levels of their society, and the capability of societies to adapt and mitigate the impacts [24]. As urban areas face rapid migration and population growth that demands basic services such as health care, availability of drinking water, and other sources, the urgency of developing an effective urban risk management framework that provides guidance and strategic planning to cope with climate risks and for maintaining and delivering essential services becomes urgent in today's climate uncertainties [25,26]. Cities need to consider the issues of climate change and urban health by evaluating related risks to identify, plan, and improve feasible programs in their preparation and management processes of the system [27]. Susceptibility to climate change and its effects on health increase as the concentration of economic activity and population density worsens the health situation in the world's major cities. The impacts of climate change on health are magnified on urban populations [28]. The capacity of the urban poor to adapt is weak in comparison because of inadequate housing, poor nutrition, overcrowded living, and population displacement. Resources and information are scarce and the urban poor cannot respond efficiently in order to take actions to mitigate climate change effects; this situation creates a gradual exposure to health risks. The poor population's vulnerability will be exacerbated by exposure to severe weather effects and lack of ability to adapt to climate change [29]. Rising sea levels make cities vulnerable to drastic environmental changes and exacerbate the economic risks faced by poor residents. Inland cities also have susceptibilities to climate change, including urban settlements on steep slopes in hazard-prone areas, and the heat island effects [30]. Sea-level rise and other coastal implications, such as changes in storm frequency, put populations at risk of climate change effects.

The rapid urbanization experienced in the 20th century and the expansion observed today has already created 20 coastal megacities. In contrast, in the 1990s there were a total of seven coastal megacities in Asia (excluding Japan) and two in South America [31]. The fragility of the sedimentary strata where the megacities are located is a concern that adds to climate change impacts on urban populations. The repercussions of climate change on megacities are varied and require each city to have an independent assessment to mitigate and adapt to climate change [32]. Urbanization has implications, both positive and negative for the inhabitants and the environment. These environments are in constant motion, mostly through construction developments but also through destruction of urban elements. While formal development is a process with long planning periods and private and public partnerships, informal settlements seem to be subject to high dynamics, social;, economic and/or environmental, in their ever fragmentary urban form. Acute shocks and chronic stresses have repercussions and long-term impacts on human development. Population's vulnerabilities to severe shocks are closely related to poverty and the detrimental effects are exacerbated by these impacts [33].

Climate has always affected our health, and the growing acknowledgment of climate change and its consequences on health is building up consensus on addressing and coping with climate

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health risks. There are four factors that influence the outcome of climatic events on health: population growth, urbanization, land use reduction, and freshwater resources [34]. These factors affect the population's health but the impacts are not felt equally across the different demographics and socio-economic levels [35]. Because of the aforementioned elements affecting the urban population's health from climate change, the poorest people in the world will suffer the worst consequences. In regards of the socio-economic status of the population, the rural population's migration to major cities creates a steady growth in urban settlements with high density, human created structures that are unsafe and exacerbate their health-related problems of climate change. As the climate changes, health issues faced by the urban poor will create stressor to the health system and directly and indirectly will weaken the urban system [36,37]. Climate change will increase the exposure of the urban poor to malnutrition, disease and other health risks due to reduced food security; compromised drinking water; and water-rodent-borne diseases associated with floods, droughts, and the correlation of high temperatures and heat stress [38]. The economic and social inequality will be affected and will gradually increase affecting future generations' health and maximize their risk factors [39]. Henceforth, the urban poor; a situation of dwellers as a result of migration, lack of economic opportunities and social equity are affected by climate change, exacerbating extreme poverty in urban areas and increase poverty levels [40,41].

3.1.1. Climate, Health and the Urban Poor

There are several publications highlighting the links between climate change, the urban poor's vulnerabilities and health risks particularly in low and middle-income countries [42]. The urban poor is susceptible to direct health impacts because often they inhabit the least desirable land with precarious housing, and in flood zones that makes them vulnerable to severe climate risks. Frequent flooding also tends to cause an increase in insect population, which causes an increase in vector borne diseases like malaria. Moreover, extreme rainfall variability impacts crops with an effect on food prices affecting the poor the most [43,44]. Today, economic and environmental systems are at risk of collapsing, and these challenges dissuade any initiatives to develop and implement concise climate change resilience frameworks. The economic difficulties being experienced globally are exhausting financial resources as the impact of climate change is more evident with rising temperatures and more frequent extreme weather events mostly affecting the poor dwellers. Structural changes and strategic investments in cities' operational infrastructure are crucial to call attention to the perils of climate change for the urban poor's health and well-being [43,45].

The impacts of climate change on health are a major threat recognized by the Intergovernmental Panel on Climate Change's Sixth Assessment Report [46]. The changing climate is already affecting cities and, the effects will only get worse as many cities across the world are facing climate change impacts to their populations, communities and infrastructure. Cities are motionless and vulnerable to the impacts of severe weather events and climate change [47,48]. As the occurrence of extreme weather events increases year after year, the acute vulnerability of urban populations, especially children, the elderly, and the poor, will be exacerbated by climate change. The interruption of critical supplies to urban populations is a serious threat that is aggravated by the megacities' dependency on food imports [49]. Currently, 55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 [50].

The remarkable growth of megacities during the past century has motivated a continues series of scientific inquires as many of them are in developing countries, and their high population density and dependence on a complex infrastructure and networks makes them particularly vulnerable to the impacts of climate change events. The transformative and dynamic operations of megacities and the risks of climate change are building an urgent need of developing methodologies and adaptation programs to their evolving environments [51]. Urban design and planning can make a significance difference in the health outcomes of the urban dwellers [52]. Henceforth, the urban system developing adaptation programs must include public health system advocacy for policy, forecasting of climate health risks and urban agendas aimed at the urban population vulnerabilities to severe weather events and climate change. In this context, health systems should be prepared for potentially

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enhanced disease risks, which are expected to exacerbate the frequency and severity of existing diseases [53]. In this case, megacities will experience magnified effects due primarily to its high population densities.

Megacities have certain characteristics that make them more susceptible to climatic health risks such as impermeability of hard surfaces, the urban heat island, and increased pressure on local ecosystems for housing developments, networks infrastructures, and waste, air pollution, and urban slums in developing countries [54]. These factors affect the entire urban system and are challenging the megacities' public health systems to promote physical and mental health, and prevent disease, injury, and disability [55]. Managerial responsibility for climate health risk in cities is fundamental to maintain a balanced socio-economic and environmental equity and achieving health for residents in a sustainable way.

4.1. The Nexus between Climate, Health and Risk Management

Risk management serves to identify potential opportunities, assess, and develop concise actions to prevent adverse effects. It also emphasizes the probability of events and their consequences, which are measurable both qualitatively and quantitatively. These characterizations also apply to climate change, health risks and urban planning and disaster events [49,56]. Risk management frameworks addresses the full spectrum of challenges in areas such as planning, strategy, operations, finance, and governance with emphasis on minimizing, transferring and adapting to risks. In context to urban health resilience, it supports the identification of likelihoods, and opportunities of the city's different departments and functions as well as the potential impacts of parallel threats and events. The systematic analysis and management of health risks through a well-planned strategic approach to integrating recovery measures, preventing and mitigating risks, and identifying a population's vulnerabilities are significant challenges for urban areas to lessen climate health risks impacts. As population growth in urban areas keep increasing exponentially, city leaders must assess the opportunities and concerns in both internal and external environments. After that, the focus is to apply the best available scientific data and resources to plan and implement strategies and programs so that they can achieve medium- and long-term goals. Marolla [49] and Oppenheimer [57] presented three questions related to the cities' strategic approach to climate risks:

• Where are we? • Where do we want to go?

• How do we get there? In this context, the management and planning for the health sector and the megacities' leadership to respond to three fundamental questions:

• How do we identify climate change hazards and their locations? Hazards can be identified using global and regional scenarios developed by climate scientists.

It is noteworthy that climate scientists still face uncertainty, even though this is a known science and fairly investigated [57]. Many efforts are being developed to reduce those uncertainties in order to support health care systems, city policies, plans, and programs.

• How do we mitigate those hazards? To mitigate health hazards, cities should identify, plan, implement, and monitor strategies that can reduce the emission of greenhouse gas. Unfortunately, the reduction of emissions in one city does not mean that the effects of climate change will be reduced by the same proportion. Managers should always look to adopt mitigation strategies that take into account co-benefits for the health of city dwellers, for example, transportation strategies.

• How do we prepare the city to prevent or reduce the impacts considering those hazards? The term adaptation refers to the process of designing, implementing, monitoring, and evaluating strategies, policies, and measures intended to reduce climate change impacts and to take advantage of opportunities [55].

In public health, the analogous term is prevention. Adaptation generally entails understanding a system vulnerability, and to plan and manage systems in response to an anticipated change [58]. Vulnerability has many different definitions. The most common, according to Adger [59], is that vulnerability consists of exposure and sensitivity to disturbances or external tensions and the ability to adapt. Adaptation strategies adopted by different sectors may reduce impacts to the health system. It is noteworthy that effectively responding to climate change is a process, not a one-time assessment

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of risks and likely effective interventions [60. 61]. It is necessary to periodically assess the adequacy of the results on the way to achieving the goals set. Climate risk management practices tailored to adaptation build pathways to reduce risks by managing hazards and potential effects that can exacerbate the vulnerability of communities and landscapes and increase their resilience [62]. Climate resilience programs integrate a climate projection approach to screen for climate change and the overall assessment of potential risks. Table 1 shows a step by step analysis of evaluating adaptation strategies to enhance climate resilience in urban areas.

Table 1. Climate Resilience of Urban Health Care Systems frameworks [63].

Access Project Exposure and Criticality	→ Determine Performance Indicators
↓	
Assess Climate Vulnerabilities	→ Establish Climate Baselines and Projections
↓	
Develop and Evaluate Strategies	→ Analyze Project Performance
↓	
Recommend a Course of Action	→ Assess Vulnerability

As climate change exacerbate the health care systems' vulnerabilities on care and treatment for individuals and communities, it is primordial to focus on increasing the access of health care services and the efficient implementation of the urban care system strategy is measured through various health performance indicators, including the number of children immunized, the percentage of vulnerable populations exposed to climate health risks, and the number of people receiving health, nutrition and population services in comparison to the overall population [63].

Moreover, the assessment of health care facilities capable to provide services requires additional indicators such as the percentage of health care facilities that provides a minimum standard of quality, meeting the community's needs of a quality health service and accessibility and time waited to treatment [63,64]. It is critical to run a PDCA (plan-do-check-act) cycle.

This framework is an iterative four step management method used for the control and continual improvement of processes and programs. It can also be used to understand the weaknesses of their measures and make necessary improvements to the process, which is essential to make progress and identify gaps throughout the implementation process [49].

Figure 1 shows a step by step process model that can be used to improve quality management in healthcare. The PDCA cycle assessment should follow these steps:

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Figure 1. PDCA cycle [65].

• Plan: Thereafter, based on the analysis/evaluation results, it is requested to develop preservation and utilization plans to stipulate how the targeted area should be preserved and used, and who takes what action in which time- frame.

• Do: Following this stage, actions should be taken for preservation activities and sustainable use based on these preservation and utilization plans.

• Check: To understand accurately how many wild animals and plants live and grow in which location inside the targeted area.

• Act: Then, it is essential to carry out analysis and evaluation based on this study and monitoring data and to understand the current status and the time-related changes [66].

Risk health assessment is one of the key stages in the risk management process and involves the identification, assessment and analysis of risk stressors and detrimental events and setting priorities in risk management in many fields including health care management [49]. The following are considerations to evaluate a health care systems management plan for adaptation: • Historical—Identifying severe weather events within the city and its jurisdictions?

• Geographic—Level of impact in your city considering its geographical location and vulnerabilities to climate change?

• Structural—Factors affecting the functional ability and management of the health care's operations?

• Human factors—Considerations to minimizing human-caused emergencies that can result from inadequate training, supervision, or negligence [49,67]. Table 2 Risk matrix assessments [68].

Table 2. Risk matrix assessments [68].

Impact	High impact; outlier result with little or no evidence that conditions are possible	High impact; many results within this range of values	High impact; many modeled results within this range of values, evidence from historical records
	Medium impact; outlier result with little or no evidence that conditions are possible	Medium impact; many results within this range of values	Medium impact; many modeled results within this range of values, evidence from historical records
	Low impact; outlier result with little or no evidence that conditions are possible	Low impact; many results within this range of values	Low impact; many modeled results within this range of values, evidence from historical records
		Likelihood	

Table 2 presents an illustrative example of a risk matrix assessing likelihoods and impacts (consequences) where higher impacts and higher likelihoods lead to higher levels of risk [63,69]. When assessing the climate resilience and adaptation program, the identification of vulnerabilities through the implementation phase is crucial to highlight those at higher levels of risk that should advance to the next step of the framework to examine whether the project's resilience is effective and needs improvement.

The risk is the likelihood of harm occurring together with an indication of how serious that harm could be.

Risk rating = Likelihood score × Consequence score

As described earlier, the potential projected health impact can be evaluated through a qualitative and/or quantitative risk rank analysis, and assist in mitigation and adaptation measures. The framework applies to public health events that require an immediate response and are potentially caused by more than one hazard. It also classifies each potential health effect (very low, low, moderate, and high risk) and they are ranked in order of highest concern by health impact [70,71].

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Table 3. The consequence score [48,66].

The Consequence Score

	Likelihood				
Consequence	**Rare (1)**	**Unlikely (2)**	**Possible (3)**	**Likely (4)**	**Almost Certain (5)**
Catastrophic (5)	5	10	15	20	25
Major (4)	4	8	12	16	20
Moderate (3)	3	6	9	12	15
Minor (2)	2	4	6	8	10
Negligible (1)	1	2	3	4	5

Table 4. Assessing the risk score [66].

The Risk Score

Risk Score	Risk	Description
1	Very low risk	Local investigation where appropriate.
2	Low risk	Contributory factor(s) to be identified; discuss with city's management the need for any changes in current and future adaptation strategy, practice, policies, procedures, education, or training.
3	Moderate risk	Report incident immediately to manager/head of department. Identify contributory factors. Discuss at the city's governance meeting the action plans to be implemented. Assess existing strategies and monitor centrally.
4	High risk	Report incident immediately to manager/head of department. Inform risk manager. Full investigation to be undertaken including interview with staff and identification of root causes. Action plans to be monitored and reported to central government. Put in place a continuity management system to operate under catastrophic levels of disruption.

The health care's risk assessment team should decide on a series of initiatives related to their development of a strategy to address climate change impacts on public health. Therefore, leaders must define the scope of the assessment and ensure that all the relevant information is collected. The World Health Organization (WHO) developed a manual to guide rapid risk assessment of acute public health risks from any type of hazard in response to requests from member states. It aims at reducing or preventing disease in affected populations, and minimizes negative social and economic consequences that exacerbate the population vulnerabilities.

Additional benefits include:

- Defensible decision making
- Implementation of appropriate and timely control measures
- More effective operational communication
- More effective risk communication
- Improved preparedness [72].

As urban dwellers and local governments will face more intense climate impacts and be forced to cope with rising incidents of disasters, risk assessments become an important part of the strategy to reduce risks, loss, and damage. Using risk frameworks is an important tool to create a stronger, more resilient community. This methodology to determine the nature and extent of risks by analyzing potential hazards and evaluating existing conditions of vulnerability answers the fundamental question: What would happen if a health hazard event occurred in my city? [73,74]. Assessing risk based solely on past events does not provide a comprehensive current state of risks faced by the megacity. Urbanization and rapid population growth are creating high-risk prone urban areas. Risk management and strategic planning help to improve understanding of climate change patterns as well as their effects on human health and potential outcomes. These changes can now be better

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understood and scenarios for the future can be developed allowing policy-makers to identify adequate strategies for response and adaptation [75].

4.1. Rapid Risk Assessment for Health Care

Risk assessment is a crucial step in managing public health risks. Rapid risk assessment is a systematic process that enables a risk management process during an acute public health event, and assists decision making and operations to improve processes and deliver efficiency while making the best use of the limited time available [76]. Strategic planning and preparation to identify threats ensure that potential risks are categorized for better understanding in how to address, assess, and manage outcomes.

There are important steps to take to be well prepared and to anticipate any risk that threatens a megacity's functionality of operation and public health:

- Develop evidence-based protocols and guidance as tools to appropriately respond to climatic events and public health risks
- Institute concrete, defined procedures for identifying sources of key information for rapid risk assessment and identify the efficient use of those procedures
- Identify and maintain lists of named individual experts
- Ensure well-trained personnel [48].

The level and severity of climate change impacts on human health depends on many factors that would transpire through pathways of varying complexity, scale, and directness, and with different timing. The actual health impacts, however, are not uniform across countries and regions [76]. Taking into consideration the changeable nature of the climatic system and impacts, during a catastrophic event, a rapid, concise, and efficient response is crucial to save lives and minimize health risks and damage to the megacity's infrastructure. Responders and well-trained personnel must assess risks in a timely manner and make decisions based on priorities to reduce hazards—all within minutes to hours. It is important to have a prior evaluation of science-based risk assessments for an accurate identification of health impacts to address the potential adverse effects on human health and make projections of the extent and duration of these effects. The rapid risk assessment tool will be both understandable and applicable to the emergency management community, and would be a valuable asset during any climate disaster [77].

5. Discussion

There has been considerable thought and investigation about the health implications of climate change on urban dwellers. This paper identified and explored key links between climate change, urbanization, and the urban poor's health risks and the results affirm a correlation between observed climate change impacts and prevailing health conditions on the urban poor. Moving forward, there is ample evidence to signal both direct and indirect linkages between climate induced weather events and prevalence of diseases, increasing the risk of deaths, communicable and non-communicable diseases as well as the emergence of novel diseases. A robust risk management assessment, continuity management systems adaptation, and decision making under deep uncertainties with unknown outcomes are recommended. The study, ultimately, indicated that analyzing and characterizing uncertainty by means of likelihood and consequence can be a very efficient approach for selection and prioritization of preferred adaptation policies to reduce future climate related health risks and succeeds in demonstrating the nexus of climate change, health, and urbanization and the urgent need of a risk management strategy for the health sector in addressing and minimizing climate health risks in urban areas affecting the most vulnerable urban population.

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Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author,

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References

1. Rocha, J., Oliveira, S., Viana, C.M., Ribeiro, A.I., Chapter 8 - Climate change and its impacts on health, environment and economy, Editor(s): Joana C. Prata, Ana Isabel Ribeiro, Teresa Rocha-Santos, One Health, Academic Press, 2022, Pages 253-279, ISBN 9780128227947, https://doi.org/10.1016/B978-0-12-822794-7.00009-5.
2. Nadakavukaren, Anne, and Jack Caravanos. Our global environment: A health perspective. Waveland Press, 2020.
3. Salimi, Mohsen, and Sami G. Al-Ghamdi. "Climate change impacts on critical urban infrastructure and urban resiliency strategies for the Middle East." Sustainable Cities and Society 54. 2020: 101948.
4. Leichenko, Robin, and Julie A. Silva. "Climate change and poverty: vulnerability, impacts, and alleviation strategies." Wiley Interdisciplinary Reviews: Climate Change 5, no. 4. 2014: 539-556. 5. El-Sayed, Amr, and Mohamed Kamel. "Climatic changes and their role in emergence and re-emergence of diseases." Environmental Science and Pollution Research 27 (2020): 22336-22352. 6. Ebi, Kristie L., and Jeremy J. Hess. "Health Risks Due To Climate Change: Inequity In Causes And Consequences: Study examines health risks due to climate change." Health Affairs 39, no. 12 (2020): 2056-2062.
5. 7. Rodriguez, A. et al. Impact of climate change on health and disease in Latin America. Faculty of Medicine, Universidad Central de Venezuela. pp. 12–15. 2009.
6. 8. van der Merwe, Eduard, Matthew Clance, and Eleni Yitbarek. "Climate change and child malnutrition: a Nigerian perspective." Food Policy 113. 2022: 102281.
7. 9. Jankowska MM, Lopez-Carr D, Funk C, Husak GJ, Chafe ZA. Climate change and human health: Spatial modeling of water availability, malnutrition, and livelihoods in Mali, Africa. Applied Geography. 2 Apr 1;33:4-15.2012
8. 10. Wilbanks, T., Steven Fernandez, G. Backus, P. Garcia, K. Jonietz, P. Kirshen, M. Savonis, W. Solecki, and L. Toole. "Climate change and infrastructure, urban systems." In And Vulnerabilities: Technical Report for the US Department of Energy in Support of the National Climate Assessment. 2013.
9. 11. Najafi, Mohammad Reza, Ying Zhang, and Nick Martyn. "A flood risk assessment framework for interdependent infrastructure systems in coastal environments." Sustainable Cities and Society 64. 2021: 102516.
10. 12. Jurgilevich, Alexandra, Aleksi Räsänen, and Sirkku Juhola. "Assessing the dynamics of urban vulnerability to climate change: Case of Helsinki, Finland." Environmental Science & Policy 125. 2021: 32-43.
11. 13. D'Amato, Gennaro, Herberto Jose Chong- Neto, Olga Patricia Monge Ortega, Carolina Vitale, Ignacio Ansotegui, Nelson Rosario, Tari Haahtela et al. "The effects of climate change on respiratory allergy and asthma induced by pollen and mold allergens." Allergy 75, no. 9. 2020: 2219-2228.
12. 14. Caminade, Cyril, Sari Kovats, Joacim Rocklov, Adrian M. Tompkins, Andrew P. Morse, Felipe J. Colón-González, Hans Stenlund, Pim Martens, and Simon J. Lloyd. "Impact of climate change on global malaria distribution." Proceedings of the National Academy of Sciences 111, no. 9. 2014: 3286-3291.
13. 15. Lafferty, K. The ecology of climate change and infectious diseases. Ecological Society of America, 90(4), 888–900. 2009.
14. 16. Gilioli, G., and Mariani, L. 2011. Sensitivity of anopheles gambiae population dynamics to meteo-hydrological variability: A mechanistic approach. Malaria Journal, 10, 294; 2011.
15. 17. Confalonieri, Ulisses EC, and Flávia RL Suassuna Dutra. "Climate Change and Vector Borne Diseases in Latin America." Environmental Deterioration and Human Health: Natural and anthropogenic determinants. 2014: 315-324.
16. 18. Duval, Laetitia. "Climate Change, Vector-Borne Diseases, and Migration." In Handbook of Labor, Human Resources and Population Economics, pp. 1-15. Cham: Springer International Publishing, 2022.
17. 19. World Health Organization [WHO]. Global Report for Research on Infectious Diseases of Poverty. World Health Organization on Behalf of the Special Programme for Research and Training in Tropical Diseases 2012. http://apps.who.int/iris/bitstream/10665 /44850/1/9789241564489_eng.pdf.
18. 20. Hallegatte, Stephane, Jun Rentschler, and Julie Rozenberg. "Adaptation principles: a guide for designing strategies for climate change adaptation and resilience." 2020.
19. 21. Strauss, Benjamin H., Philip M. Orton, Klaus Bittermann, Maya K. Buchanan, Daniel M. Gilford, Robert E. Kopp, Scott Kulp, Chris Massey, Hans de Moel, and Sergey Vinogradov. "Economic damages from Hurricane Sandy attributable to sea level rise caused by anthropogenic climate change." Nature communications 12, no. 1; 2021: 2720.

 doi:10.20944/preprints202403.1506.v1

20. 22. Suter, Melissa A., and Kjersti M. Aagaard. "Natural disasters resulting from climate change: The impact of hurricanes and flooding on perinatal outcomes." In Seminars in Perinatology, p. 151840. WB Saunders, 2023.
21. 23. Kookana, Rai S., Pay Drechsel, Priyanka Jamwal, and Joanne Vanderzalm. "Urbanisation and emerging economies: Issues and potential solutions for water and food security." Science of the Total Environment 732. 2020: 139057.
22. 24. Dickson, E. et al. Understanding urban risk: An approach for assessing disaster and climate risk in cities. World Bank. 2011.
23. 25. Gu, Danan, Kirill Andreev, and Matthew E. Dupre. "Major trends in population growth around the world." China CDC weekly 3, no. 28; 2021: 604.
24. 26. Castells-Quintana, David, and Hugh Wenban-Smith. "Population dynamics, urbanisation without growth, and the rise of megacities." The Journal of Development Studies 56, no. 9; 2020: 1663-1682.
25. 27. Sharifi, Ayyoob, Minal Pathak, Chaitali Joshi, and Bao-Jie He. "A systematic review of the health co-benefits of urban climate change adaptation." Sustainable Cities and Society 74; 2021: 103190.
26. 28. Feiden, P. Adapting to climate change: Cities and the urban poor. International Housing Coalition. 2011.
27. 29. Twinomuhangi, Revocatus, Hakimu Sseviiri, Catherine Mulinde, Paul Isolo Mukwaya, Alex Nimusiima, and Arthur Martin Kato. "Perceptions and vulnerability to climate change among the urban poor in Kampala City, Uganda." Regional Environmental Change 21; 2021: 1-13.
28. 30. Griggs, Gary, and Borja G. Reguero. "Coastal adaptation to climate change and sea-level rise." Water 13, no. 16; 2021: 2151.
29. 31. Rose E. A sinking world: A model framework for climate change adaptation measures in coastal cities. Vand. J. Transnat'l L.. 2020;53:367.
30. 32. Doberstein, Brent, Anne Tadgell, and Alexandra Rutledge. "Managed retreat for climate change adaptation in coastal megacities: A comparison of policy and practice in Manila and Vancouver." Journal of environmental management 253; 2020: 109753
31.

a. 33. Dodman D, Hayward B, Pelling M, Castan Broto V, Chow W, Chu E, Dawson R, Khirfan L, McPhearson T, Prakash A, Zheng Y. Cities, Settlements and Key Infrastructure Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022.

32. 34. Sharifi, Ayyoob. "Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review." Science of the total environment 750; 2021: 141642. 35. Smiley, Kevin T., Ilan Noy, Michael F. Wehner, Dave Frame, Christopher C. Sampson, and Oliver EJ Wing. "Social inequalities in climate change-attributed impacts of Hurricane Harvey." Nature communications 13, no. 1; 2022: 3418.
33. 36. Agache, Ioana, Vanitha Sampath, Juan Aguilera, Cezmi A. Akdis, Mubeccel Akdis, Michele Barry, Aude Bouagnon et al. "Climate change and global health: a call to more research and more action." Allergy 77, no. 5; 2022: 1389-1407.
34. 37. Kaczan, David J., and Jennifer Orgill-Meyer. "The impact of climate change on migration: a synthesis of recent empirical insights." Climatic Change 158, no. 3-4; 2020.
35. 38. Salm, Leah, Nicholas Nisbett, Laura Cramer, Stuart Gillespie, and Philip Thornton. "How climate change interacts with inequity to affect nutrition." Wiley Interdisciplinary Reviews: Climate Change 12, no. 2; 2021: e696.
36. 39. Islam, Nazrul, and John Winkel. Climate change and social inequality.2017.
37. 40. Sam, Abdoul G., Babatunde O. Abidoye, and Sihle Mashaba. "Climate change and household welfare in sub-Saharan Africa: empirical evidence from Swaziland." Food Security 13 (2021): 439-455.
38. 41. Halder, Bijay, and Jatisankar Bandyopadhyay. "Evaluating the impact of climate change on urban environment using geospatial technologies in the planning area of Bilaspur, India." Environmental Challenges 5 ;2021: 100286.
39. 42. Twinomuhangi R, Sseviiri H, Mulinde C, Mukwaya PI, Nimusiima A, Kato AM. Perceptions and vulnerability to climate change among the urban poor in Kampala City, Uganda. Regional Environmental Change. 2021 Jun;21:1-3.
40. 43. Kogo, Benjamin Kipkemboi, Lalit Kumar, and Richard Koech. "Climate change and variability in Kenya: a review of impacts on agriculture and food security." Environment, Development and Sustainability 23; 2021: 23-43.
41. 44. Holleman, Cindy, Felix Rembold, Olivier Crespo, and Valentina Conti. "The impact of climate variability and extremes on agriculture and food security-An analysis of the evidence and case studies.". 2020.
42. 45. Wilbanks, T., Steven Fernandez, G. Backus, P. Garcia, K. Jonietz, P. Kirshen, M. Savonis, W. Solecki, and L. Toole. "Climate change and infrastructure, urban systems." In And Vulnerabilities: Technical Report for the US Department of Energy in Support of the National Climate Assessment. 2013.

 doi:10.20944/preprints202403.1506.v1

43. 46. Allan, Richard P., Paola A. Arias, Sophie Berger, Josep G. Canadell, Christophe Cassou, Deliang Chen, Annalisa Cherchi et al. "Intergovernmental Panel on Climate Change (IPCC). Summary for Policymakers." In Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change, pp. 3-32. Cambridge University Press, 2023.
44. 47. Hughes, Sara, Eric K. Chu, and Susan G. Mason. Climate change and cities. Oxford: Oxford University Press, 2020.
45. 48. Marolla, Cesar. Climate Change Impacts on Health: The Urban Poor in the World's Megacities. Harvard Division of Continuing Education. DASH, Harvard Library Office for Scholarly Communication. 2020.
46. 49. Marolla, Cesar. Climate health risks in megacities: sustainable management and strategic planning. CRC Press, 2016. DOI: 10.1201/9781315367323
47. 50. Almadani B, Aliyu F, Aliyu A. Integrated Operation Centers in Smart Cities: A Humanitarian Engineering Perspective. Sustainability. 2023 Jul 17;15(14):11101.
48. 51. Owen G. What makes climate change adaptation effective? A systematic review of the literature. Global Environmental Change. 2020 May 1;62:102071.
49. 52. Rydin, Y. et al. Shaping cities for health: Complexity and the planning of urban environments in the 21st century. 2012. The Lancet, 379, 2079–2108.
50. 53. Smith AB. 2010–2019: A landmark decade of US. billion-dollar weather and climate disasters. National Oceanic and Atmospheric Administration. 2020 Jan 8.
51. 54. Barata, M., Ligeti, E., De Simone, G., Dickinson, T., Jack, D., Penney, J., Rahman, M., and Zimmerman, R. Climate change and human health in cities. In C. Rosenzweig, W. Solecki, S. A. Hammer, and S. Mehrotra (Eds.), Climate change and cities: First assessment report of the Urban Climate Change Research Network, 2011; pp. 183–217. Cambridge: Cambridge University Press.
52. 55. Ebi, K. L., and Semenza, J. C. 2008. Community-based adaptation to the health impacts of climate change. American Journal of Preventive Medicine, 35(5), 501–507; 2008.
53. 56. Jones, R. N., and Preston, B. L. Adaptation and risk management. Working Paper No. 15, Centre for Strategic Economic Studies, 2010. Victoria University, Melbourne.
54. 57. Oppenheimer, M. et al. The limits of consensus. Science, 317(5844), 1505– 1506; 2007. Retrieved from http://www.sciencemag.org/content/317/5844/1505.full.
55. 58. Moser, S. C., and Ekstrom, J. A. A framework to diagnose barriers to climate change adaptation. Proceedings of the National Academy of Sciences, 107(51), 22026–22031; 2010.
56. 59. Adger, W. N. Vulnerability. Global Environmental Change, 16, 268–281; 2006.
57. 60. Spickett JT, Brown HL, and Katscherian D. Adaptation strategies for health impacts of climate change in Western Australia: Application of a Health Impact Assessment framework. Environmental Impact Assessment Review. 2011 Apr 1;31(3):297-300.
58. 61. Ebi KL, Berry P, Campbell-Lendrum D, Cissé G, Hess J, Ogden N, Schnitter R. Health system adaptation to climate variability and change. Washington, DC: Global Center on Adaptation. 2019 Dec 2.
59. 62. Caldecott, B. (2022). Climate risk management (CRM) and how it relates to achieving alignment with climate outcomes (ACO). Journal of Sustainable Finance & Investment, 12(4), 1167-1170.
60. 63. World Bank: Climate Resilient Investment in Sub-Saharan Africa Compendium Volume – A Focus on Infrastructure Project Design in Key Sectors. 2023. World Bank. Washington D.C. The report was prepared in collaboration with Industrial Economics Inc. under the Africa Climate Resilient Investment Facility (AFRI-RES) program.
61. 64. Prats, Elena Villalobos. WHO guidance for climate-resilient and environmentally sustainable health care facilities. World Health Organization, 2020.
62. 65. Agency for Health Care and Quality, Plan-Do-Check-Act Cycle. 2022. https://digital.ahrq.gov/health-it-tools-and-resources/evaluation-resources/workflowassessment-health-it-toolkit/all-workflow-tools/plan-do-check-act-cycle
63. 66. Pojasek, R.B. Organizational Risk Management and Sustainability: A Practical Step-by Step Guide (1st ed.). 2016. CRC Press. https://doi.org/10.1201/978131537062067.
b. 67. Kazantzidou Firtinidou D, Gkotsis I, Eftychidis G, Sfetsos A, Petrovic N, Stranjik A. Climate Related Business Continuity Model for Critical Infrastructures. Annals of Disaster Risk Sciences: ADRS. 2019 Dec 28;2(1-2):11-27.
64. 68. Ray PA, Brown CM. Confronting climate uncertainty in water resources planning and project design: The decision tree framework. World Bank Publications; 2015 Aug 20.
65. 69. Gallina V, Torresan S, Critto A, Sperotto A, Glade T, Marcomini A. A review of multirisk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. Journal of environmental management. 2016 Mar 1;168:123- 32.
66. 70. Izaguirre C, Losada IJ, Camus P, Vigh JL, Stenek V. Climate change risk to global port operations. Nature Climate Change. 2021 Jan;11(1):14-20.
67. 71. Gale P, Estrada- Peña A, Martinez M, Ulrich RG, Wilson A, Capelli G, Phipps P, De La Torre A, Muñoz MJ, Dottori M, Mioulet V. The feasibility of developing a risk assessment for the impact of climate change

 doi:10.20944/preprints202403.1506.v1

on the emergence of Crimean- Congo haemorrhagic fever in livestock in Europe: a Review. Journal of Applied Microbiology. 2010 Jun 1;108(6):1859-70.

68. 72. World Health Organization (WHO). Global Report for Research on Infectious Diseases of Poverty. World Health Organization on Behalf of the Special Programme for Research and Training in Tropical Diseases. 2012. http://apps.who.int/iris/bitstream/10665 /44850/1/9789241564489_eng.pdf.
69. 73. Kumar N, Poonia V, Gupta BB, Goyal MK. A novel framework for risk assessment and resilience of critical infrastructure towards climate change. Technological Forecasting and Social Change. 2021 Apr 1;165:120532.
70. 74. Cheshmehzangi, A. The City in Need. Springer Singapore; 2020.
71. 75. Sekar LG, Androws X, Annaidasan K, Kumar A, Kannan R, Muthusankar G, Balasubramani K. Assessment of shoreline changes and associated erosion and accretion pattern in coastal watersheds of Tamil Nadu, India. Natural Hazards Research. 2023 Sep 21.
72. 76. Rechel, B., and McKee, M. Facets of public health in Europe. Maidenhead, UK: McGraw-Hill Education.2014.
73. 77. Simpson NP, Mach KJ, Constable A, Hess J, Hogarth R, Howden M, Lawrence J, Lempert RJ, Muccione V, Mackey B, New MG. A framework for complex climate change risk assessment. One Earth. 2021 Apr 23;4(4):489-501.