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Special Article

Rooted Resilience: Urban Forestry's Role in Building Climate-Strong Cities

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Abstract

This research paper explores the complex relationship between climate change and urban forestry. The paper is divided into four parts, each focusing on different aspects of this relationship. The first part offers an overview of the current state of climate change, discussing its causes, impacts, and projected effects for the 21st century. It emphasizes the growing role of urban areas as significant contributors to climate change. The second part delves into the interaction between cities and climate change, highlighting the unique challenges and opportunities presented by urban environments. It examines how urbanization affects climate change, including successful climate change programs. The third part concentrates on the role of urban forestry in addressing climate change challenges. It explores the various benefits provided by urban forests in the urban ecosystem. The fourth part investigates the specific impacts of climate change on urban forestry. It analyses how changing temperature and precipitation patterns affect the types of trees, their growth, and overall health. It also discusses potential strategies and practices to help urban forests adapt and become more resilient in the face of climate change. By reviewing existing literature, this research paper enhances our understanding of the relationship between climate change and urban forestry. It highlights the importance of incorporating urban forestry practices into climate change mitigation and adaptation strategies, ultimately promoting sustainable and resilient urban environments.

Keywords: resilient, temperature, mitigation, precipitation, urban ecosystem

ABBREVIATIONS

IPCC - Intergovernmental Panel on Climate Change
UNFCCC - United Nations Framework Convention on Climate Change

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CO2 - Carbon dioxide
GHG - Greenhouse Gas
HFC - Hydrofluorocarbons
NOAA - National Oceanic and Atmospheric Administration
GW - Gigawatts
NYC - New York City
DEP - Department of Environmental Protection
LiDAR - Light, Detection and Ranging
GDP - Gross Domestic Product
OECD- Organization for Economic Co-operation and Development

1. Climate Change in the 21st Century

Climate change has emerged as one of the most pressing challenges of the 21st century. Over the past few decades, the Earth's climate system has experienced significant disruptions due to human-induced factors. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as a change in the state of the climate that can be identified (e.g.: statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. [IPCC, 2012] The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a change in climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is in addition to natural climate variability observed over comparable periods. [UNFCCC, 2012] In simple words, we can define climate change as a long-term shift in temperatures and weather patterns.

The major cause of climate in the 21st century is the increase in greenhouse gas (GHG) emissions. The main greenhouse gases whose concentrations are rising in the lower atmosphere are carbon dioxide, methane, nitrous oxide, hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs). The GHG emission is mainly due to human activities such as the burning of fossil fuels for energy generation, transportation, industrial processes, etc. GHG emissions to the atmosphere lead to trap heat and this results in an increase in temperature. This phenomenon is known as global warming or the greenhouse effect. This long-term heating of the Earth's surface has been observed since the pre-industrial period (between 1850 and 1900).

Climate change in the 21st century is also driven by natural processes including internal variability and external forcings. The internal variability comprises cyclical ocean patterns like El Niño, La Niña, and the Pacific Decadal Oscillation. The external forcings include volcanic activity, changes in the Sun's energy output, and variations in the Earth's orbit. The global temperature is rising as we can witness the melting of ice sheets in the world. The average global temperature has increased by a little more than 1 degree Celsius since 1880. 2022 was the sixth-warmest year

on record based on the National Oceanic and Atmospheric Administration's (NOAA) temperature data. Global temperature is projected to warm by about 1.5 degrees Celsius by 2050 and 2-4 degrees Celsius by 2100. Due to the rise of global temperature, the increase in sea level rise can be witnessed. When ocean water gets warmer, it causes the volume of the water to increase. This phenomenon is known as thermal expansion. Half of the measured global sea level rise on Earth is from warming waters and thermal expansion. [NOAA, 2022]

One-third of the solar energy is reflected into space and the balance of energy is absorbed by both the land and ocean. This warms them and they can radiate this warmth as long-wave infrared or 'heat' radiation. GHGs can absorb this long-wave radiation which causes to warming of the atmosphere. We can't completely avoid these greenhouse gases because without them the Earth would be at least 35 degrees Celsius colder, which makes the average temperature of the tropics -10 degrees Celsius. Research shows global atmospheric concentrations of CO2, CH4, and N2O have increased markedly as a result of human activities since 1750, thus the Earth's climate must change somehow to restore the balance between incoming and outgoing radiation. Under the effect of global warming, the sea level will rise, which will cause potential impacts on human life.

The study suggests that people must find new styles to develop the economy by using clean energy, making new emission standards, increasing producer responsibility for pollution, etc. Natural events and human activities are believed to be contributing to an increase in average global temperatures. [Wenxin Shi et al., 2010] The total amount of energy utilized by humanity in a year is equivalent to the energy that enters the sunlit side of the Earth in a single hour. Sun power totals about 100 million gigawatts (1GW equals 1 billion watts), equivalent to the energy output of 100 million large electricity-generating plants. Our planet's average temperature is calculated by a balance between the energy coming from the Sun and the energy radiated back to space from the Earth's surface. The energy coming from the Sun is in the form of visible light, meanwhile, the infrared radiation remitted from Earth's surface is not visible but can certainly feel. These radiations are blocked by greenhouse gases and trapped inside the atmosphere, which led to rise in temperature. [Richter, 2010]

According to the research, factors that can shape climate includes solar output, the earth's orbital variations, volcanism, magnetic field strength, ocean variability, and human influences. The study points out that the sun's output has not increased since 1978, so the warming during the past 30 years cannot be attributed to an increase in solar energy reaching the earth and the orbital variations have a large impact on climate and are notable for their correlation to glacial and interglacial periods. Volcanic eruptions release gases and particulates into the atmosphere. Global climate is also correlated with the strength of the earth's magnetic field and ocean variability. [Zhong, 2016]

Back in the nineteenth century, climate modelling was pretty hard because computers did not exist, and all the calculations had to be done by hand. Also, there

was not enough technological equipment to understand the scientific side of climate change. In the 1950s, Roger Revelle the Director of the Scripps Institute of Oceanography in San Diego, California proved that ocean water only absorbs one-tenth of carbon dioxide in the atmosphere. Supporting Roger's analysis Charles David Keeling proved that carbon dioxide is increasing and staying in the atmosphere for a long time. In 1896, the Swedish chemist Svante Arrhenius made a serious attempt to understand climate by analyzing the interaction of the Earth's energy budget with the contents of the atmosphere. Svante's model states that the temperature increases because CO2 goes up, and then the amount of water vapour in the atmosphere increases too. As the water vapour is a greenhouse gas the temperature will increase more. Some scientists criticize his model because he did not include the effects of clouds.

If water vapour increases in the atmosphere, then clouds will be formed. The white clouds can reflect more solar radiation way before the darker ground itself, and it would decrease the temperature in the atmosphere. Another scientist Arvid Hoghom was interested to find where carbon came from and where it went. He estimated that human activity, mainly the use of fossil fuels was making an increase to CO2 in the atmosphere. He stated that CO2 concentration is increasing by a small amount per year. It would take a thousand years to double the level. Unfortunately, the amount of CO2 in the atmosphere has increased rapidly since the Industrial Revolution till now and it's continuing. [Elliot et al., 1979]

The unequal distribution and wealth among countries lead to uneven CO2 emissions globally. North America, Europe, and Asia emit over 90 per cent of the global CO2 emission. Developed countries have emitted more than less developed countries. Deforestation is one of the reasons for the increase in CO2 emissions. When large area of rainforests are cut down less productive land exists which reduce the capacity of land to stock CO2. Land use changes can have a negative impact on the stated situation. Thus, we can understand how urban forestry is relevant to this century.

Climate change is a threat to the present and future generations. Climate change is one of the defining challenges of the 21st century, along with poverty alleviation, environmental degradation, and Global Security. The problem is that climate change is no longer just a scientific concern, but encompasses economics, sociology, geopolitics, national and local politics, law, and health. [Maslin, 2004] Now we have advanced science and technology which could analyze the risks of climate. We can tackle the risks of climate change with appropriate adaptation and mitigation strategies. One of the strategies includes urban forestry which can make positive changes in the urban ecosystem and will be discussed in the coming part.

2. Cities and Climate Change

Cities have a crucial role to play in tackling the global challenge of climate change. With more than half of the world's population residing in urban areas, and a

projected increase to over 70% in the future, cities have become centres of population and industry. However, rapid urbanization also has significant implications for the environment, affecting climate change, air and water quality, land usage, and waste management. Cities are particularly vulnerable to the impacts of climate change. Extreme weather events can disrupt the intricate systems within urban areas, and a large portion of the global urban population resides in low-lying coastal regions. Coastal cities experiencing rapid growth are especially at risk due to rising sea levels and the potential for storm surges caused by climate change. Cities such as Guangzhou, Miami, New York, New Orleans, Mumbai, Nagoya, Tampa-St. Petersburg, Boston, Shenzhen, Osaka-Kobe, and Vancouver are considered highly vulnerable, as they face significant annual losses due to flood-related events. [OECD, 2014]

As cities continue to grow and carbon emissions from urban areas increase, new challenges arise for city governance. It is crucial to implement robust political and financial policies that minimize the risks posed by climate change. Effective planning and management in cities are best achieved when local governments are acknowledged as legitimate partners within the governance structure of a country. This recognition should be accompanied by adequate financial powers to generate revenue and responsibilities to deliver essential services, keeping pace with urban growth and expansion. When cities are empowered and recognized as significant players in national and global contexts, they gain the authority to enact legislation concerning greenhouse gas emissions. They can also promote citizen participation, engage with governmental agencies and local businesses, and collaborate on initiatives for climate change mitigation and adaptation. By empowering cities in this way, they become important centres of governance, capable of influencing policies and driving meaningful action in the face of climate change. [McCarney et.al, 2011]

Cities are emerging as crucial and effective locations for implementing climate change mitigation projects. Many cities are taking proactive steps to develop sustainable policies aimed at reducing the risks associated with climate change in urban areas. For instance, Paris has launched an initiative to plant climate change-resilient trees, with a target of 170,000 new trees by 2026. This effort is part of the city's broader plan to enhance its resilience to global warming, considering the record-breaking heatwaves experienced in recent years, particularly the hottest July on record. The strategic planting of trees in cities is essential as they can significantly lower local temperatures by up to 12 degrees Celsius, providing relief during heatwaves. Additionally, trees contribute to improved air quality by absorbing pollutants. Recognizing the changing climatic conditions, Paris is carefully selecting tree species that are resilient to heat and drought. This includes the Montpellier maple, Turkish hazel, and Holm oak. Currently, approximately 26% of Paris is covered by trees and green spaces, in contrast to 51% in Berlin and 77% in Oslo. Paris has made substantial progress in its tree-planting efforts and is on track to achieve one-third of its target of 170,000 trees by the end of this year. The city is also dedicated

to expanding green spaces by adding 300 hectares of new green space. Other cities, such as Seoul, Singapore, London, and Curitiba in Brazil, are also actively working on urban green initiatives to combat and mitigate the effects of climate change. Overall, cities are recognizing the importance of implementing nature-based solutions, such as urban forestry and increasing green spaces, as effective strategies to address climate change and build more sustainable urban environments.

Innovative strategic plans are required to increase climate change resilience in cities. In 2007, the Mayor's Office of New York City introduced an exceptional strategic plan called PlaNYC, aiming to create a greener, more extensive, and resilient urban environment. This comprehensive plan focused on nine key areas, including housing, open spaces, brownfields, water quality, and climate change. To shape the plan, New York City engaged stakeholders from diverse sectors, including the public and private sectors, think tanks, and academia.

This collaborative effort fostered cooperation between the Mayor's Office, prestigious universities, NASA, and the insurance industry. Under the PlaNYC initiative, remarkable achievements were made, such as the planting of over 380,000 trees through the MillionTreesNYC program. The city also established more than 280 'Greenstreets,' which are garden areas situated in median strips and traffic triangles. Furthermore, the NYC Green Infrastructure Plan was released, and the city obtained high-resolution LiDAR elevation data to support their efforts. To combat the heat island effect, one million square feet of rooftops were coated white through the NYC Cool Roofs program.

The city also created three Solar Empowerment Zones, encouraging the development of solar power systems. Additionally, the NYC Department of Environmental Protection (DEP) implemented the Climate Assessment and Adaptation Plan to address climate-related challenges. To bolster resilience against sea level rise, New York developed a comprehensive Waterfront Plan, which included specific strategies. The city also launched a public awareness campaign on Emergency Management, enhancing New York's emergency response and preparedness programs. Additionally, New York City actively advocated for national and international action on climate change while emphasizing the importance of engaging cities in these efforts. Overall, the implementation of PlaNYC exemplifies New York City's commitment to building climate resilience through various initiatives and collaborations, demonstrating the significance of strategic planning in addressing climate change challenges in urban areas.

Effective leadership, efficient financing, inclusive citizen participation, and judicial coordination are the four essential elements for taking climate action in cities. Leadership plays a crucial role in overcoming fragmentation between departments and investment sectors, fostering consensus on the climate change agenda in urban areas. Without strong leadership, progress in addressing climate challenges within cities can be hindered. Efficient financing is a fundamental requirement for empowered governance in cities.

Insufficient financial tools at the local government level have often posed obstacles to effectively addressing climate change issues. Therefore, establishing effective financing mechanisms is crucial for the successful implementation of climate action projects in cities. Inclusive citizen participation is another key ingredient for effective climate action. Engaging citizens in decision-making processes empowers communities and ensures that the concerns and perspectives of all stakeholders are taken into account. By involving citizens, cities can generate greater support, awareness, and commitment to climate initiatives. Lastly, judicial coordination plays a significant role in implementing climate actions and projects in cities. Coordinating legal frameworks and regulations at various levels of government helps streamline efforts and ensures consistency in climate policies. By aligning legal structures, cities can overcome legal barriers and create an enabling environment for effective climate action. By incorporating these four ingredients, cities can establish and implement highly effective climate actions and projects, driving meaningful change and building resilience against climate change impacts. [McCarney et.al, 2011]

3. Climate Change and Urban Forestry

Urban forestry refers to the practice of managing and cultivating trees, green spaces, and natural vegetation within urban areas. Urban forestry plays a vital role in mitigating the impacts of climate change and promoting sustainable urban development. Urban forestry is also defined as an integrated, city-wide approach to planting, care, and management of trees in the city to secure multiple environmental and social benefits for urban dwellers. [Miller et.al, 2015] It is the management of trees for their contribution to the physiological, sociological, and economic well-being of urban society. Urban forestry deals with woodlands, groups of trees, and individual trees, where people live – it is multifaceted, for urban areas include a great variety of habitats (streets, parks, derelict corners, etc.) where trees bestow a great variety of benefits and problems. [Carter, 1993]

One of the main causes of climate change is air pollution. In 2022, India had the highest number of polluted cities in Central and South Asia, with twelve out of the fifteen most polluted cities located within the country. Bhiwadi is ranked as the most polluted city in India. As per reports, urbanization has caused night-time temperatures in over 140 major Indian cities to rise nearly 60 per cent more than in the surrounding non-urban areas. Air pollution is a problem in both rural and urban parts of India, but the sources and types of pollutants differ between these areas. Factors like the fuels used for cooking, the number of vehicles, and the varying climate and geography contribute to differences in air pollution levels across different regions and seasons. Contrary to the idea that air pollution is equalizing, it actually worsens existing environmental inequalities. Scientific studies have shown that certain groups, such as children and the elderly, are more vulnerable to the harmful effects of air pollution.

Children can experience stunted lung development, impaired thinking abilities, and higher rates of respiratory infections due to pollution. Long-term exposure can lead to chronic respiratory and heart diseases in the elderly, and they are at greater risk of heart attacks and strokes during periods of high pollution. People with lower incomes also face higher risks because of factors like their occupation, housing conditions, and the use of polluting fuels for cooking.

Although economic growth is often seen as conflicting with environmental and health concerns, research suggests they are interconnected. A study by the World Bank in 2016 found that air pollution cost India around 8% of its GDP, equivalent to $560 billion in 2013, due to reduced productivity from premature deaths and illnesses caused by pollution. However, this study didn't include the healthcare expenses associated with treating pollution-related illnesses, which would likely increase the economic burden even further.

Air pollution affects both rural and urban areas in India, but the specific sources and types of pollutants vary. Vulnerable groups like children, the elderly, and those with lower incomes bear a heavier burden of the health effects caused by pollution. Although there's often a perception of conflict between economic growth and environmental and health concerns, addressing air pollution is crucial for sustainable development because it has significant economic costs in terms of lost productivity and healthcare expenses. [Centre for Environmental Health and Public Health Foundation of India, 2017] Planting more trees and implementing urban forestry initiatives can help India address air pollution and create healthier and sustainable environments for its people. By combining these efforts, India can take a comprehensive approach to improve air quality and promote the well-being of its residents.

Climate change is a big problem worldwide, so many countries are using urban forestry to help deal with it. Urban forests have lots of benefits for cities. They help clean the air by taking in and filtering out pollutants. Trees in cities also give us shade, which helps to cool things down and reduce the heat in crowded areas. Another important thing is that trees can soak up carbon dioxide, which is a gas that causes climate change. This helps to make cities greener and lower their carbon footprint. Urban forests can also absorb rainwater, which is good for managing storms in cities. Trees act like sponges and hold onto the water, which reduces the risk of flooding and helps the water go into the ground. So, by having urban forests in cities, we can tackle climate change, make the environment healthier, and create more sustainable urban spaces.

Urban forestry brings not only environmental benefits but also social and economic advantages. From an economic perspective, it can increase property values, attract investments, and boost economic growth in cities. Urban forests make neighborhoods more attractive to residents, businesses, and investors, which leads to higher property values and contributes to the overall development of the community. Moreover, urban forestry creates job opportunities in activities like planting and maintaining trees. As cities recognize the importance of greening

initiatives, the demand for skilled workers in urban forestry increases. This job creation not only helps people find employment but also contributes to the local economy.

In terms of social benefits, urban forests have a positive impact on well-being and mental health. They provide accessible green spaces for recreation and relaxation within urban areas. These spaces offer opportunities for physical activities like walking or jogging, promoting a healthier lifestyle and countering the sedentary nature of urban living. Spending time in nature has been proven to reduce stress, improve mood, and enhance overall well-being. Urban forests also help people connect with nature in urban environments. In cities dominated by concrete and buildings, the inclusion of green spaces through urban forests allows individuals to reconnect with the natural world. These green spaces provide a peaceful escape from the fast-paced urban lifestyle and offer a refuge from daily demands. They give people the chance to experience the benefits of nature first-hand, leading to a greater appreciation for the environment and encouraging responsible environmental practices.

In summary, urban forestry brings social and economic benefits alongside its environmental advantages to the urban ecosystem. It enhances property values, attracts investments, and stimulates economic growth. Additionally, it provides accessible green spaces for recreation, promotes physical activity, and improves mental well-being. Urban forests also enable a deeper connection between people and nature in busy cities, offering solace and fostering environmental awareness.

4. Climate Change and its Effect on Urban Forestry

While we acknowledge the role of urban forestry as a climate change mitigation strategy, it is essential to recognize that climate change poses significant threats to existing urban forests. As temperatures increase and weather patterns become increasingly unpredictable, urban forests encounter various obstacles that can hinder their ability to deliver the intended environmental, social, and economic advantages.

The altering temperature and precipitation patterns are one of the primary effects of climate change on urban forestry. As temperatures rise, trees face increased water stress, particularly during droughts. Additionally, higher temperatures contribute to the urban heat island effect, intensifying heat-related problems in densely populated areas. These conditions weaken tree health, making them more susceptible to pests, and diseases, and lowering their survival rates. Changes in rainfall, including its amount, frequency, and intensity, impact soil moisture levels, leading to both waterlogging and drought conditions. Floods and storms can cause damage to trees and their roots, while extended periods of drought hinder tree growth and increase mortality rates. Furthermore, climate change alters the geographic distribution of tree species. As temperatures and growing conditions shift, some species may struggle to adapt or survive in their current locations.

This leads to changes in the composition of tree species within urban forests, affecting their diversity and overall functioning as ecosystems. Elevated levels of carbon dioxide (CO2) and warmer temperatures can initially enhance the growth of urban trees by speeding up the process of photosynthesis. However, when the warming is excessive and lacks sufficient water and nutrients, it can negatively impact tree growth by causing stress and hindering future development.

Warmer winter temperatures also raise the risk of winter kill, a phenomenon where trees suffer damage or die due to the combination of warmer temperatures and frozen ground. In such cases, trees require water to nourish their cells, but the frozen ground prevents water release, leading to moisture deprivation and harm to the plant. Climate change brings warmer winter temperatures, which can benefit populations of tree pests and diseases that are usually kept in check by cold temperatures. While some species may decrease in numbers due to climate change, others have a better ability to adapt to changing environments compared to the trees they affect. This is because pests and diseases have shorter lifecycles and can evolve more quickly. Hot and dry environments create higher levels of carbohydrates in tree foliage which makes urban trees more appealing to pests and pathogens.

Climate change also affects water cycles, which have consequences for urban forests. In winter, more precipitation can lead to increased snow and ice, posing a higher risk of physical damage to urban forests. In summer, increased evaporation and transpiration can cause water shortages, especially when combined with compacted soil and impermeable surfaces in urban areas. More frequent and intense extreme weather events can result in severe flooding, uprooting trees and damaging their root systems if waterlogged soils persist for long periods. As temperatures rise and pests and diseases become more active, urban forests face physiological challenges that weaken their ability to provide essential services in combating climate change. Climate change also affects the distribution of tree species and their ability to regenerate, which further impacts the health and composition of urban forests. It is very evident that climate change also harms urban forests, but taking adequate measures and implementing effective policies can help mitigate these risks. [Safford et.al, 2013]

5. Conclusion

In conclusion, this research paper presents a comprehensive review of the intricate relationship between climate change and urban forestry. The findings highlight the significant challenges posed by climate change in the 21st century and the unique vulnerabilities and opportunities presented by urban environments. Urban forestry emerges as a valuable solution for mitigating and adapting to climate change, providing multiple benefits such as carbon sequestration, temperature regulation, and stormwater management. The paper emphasizes the need to integrate urban forestry into urban planning and design, considering the specific impacts of climate change on tree species composition, growth, and overall health. By incorporating

urban forestry practices into climate change strategies, we can foster sustainable and resilient urban environments. This research contributes to a better understanding of the relationship between climate change and urban forestry and underscores the importance of collective efforts to create a more sustainable future.

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