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*Original Paper*

# Urbanization, Climate Change and Environmental Resilience: Experiences in Sri Lanka

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***Abstract***

*Urbanization in conjunction with climatic change affecting urban life and pose challenges to cities worldwide creating urban residents increasingly vulnerable to extreme weather and other natural disasters. Improvement of urban ecosystems provide cost-effective solution against negative impacts of climate change accelerated with high population pressure and promote resilience of urban dwellers. The cities in Sri Lanka are focused on improving land use planning and management of urban forest ecosystems for adaptation to and mitigation of climate change impacts with the rapid urbanization. This study attempts to ascertain the effects of urbanization, analyze the impacts of urbanization and climate change, and examine the environmental resilience with urban forests in Sri Lanka, reviewing the relevant literature. This paper explore the effects of urbanization in terms of increase population, land use change, rising greenhouse gas emissions and intensity of urban heat island. The impacts of urbanization and climate change are revealed as change of annual rainfall, urban warming, extreme weather events, and urban health hazards. Disaster resilient cities, sustainable urbanization, greening the cities, other environmental resilience strategies as well as institutional and policy setting are discussed for environmental resilience to urbanization and changing climate. Limiting* $CO_2$ *emission, reducing land surface temperature, and controlling urban heat island effect are discussed under the other environmental resilience strategies. Institutional and policy setting is explained through popularizing urban forestry and developing policy support. Urban forestry strategies incorporating urban planning should be manifested in urban development policy in order to counteract the negative effects of climate change in the process of environmental resilience and sustainable urbanization.*

***Keywords***
*urban ecosystem management, urban forestry, disaster resilient cities, sustainable urbanization, greening cities*

## 1. Introduction

### *1.1 Urbanization*

Urbanization has a continuing trend globally which is taking place in conjunction with climatic change affecting urban life and pose challenges to cities worldwide. Evidently, climate change may create hundreds of millions of urban residents increasingly vulnerable to extreme weather and other natural disasters in the coming decades. According to the World Health Organization (WHO), the urban population in the world is expected to grow approximately 1.84 percent per year between 2015 and 2020, 1.63 percent per year between 2020 and 2025, and 1.44 percent per year between 2025 and 2030 (https:// www.who.int/data/gho/data/indicators). South Asia with an area of about 4.5 million $km^2$ represents 3.31% of the world's land mass and has 22% of the world's population which has increased from 1.13 billion to 1.76 billion from 1990 to 2016 as one of the fastest and leading urbanizing zones in the world (Saparamadu et al., 2018). According to the UN estimates revealed at the World Economic Forum on ASEAN, over half of the population in Asian (4.5 billion) will live in cities by 2026 (World Economic Forum, 2018). Unplanned urbanization face traffic congestion, increased waste resources, limited social services, disorder and confusion in land-use patterns and contribute to environmental challenges including natural disasters and environment pollution. The vulnerability of urban populations to events of higher temperatures, sea-level rise and reductions in freshwater availability in major cities have become a common feature in many locations in the world. The local warming caused by overall tendency of urbanization has induced a proportion of global warming during the last century, as a key issue from the climate change perspective (Paranunzio et al., 2019). The impacts of climate and land use changes driven by urbanization effectively reduce the trade-offs and increase losses of ecosystem services. Hence, urban planning to enhance ecosystem services under future climate change impacts has great importance in ecosystem management and policy making for environment resilience urbanization (Lyu et al., 2018).

### *1.2 Urban Forest Ecosystem*

Improvement of forest ecosystems in urban centers can provide cost-effective solution against negative impacts of climate change accelerated with high population pressure. Urban forests such as urban wetlands, nature reserves, urban parks, landscaped and green pathways, river corridors, coastal paths, street trees, woodlots, shelter belts of trees, public gardens, orchards, urban home-gardens etc., are broadly recognized in many different shapes and sizes. Urban forests have a diverse structure, found in stands or arranged in lines or as single trees, remnants of native forests or be deliberately grown vary in composition, diversity age, health status and ownership patterns (Ordóñez et al., 2010). Green elements of urban forests are integral components of the territorial development of urban regions reducing the human impact and the effect of climate change on the urban environment (Grădinaru & Hersperger, 2019). Urban forestry preserves biodiversity and increase ecological connectivity in urban centers while reducing environmental fragmentation and increasing the resilience of natural ecosystems to increasing population pressure. Urban forests and green spaces resilient rising heat and the threat of more extreme weather hazards of changing climate and improve health, well-being and promote resilience of urban dwellers. According to IUCN (2016), urban forests provides nature-based solutions for the rapid urbanization as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". The Asian Development Bank (ADB) emphasize the importance of boosting sustainable urban infrastructure with operational plan promoting green, inclusive, competitive and livable cities against climate change (ADB, 2018). Urban forest provides numerous important values including ecosystem function, forest products, and amenities to the people live in cities. Urban forests and trees make positive impacts on urban environmental conditions, and livelihoods and well-being of city dwellers. Under the framework of the Sustainable Development Goal (SDG-Goal 11) urban forests make valuable contribution to create safe, resilient and sustainable cities and human settlements (Gil et al., 2019). Hence, identification of major challenges and suggestion for changes to planning and management practices are needed to ensure the values of urban-forests are sustained and promote resilience of urban dwellers.

*1.3 Case in Sri Lanka*

Sri Lanka is making efforts to develop required policies and strategies in order to adapt to and to mitigate climate change impacts on cities as a signatory to UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Small island states with urbanization are amongst the most exposed countries and face greatest challenges for climate change (Garschagen & Romero-Lankao, 2013). The urban area of Sri Lanka grew by 9.57 percent per year comparatively a high figure by global standards, during the period 1995-2017 (UN-HABITAT, 2018). Sri Lanka's total GHG emission is however less than 0.1 percent of the global emissions and the per capita emission is 0.6t $CO_2$ (Ministry of Mahaweli Development and Environment, 2016). Even though the contribution to global emissions is relatively low, Sri Lanka is attempting to reduce the emissions by up to 23 percent by 2030 (WHO, 2016). The mean temperature in Sri Lanka is predicted that it would rise as much as $2.4^0$C by the year 2100 under the climate change scenario (Samarasinghe, 2009). The vitality of Climate change adaptation for the disaster resilience has been recognized by The National Climate Change Adaptation Strategy for Sri Lanka 2011-2016 (Climate Change Secretariat, 2010). The cities in Sri Lanka focus on improving land use planning and management for adaptation to and mitigation of climate change effects. The stone edicts of the twelfth century AD in Sri Lanka show that cultural features of the country due to the influence of Buddhism have served to conserve the nature and the prevalence of concepts of 'urban nature reserves' (UN-REDD Programme, 2012). Meeting the challenges of climate change and green cities for health and prosperity were among the ten missions of Haritha (Green)

Lanka Program launched by the Ministry of Environment, Sri Lanka in 2009 (Ministry of Environment, 2012). However, the impacts of climate change on urban centers with rapid urbanization and adaptation of urban ecosystem with urban forestry to climate change are the least studied areas in Sri Lanka. Planning and designing of urban forest in major cities in Sri Lanka is a challenging task with the rapid urbanization and increasing climate change impacts. Urban-forestry receives limited attention from researchers and policy makers in urban planning and management of natural resources in urban centers (Colgan et al., 2014).

### *1.4 Methodology*

This study therefore attempts to ascertain the effects of urbanization in major cities, analyze the climate change impacts of rapid urbanization and examine the resilience of urban environment to sustain and improve health and well-being of the urban dwellers. This study is based on a review of literature considering urbanization, climate change and environmental resilience of urban forestry with special reference to Sri Lanka. This paper discuss the effects of urbanization; impacts of urbanization and climate change; and environmental resilience to urbanization and changing climate in urban areas in Sri Lanka.

## 2. Effects of Urbanization

### *2.1 Increase Population*

Rapid growth of urban population due to natural growth, migration and expansion of cities integrating rural areas declines the quality of urban environment has become serious concern of the urban planners. It is difficult to make international comparisons of urban population because the countries are using very different urban definitions. The urban landscape of Sri Lanka consist of 6 cities with more than 100,000 population, 34 intermediate or medium-size towns with 20,000~100,000 population, and 94 small towns of fewer than 20,000 (The World Bank, 2012). An alternative projection of the urban population is based on agglomerations of more than 20,000, 50,000, 100,000 or 500,000 in ranking a list of towns and cities by the size in each country (Bocquier, 2005).

Compared to the United Nations estimated 60 percent urban population in Asia, the urban population in Sri Lanka will remain 40 percent by 2050 along with marginally dropped percentage of urban population of the country during last three decades (Gasimli et al., 2019). The UN Habitat III Country Report on Sri Lanka shows the urban population growth from 2,848,116 in 1971 to 3,704,470 in 2012 while reducing the percentage of urban population from 24.4 in 1971 to 18.2 in 2012 (Ministry of Housing & Construction, 2016) (Table 1).

**Table 1. Population Growth in Sri Lanka**

| Census Year | Total Population | Urban Population | Urban % |
|---|---|---|---|
| 1971 | 12,689,897 | 2,848,116 | 22.4% |
| 1981 | 14,846,750 | 3,192,489 | 21.5% |
| 2001* | 18,797,257** | 2,467,301* | 13.1%* |
| 2012 | 20,359,439 | 3,704,470 | 18.2% |

* Incomplete census ** Estimate

Source: Ministry of Housing & Construction (2016). UN Habitat III Country Report-Sri Lanka.

There is a disagreements from different conceptual models of urbanization derived from a statistical perspective. Urbaneness is defined in India concerning the legal boundaries of urban jurisdictions other than population density, areal contiguity, and the total population of sufficiently dense adjoining areas (Balk et al., 2019). Analysis of population growth rate with urbanization has also become a complex and challenging task. According to The World Bank (2012), the compounded annual growth rate of urban population is comparatively and positively high in Colombo (4.9 percent), Galle (3.8 percent) and Gampaha (3.2 percent) while negative in Anuradhapura (-0.4 percent) and Kurunegala (-0.6 percent), the major cities in Sri Lanka during the period from 2001 to 2009 (Table 2). However, the Target compound annual growth rate during 2009~2030 shows negative growth rate in Kandy the last kingdom (-2.6 percent) and slow growth rates in Colombo the capital city (0.5), Gampaha adjoining to the capital city (3.1 percent) and Galle the capital city of the southern province (3.3 percent). Target compound annual growth rates in Hambantota and Anuradhapura the cities in dry zone with ample lands for urban expansion are estimated as high as 18.1 percent and 16.1 percent respectively during 2009~2030. The results of a study conducted based on 154 countries across the globe indicate that the growth of urbanization associated with population growth rate was highly positive before 2000 and progressively declining thereafter depending on the size and spatial heterogeneity of the urban centers (Cividino et al., 2020).

**Table 2. Actual (2001 and 2009) and Planned Population (2030) of Main Urban Centers in Sri Lanka**

| | District urban population (2001) | District urban population (2009) | Planned population (2030) | Compound annual growth rate, % (2001-09) | Target compound annual growth rate, % (2009-30) |
|---|---|---|---|---|---|
| Colombo MR | | | | | |
| Colombo | 1,229,046 | 1,819,069 | 2,000,000 | 4.9 | 0.5 |
| Gampaha | 301,344 | 390,235 | 750,000 | 3.2 | 3.1 |
| Kalutara | 112,996 | 134,103 | 750,000 | 2.1 | 8.2 |
| North-Central MR | | | | | |
| Anuradhapura | 52,895 | 51,034 | 1,500,000 | –0.4 | 16.1 |
| Polonnaruwa | NA | NA | 500,000 | NA | NA |
| Trincomalee | NA | NA | 1,000,000 | NA | NA |
| Dambulla | 36,162 | 40,086 | 1,000,000 | 1.3 | 15.3 |
| Southern MR | | | | | |
| Hambantota | 21,566 | 22,599 | 1,000,000 | 0.6 | 18.1 |
| Galle | 110,001 | 149,604 | 300,000 | 3.8 | 3.3 |
| Northern MR | | | | | |
| Jaffna | NA | 134,134 | 1,000,000 | NA | 9.6 |
| Eastern MR | | | | | |
| Ampara | 112,670 | 121,495 | 500,000 | 0.9 | 6.7 |
| Batticaloa | NA | 139,497 | 500,000 | NA | 6.1 |
| District capitals | | | | | |
| Kandy | 156,038 | 172,571 | 100,000 | 1.3 | –2.6 |
| Kurunegala | 35,040 | 33,488 | 200,000 | –0.6 | 8.5 |

Source: The World Bank (2012). Turning Sri Lanka's Urban Vision into Policy and Action. (www.worldbank.org/lk)

Urbanization has also altered traditional livelihoods strategies in Sri Lanka. Although the Sri Lanka is comparatively experiencing low level of urbanization, urban population is heavily concentrated on Greater Colombo area, the commercial capital where 43 percent of them live in slum and shanty settlements (Ministry of Environment, 2012). The poverty of the urban sector in Sri Lanka has declined remarkably from 32 percent 8.8 percent and continued to remain well below the national average during the past decade (MOSDWRD, 2018). The urban infrastructures are not necessarily developed and benefits are not distributed equitably among urban communities where the urban poor living in unacceptable conditions (George & Leeson, 2018).

*2.2 Land Use Change*

Connecting land use pattern with urbanization process under the changing climate has become an important attempt to explore and quantify urbanization. Urban concepts and measures undergo frequent revision as there is no well-established, consistent way to measure either urban land or density of population. For the comparison urban structure and its changes, land that is more than 50 percent built-up and people living are classified as urban while less than 30 percent built-up areas classified as suburban and peri-urban according to urban proxies for the US (Balk et al., 2018). According to a spatial analysis, the urban built-up area in Colombo the capital city of Sri Lanka increased from 41 km$^2$ in 1995 to 281 Km$^2$ in 2017 diminishing the non-built up areas from 125 Km$^2$ to 10 Km$^2$ (UN-HABITAT, 2018). Another study has proved that the land use change where built-up area has increased by 29.36 km$^2$ while decreased in other cultivation (-11.75 km$^2$), paddy (-8.46 km$^2$), boggy (-5.11 km$^2$), water (-1.74 km$^2$), and sand land use (-1.51 km$^2$) in Colombo city from 1990 to 2015 (Saparamadu et al., 2018) (Table 3).

**Table 3. Land Use Change of Colombo City in 1990 and 2015**

| Land use | Area km$^2$ | | Percentage% | | Land use changes km$^2$ |
|---|---|---|---|---|---|
| | 1990 | 2015 | 1990 | 2015 | |
| Buildup | 142.87 | 172.23 | 67 | 81 | 29.36 |
| Boggy | 8.99 | 3.88 | 4 | 2 | -5.11 |
| Water | 5.41 | 3.67 | 3 | 2 | -1.74 |
| Paddy | 29.89 | 21.43 | 14 | 10 | -8.46 |
| Other Cultivation | 23.87 | 12.12 | 11 | 5 | -11.75 |
| Sand Land Use | 1.51 | 0 | 1 | 0 | -1.51 |

Source: Saparamadu et al., 2018

The green space in Colombo city in Sri Lanka has remarkably change with "annual reduction rate of 0.46km2 (1980-1988), 0.39km2 (1988-1997), 0.37km2 (1997-2001), 1.37km2 (2001-2011) and 0.71km2 (2011-2015)" due to a higher rate of increasing population density and economic development of the country (Li & Pussella, 2017).

Urbanization in Sri Lanka has converted large area of agricultural lands to housing and commercial use. Urbanization induce land scarcity through anthropogenic interference related to forest degradation for urban agricultural expansion, urbanization on formerly agricultural land, or the competition for the use of urban space (Froese & Schilling, 2019). Change of land use pattern with urbanization process and climate change has become critical knowledge gap in enhancing and managing the tradeoffs between agricultural production, food security, and environmental goals in urban areas. The urbanization processes in Sri Lanka is the main driven force leading the land use/land cover (LULC) change particularly the trend of demands and pressure on agricultural land to become non-agricultural land. With rapid urbanization, the built-up area of Nuwara Eliya, the capital city of up-country in Sri Lanka, increased from 289.9 ha in 1996, 785.5 ha in 2006 and to 2,080.4 ha in 2017 with an 85.3 ha per year annual growth rate (Table 4). The land area under agriculture decreased from 8503.2 ha in 1996, 8085.5 in 2006 to 6583.9 ha in 2017 with the rapid changes of the built-up land area (Ranagalage et al., 2019).

**Table 4. Land Use/ Land Cover (LULC) Changes in Nuwara Eliya during1996, 2006, and 2017**

| Land Use/Land Cover | 1996 | | 2006 | | 2017 | |
|---|---|---|---|---|---|---|
| | Area (ha) | Percentage (%) | Area (ha) | Percentage (%) | Area (ha) | Percentage (%) |
| Built-up | 289.9 | 1.3 | 785.5 | 3.5 | 2080.4 | 9.3 |
| Forest | 13,076.7 | 58.2 | 13,502.1 | 60.1 | 13,234.3 | 58.9 |
| Agricultural Land | 8503.2 | 37.9 | 8085.5 | 36 | 6583.9 | 29.3 |
| Other Land | 511.8 | 2.3 | 6 | 0 | 481.8 | 2.1 |
| Water | 73.4 | 0.3 | 75.9 | 0.3 | 74.6 | 0.3 |
| Total | 22,455 | 100 | 22,455 | 100 | 22,455 | 100 |

Source: Ranagalage et al., 2019

Kesbewa predominantly an agricultural area converted to an Urban Council area hosting over 244,000 inhabitants on 49 km2 of land, losing 60 percent of agricultural lands for residential purposes by 2012 with the expansion of urban boundaries of Colombo Metropolitan Region (Mohamed & Gunasekera, 2014).

The native forest area reservations in urban areas and identification of key trends and underlying environmental and socio-economic factors are critical in urbanization in Sri Lanka under climate change. In Kandy City, the last kingdom of Sri Lanka shows Land Use/Land Cover (LULC) changes during the last two decades (Table 5). The Impervious Surface (IS) has increased significantly from 2.3 percent in 1996, 6.7 percent in 2006 and 23.9 percent in 2017. The Forest Cover (FC) has noticeably declined from 66.9 percent in 1996, 56.6 percent in 2006 and 46.6 percent in 2017 (Dissanayake et al., 2019).

**Table 5. Changes of Land Use/Land Cover (LULC) Areas with Percentages**

| LULC | 1996 | | 2006 | | 2017 | |
|---|---|---|---|---|---|---|
| | Area (ha) | Percentage (%) | Area (ha) | Percentage (%) | Area (ha) | Percentage (%) |
| IS | 528.7 | 2.3 | 1514.0 | 6.7 | 5382.5 | 23.9 |
| FC | 15,041.9 | 66.9 | 12,742.1 | 56.6 | 10,483.4 | 46.6 |
| CL | 5570.8 | 24.8 | 6486.3 | 28.8 | 5372.6 | 23.9 |
| WB | 248.2 | 1.1 | 296.5 | 1.3 | 239.6 | 1.1 |
| OL | 1110.4 | 4.9 | 1461.2 | 6.5 | 1022.0 | 4.5 |
| Total | 22,500.0 | 100.0 | 22,500.0 | 100.0 | 22,500.0 | 100.0 |

IS-Impervious Surface; FC-Forest Cover; CL-Croplands; WB-Water Body; OL-Other Land.

Source: (Dissanayake et al., 2019)

Vulnerable and marginalized people in the cities are not properly assessed and prioritized in urban land use planning in Sri Lanka. The patterns of urbanization play more important role in the speed of urban land expansion which make more contribution for climate change, compare to the contribution of social and economic development (Ke et al., 2013).

*2.3 Rising Greenhouse Gas Emissions*

Rapid urban population growth, increased vehicle ownership and higher consumption of fuel, make contribution to rising greenhouse gas emissions in Sri Lanka. The transport sector in Sri Lanka consumed 50 percent of the total fossil fuel consumption and contributes 30 percent of the total urban air pollution in the country (Ministry of Environment, 2012). Although CH4 and N2O are commonly found in urban areas, the most prominent anthropogenic greenhouse gas is CO2. It has been measured that Methane gas emission was 1507.681 $m^3$ and $CO_2$ gas emission was 9474.516 $m^3$ in Colombo Metropolitan Region (CMR) in 2003 (http://www.climatechange.lk/Documents/Project_Terminal_Report.pdf). The carbon emission is changed with the changes of urbanization level particularly in response to the changes in energy consumption, and economic levels. A study in Sri Lanka confirm that urbanization has significant effect on carbon emissions in the long term as well as in the short term with increase of the energy consumption (Gasimli et al., 2019). Urban areas are mainly responsible for more than 70 percent $CO_2$ emissions related to global energy consumption and increase with the continuous trends of urbanization (Hegazy et al., 2017). According to a study conducted in Pettah division predominantly a commercial area of Colombo city in 2012, vehicle is the highest CO2 emitting source contributing 47737.69 ton $CO_2$ about 95 percent of the total annual emission 50352.05 ton $CO_2$. The contribution CO2 emission from Fire-wood (41.85 tons) is not significantly high compared to vehicle emission and commuting population (Sugathapala & Jayathilake, 2012) (Table 6).

**Table 6. Annual Carbon Dioxide Emission in Colombo City (Pettah GN Division)**

| Sources of emission | $CO_2$ Emission (ton $CO_2$) |
|---|---|
| Kerosene | 3.38 |
| LPG | 11.17 |
| Fire wood | 41.85 |
| Commuting population | 2557.96 |
| Vehicle emission | 47737.69 |
| Total emission | 50352.05 |

Source: After Sugathapala and Jayathilake (2012)

Negambo Municipal Council area in Sri Lanka has emitted 384.65 Kt $CO_2$ equivalents in 2010 through the key aspects of solid waste, diesel consumptions for fishery and road transportation activities, and domestic fuel wood consumption as energy source for cooking (UN-HABITAT, 2010). Firewood is still an important form of cooking fuel in Sri Lanka in both 42 percent of urban and 88 percent of rural sectors. The use of LPG as cooking fuel is becoming popular in urban sector as 46 percent compared to 10 percent in rural sectors with the increase in economic and income generation activities within urban families (Ministry of Environment, 2012). A long-term relationship between carbon emissions and urbanization together with energy consumption, income level, and trade openness has found in Sri Lanka (Gasimli et al., 2019). The impact of urbanization level on carbon emission is significant in the long or short term, until the continuously increased GDP and technology advances make the stable decline in per capita carbon emission (Zhang et al., 2015).

*2.4 Intensity of Urban Heat Island*

The Urban Heat Island (UHI) effect in a large cities in Sri Lanka are experiencing with rapid urbanization resulted in a tremendous land cover change dynamics and consumed vast areas of land adjacent to the cities. The phenomenon of Urban Heat Island (UHI) is that the temperature in urban areas is higher than the surrounding rural areas, which is a critical issue in the cities with rapid urbanization. Gradual enhancement of the effect of Urban Heat Island (UHI) is usually noted an increasing trend of Surface Air Temperature (SAT) in local observation series, in comparison with nearby rural stations as the urban environment develops (Yan et al., 2016). The Urban Heat Island (UHI) is caused by the heat-storing structures that increase the heat capacity of the cities with rapid urbanization and create relative warmth of the urban areas with respect to the rural surroundings (Argüeso et al., 2014). An empirical finding on Nuwara Eliya a mountain city in Sri Lanka a renowned tourist destination is experiencing the Urban Heat Island (UHI) with variations in Land Surface Temperature LST as a critical environmental impact of urbanization. The mean Land Surface Temperature (LST) shows an increasing trend from 18.9$^0$C in 1996, 17.9$^0$C in 2006 to 21.0$^0$C 2017 with the increase of mean LST by 2.1$^0$C during the past 21 years. The difference of mean annual temperature between the urban and rural areas shows an increasing pattern from $1.0^{0}$C in 1996, $1.3^{0}$C in 2006 and $3.5^{0}$C in 2017 (Ranagalage et al., 2019).

The warmer temperatures in urban areas in Sri Lanka due to high-rise buildings, concrete structures, poor air quality and limited shade and green space adversely contribute to Urban Heat Islands (UHI) effect. Although large areas of Colombo city in Sri Lanka remain low rise, a significant urban warming has been recorded with high-rise development. Even though a large area of Colombo city remains “low-rise” blocks, the Urban Heat Island (UHI) is intensified by the mixture of ‘mid-rise’ and ‘high-rise’ blocks (Herath et al., 2018). The greatest difference in Urban Heat Island intensity (UHI) of the Colombo city of 4.09oC is seen when Local Climate Zones (LCZ) with lightweight low-rise ($0.31^{0}$C) is transformed in to LCZ with compact high-rise areas ($4.40^{0}$C) (Perera et al., 2013). High-rise housing complexes are rapidly spreading at heart of the cities, bordering the beautiful coastline and alongside the scenic wetlands in Sri Lanka (Figure - 1). Architecture of buildings and construction materials in urban areas absorb more heat than vegetation and soils, and minimizes the cooling effect of evapotranspiration making urban areas warmer than their surroundings, causing the urban heat island (UHI) effect (Oleson et al., 2013)

**Figure 1.**

| Initiative of Urban Development Authority | Historic City of Galle - Apartment Configurations | Wetlands Surrounding of Colombo High-rise Apartments |
|---|---|---|

Source: https://www.maga.lk/portfolio/ongoing-projects/building/#

The urban heat island effect is severe in cities where temperatures are higher due to higher population densities with less vegetation and open space. Evapotranspiration is reduced in urban areas due to replacement of vegetation with Impervious Surfaces (IS) in rapidly growing urban areas in Sri Lanka. The enhanced local heat island effect caused by rapid urbanization in Sri Lanka has been observed throughout the country with the highest warming trends in Anuradhapura and Badulla (Eriyagama et al., 2010). Urban Heat Island (UHI) with higher temperature in urban area compared to surrounding area has been observed in Kandy city in Sri Lanka due to the increase the density of Impervious Surface (IS), changes of Land Use/Land Cover (LULC) and other anthropogenic activities during the last two decades. The average Land-Surface Temperature (LST) has been increased from $25.2^{0}$C in 1996, $26.2^{0}$C in 2006 and $27.6^{0}$C in 2017. The edges of the city with newly added Impervious Surface (IS) cooled by the surrounding nonurban surfaces with low-temperature class (24-26°C) (Dissanayake et al., 2019). The temperature response to urbanization is determined by the thermal properties and surface evapotranspiration of the urban structures (Argüeso et al., 2014).

However, Colombo, the capital city of Sri Lanka is highly humid area and with this higher temperature values ranged the average between $23^{0}$C-$32^{0}$C. The city is suffering from Urban Heat Island (UHI) intensities of 0.090C-4.40C compared to surround rural and suburb areas creating undesirable living condition and poor thermal comfort (Herath et al., 2018). More than 60 percent of agricultural lands in Kesbewa Urban Council area was converted to residential areas by 2012 for the expansion of boundaries of Colombo Metropolitan Region (Mohamed & Gunasekera, 2014). Land cover changes from natural or agricultural lands to build-environments due to rapid urbanization increase air and surface temperatures in the urban area as compared to its rural surroundings, transform cities into urban heat islands (UHI) (Middel et al., 2015). The empirical finding of a study indicate the reductions in green space in high-density residential areas and town centers in 10 percent will increase surface temperatures by 7-8.2°C by 2080 (Dulal, 2017). Any occupational health hazards caused by UHI has not been reported yet in Sri Lanka. UHI has a significant adverse health experiences in elsewhere depending on duration of working in the city, and being in high-rise and high-density buildings (Wong et al., 2017)

## 3. Impacts of Urbanization and Climate Change

### *3.1 Change of Annual Rainfall*

Sri Lanka is experiencing in increasing trend of percentage change in annual rainfall and predicted several extreme weather events with very heavy rainfall in the future. The analysis of long-term trends of rainfall as climatic variables in Colombo city of Sri Lanka indicate that the average annual dry days (193.41) and average annual wet days (171.84) are changing with large standard deviation annually (Chen & De Costa, 2017). High intensity and frequent rainfall has been recorded in wet-zone cities particularly Ratnapura, Ratmalana, and Colombo by El Niño-Southern Oscillation (ENSO) as the primary climate driver in Sri Lanka (Naveendrakumar et al., 2018). The long-term trend of the annual rainfall records in Colombo the capital city of Sri Lanka for the 30 years from 1981 to 2010 shows that there was an increase ($R^2$ = 0.146) slightly from the average annual rainfall of 2302 mm with some recorded high rainfall values (Figure 2). Further analysis with simulated rainfall data from 2011~2099 of Colombo city in Sri Lanka has revealed that very heavy rainfall as an extreme weather event may occur in the future particularly during 2080~2099 (Lo & Koralegedara, 2015). Contrary, a study has shown that the periphery of urban areas experienced a higher probability of heavy rainfall while the urban areas have decrease in rainfall with climate change impacts (Niyogi et al., 2017).

The analysis of rainfall has shown a strong increase trend of monsoon rainfall in Batticaloa Municipal Center (28 percent) and Negombo Municipal Center (34 percent) and increase of minor floods during the last two decades (Ministry of Environment, 2012). The combined impacts of urbanization and climate change pose significant threats for flooding in urban areas with increased rainfall (Miller & Hutchins, 2017).

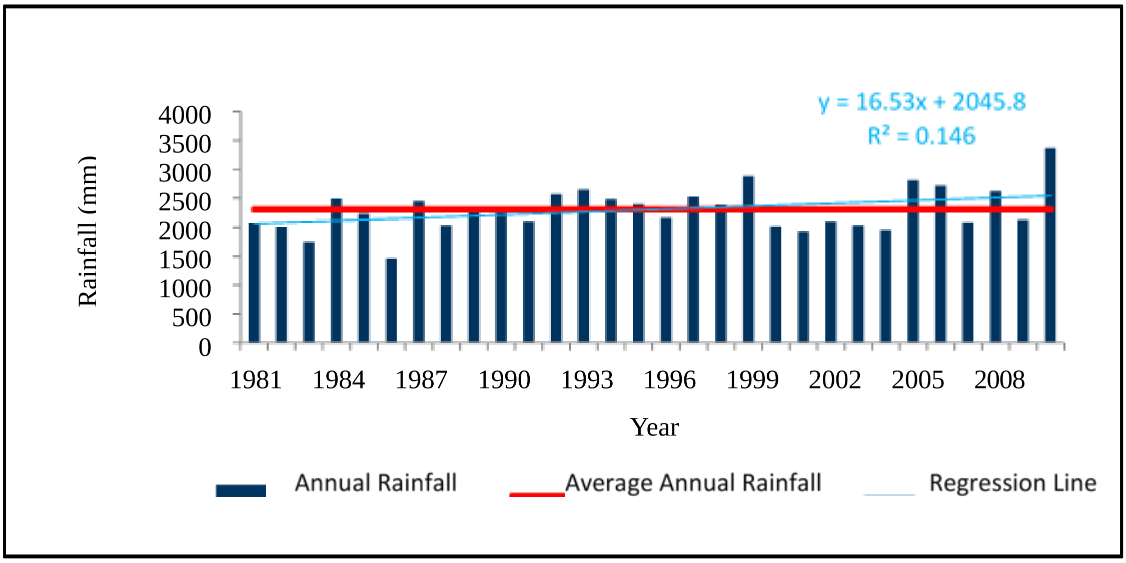



**Figure 2. Average Annual Rainfall in the Colombo City Area (1981-2010)**

Source: Lo and Koralegedara, 2015

*3.2 Urban Warming*

Urban warming with anthropogenic heat emissions is a profound impact of urbanization process and climate change. The higher spatiotemporal variations of Land Surface Temperature (LST) values ranged from 22.31~35.94$^0$C, with a mean of 28.62$^0$C were found in more urbanized part of the Colombo Metropolitan Area (CMA) in Sri Lanka mostly along the coastal belt in 2017 (Ranagalage et al., 2017). The stations near large cities have the comparatively higher annual mean urbanization-induced warming compared to the small city station (Ren, 2015). The Pliyandala City Center within Kesbewa Urban Council (KUC) area which has about 20 km distance from the capital Colombo, is under rapid urbanization during past years in Sri Lanka. The air temperature in Pliyandala City Center has increased by 2$^0$C (Figure 3) while deviating the daily temperature values from the average temperature (Figure 4) during the last five years from 2008 to 2013 (Ranagalage et al., 2014). The impacts of climate change in the in Batticaloa Municipal Center in Sri Lanka shows that the recorded daily temperature during the last two decades has a trend of increasing in 0.4-0.5$^0$C compared to the previous two decades (Ministry of Environment, 2012). The trend of temperature in Colombo city of Sri Lanka is increasing with 0.0164$^0$ C/year and $R^2$=0.67 with the change of micro climate conditions due to increasing population and rapid urbanization (Chen & De Costa, 2017). Increases of high heat stress in urban areas as an impact of climate change dependent on urban density and the climatic setting of the city (Oleson et al., 2013). However, urbanization-induced warming in urban areas is greatly complicating in the determination of actual climate change (Ren, 2015).

The results from the interaction of urban human activities and local climate change contribute to human-induced heat emission. The rising trend of temperatures in urban areas is more apparent with the transformation of rural landscape and its natural vegetation to urban landscape, under urban land expansion together with climate change impacts. Changing temperatures may negatively impact on terrestrial forest cover near urban settlements and the flora and fauna they contain as Sri Lanka is a biodiversity hotspot.

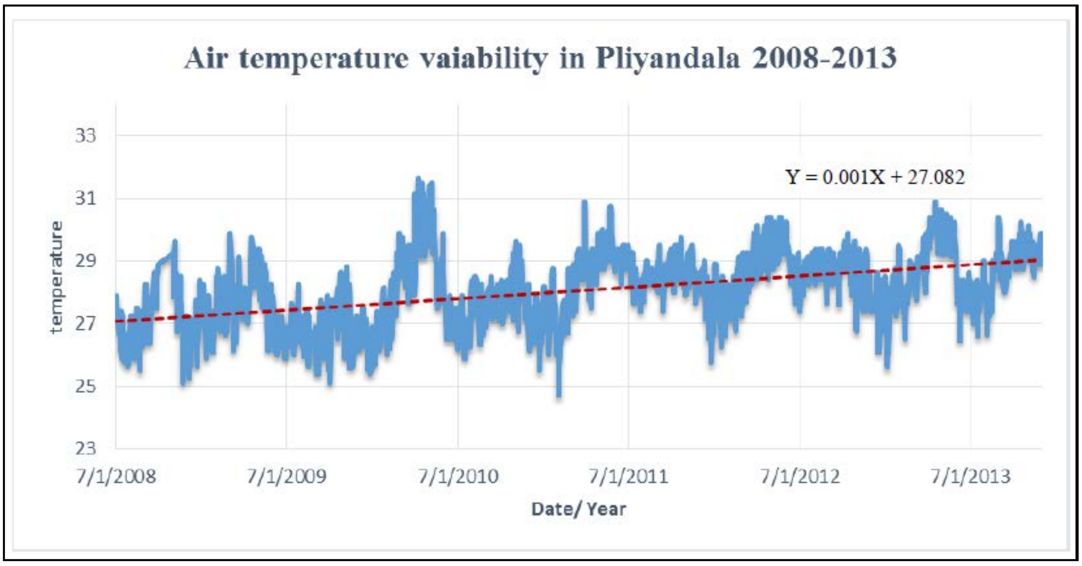



**Figure 3. Increasing trend of air temperature in Piliyandala (from 2008 to 2013)**

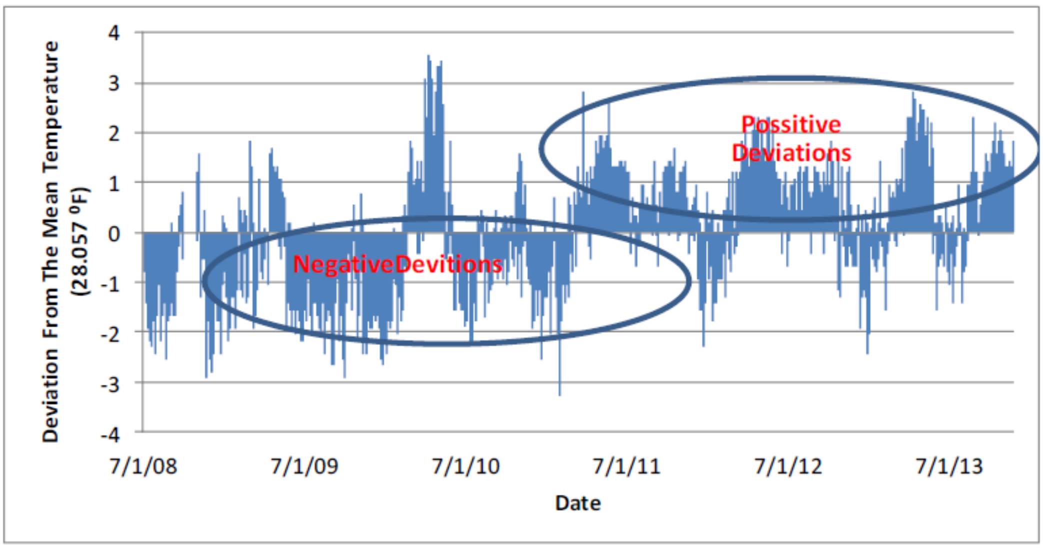



**Figure 4. Deviation Diagram of Air Temperature in Piliyandala1 (from 2008 to 2013)**

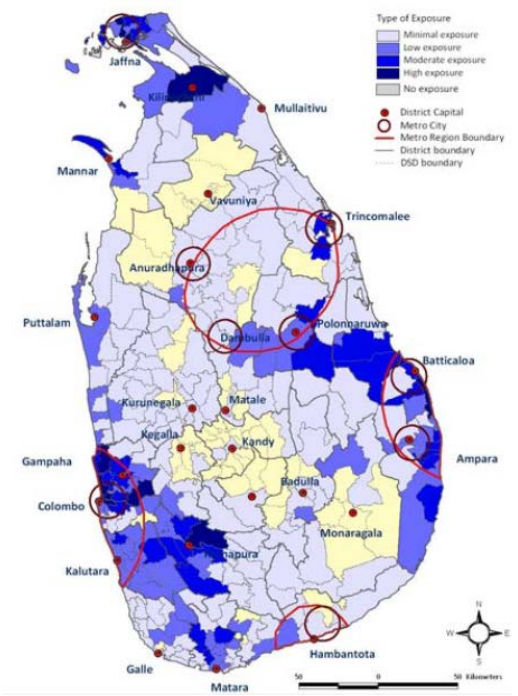
Source: Ranagalage, et al., 2014

The annual cost of energy consumption in residences in Colombo Metropolitan Region (CMR) under conventional design options is estimated at US$ 3 million per square km (at domestic electricity rate of US$ 0.08-0.10/kWh) with significant increases in the cooling load due to urban warming (http://www.climatechange.lk/Documents/Project_Terminal_Report.pdf). Socially and economically disadvantaged populations within urban areas are vulnerable to the adverse effects of climate change and expose to higher extreme temperatures and also less able to take adaptive actions (Fagliano & Diez Roux, 2018).

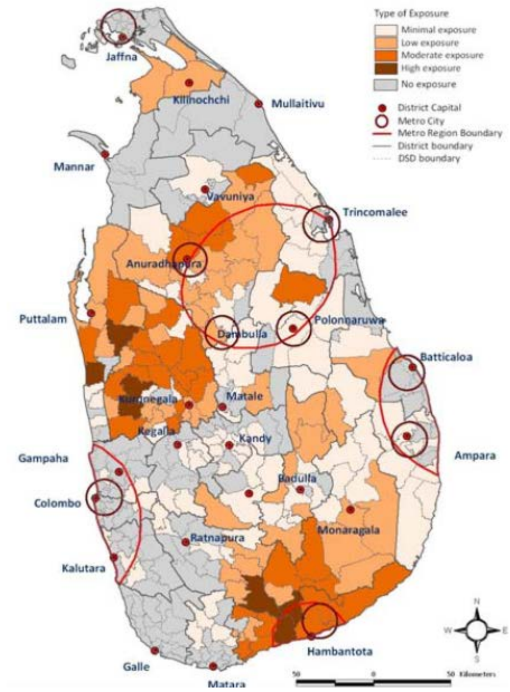
*3.3 Extreme Weather Events*

Rapid urbanization increases in demand and use of urban resource while the urban dwellers exposed to climate change and climate induced extreme weather events. Expansion of cities with complex and interdependent structural systems under urbanization to accommodate increased population and in response to increases in greenhouse gas emissions, make cities extremely vulnerable to threats from natural hazard. The Global Climate Risk Index 2019 has listed Sri Lanka as one of the most affected country from extreme weather conditions with significant increase in vulnerability especially urban communities to climate change (Karunanayake, 2019). Vulnerability to high intensity rainfall, frequent and prolonged droughts, increased storm activity and sea-level rise have been identified as significant impacts of climate change to the coastal city habitats and thus the whole economy of Sri Lanka. The following maps shows the exposure indices for floods, droughts, landslides, and sea level rise respectively in the planned mega cities and urban centers in Sri Lanka (Map–1~4) (http://www.climatechange.lk/Documents/Project_Terminal_Report.pdf).

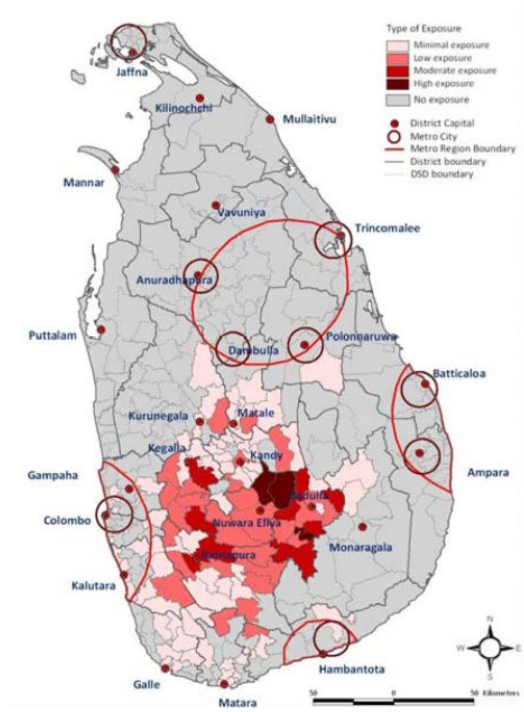
Likelihood of flooding becomes higher in many urban areas in Sri Lanka and also exacerbated by higher rainfall intensities. Rainfall extremes with high intensity and frequent rainfall causing flash floods in urban areas has been frequent during recent years particularly in wet-zone cities in Sri Lanka mainly Ratnapura, Ratmalana, and Colombo (Naveendrakumar et al., 2018). The analysis of historical rainfall data and simulated rainfall data of Colombo city in Sri Lanka has predicted several very heavy rainfall in the future particularly during 2080~2099 causing excess runoff, and potential overflow and urban floods as a result of the Climate change impacts (Lo & Koralegedara, 2015). There are more dry days than wet days even within the highly changing dry and wet days in Colombo city of Sri Lanka rising more frequent flooding particularly in lower part of Kelani River causing flash floods (Chen & De Costa, 2017). Balangoda town which is strategically and economically importance in the central hilly region of Sri Lanka experiencing severe flooding during heavy rains over recent years (https://www.fukuoka.unhabitat.org/projects/sri_lanka/detail20_en.html). The largest flood occurred in the Batticaloa MC during December 2009-January 2010 for the last 100 years loosed lives and properties while damaging the tourism industry emerging in the coastal city (Ministry of Environment, 2012). Frequency and magnitude of urban flooding in many regions of the world has substantial increased as the urban drainage systems have ineffective to collect and convey increased storm water and wastewater due to rapid urbanization and changing climate (Zhou, 2014).

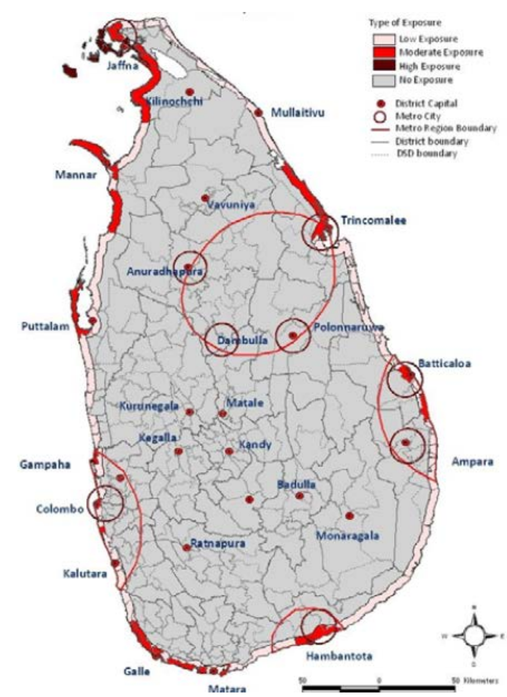



**Map 1. Cities with flood exposure**




**Map 2. Cities with drought exposure**




**Map 3. Cities with landslide exposure** **Map 4. Cities with sea level rise exposure**

Source: www.climatechange.lk

With the rapid urbanization, around 80% of national economic infrastructure as well as 70% of the population of Sri Lanka are concentrated in cities located in coastal and hilly areas have become highly vulnerable to disasters of climate change and predicted impacts. Sea level rise, salination of water resources, storm surges, floods and landslides as climate change impacts together with malaria and dengue epidemics of coastal cities and cities in disaster prone hilly areas in Sri Lanka create constraints achieving the Millennium Development Goals in terms of productivity of cities and delivery of service especially for the urban poor (https://www.fukuoka.unhabitat.org/projects/sri_lanka/detail20_en.html). Climate change have significant impacts increasing episodic (e.g., storm events) and chronic (e.g., sea level rise) hazards on the cities in coastal zone in Sri Lanka where a large percentage of population is located and also the areas making significant contribution for the economic growth of the country (Hettiarachchi & Samarawickrama, 2012). The climate change impacts on coastal zone in Sri Lanka which accounts for about 43% of the GDP make substantial impacts on the national economy (Nayanananda, 2007). The studies have revealed that the sea level rise in coastal cities in Sri Lanka may inundate and displace low lying wetland and coastal areas; erode coastal and degrade shoreline; salinize freshwater aquifers and estuaries, and relocate fresh water intakes; and change and migrate coastal habitats and eco-systems (Hettiarachchi & Samarawickrama, 2012). Negambo MC and Batticaloa MC areas in Sri Lanka are predicted to be vulnerable to rise of sea level affecting 15~20 percent of the total population by 2040 (Ministry of Environment, 2012).

The Tsunami the greatest disaster of the climate change Sri Lanka faced in December 2004 claimed nearly 35,000 human lives. Even after the Tsunami, a serious consequences of climate change induced extreme natural events are increasing in Sri Lanka as a small island country where greater number of people in the cities of high-risk coastal areas. Many urban forest lands, mangroves, and wetlands in coastal cities in Sri Lanka were cleared for resettlement of affected communities by tsunami 2004. The settlers further encroached the urban vegetation for their livelihoods. A number of NGOs have replanted mangroves with non-native species and also planted in areas unsuitable for mangroves as part of the post-tsunami recovery (Sudmeier-Rieux et al., 2006). Even after the tsunami, Negambo MC and Batticaloa MC areas are experiencing frequently increasing storm surges and resulted with losses to livelihoods significantly. Low-income urban neighborhoods live in areas that are more subject to flooding due to adverse effects of climate change have fewer resources to adjust to flooding (Fagliano & Diez-Roux, 2018). Replacement of natural vegetation with exotics in terrestrial forest cover in urban settlements diminish appeal to eco-tourists in Sri Lanka as a biodiversity hotspot.

*3.4 Urban Health Hazards*

Incidence and the level of exposure of wide range of vector-borne diseases are increased with the increased temperatures, changes in precipitation together with urban waste in major cities in Sri Lanka. Colombo Municipal Council area denote higher vulnerability (0.46: moderate vulnerability) to dengue compared to Kandy Municipal Council area (0.41: moderate vulnerability), because of high degree of urbanization, poorly planned waste disposal, and high percentage of built-up environments along with relatively higher temperature (Udayanga et al., 2020). Urban residents in selected urban area tested in 2010 reported a significantly higher prevalence of coughs, phlegm and wheezing than those living in the rural area (Perera et al., 2010). Rapid urbanization and increase in extreme weather events lead to human health consequences such as heat stress, cardio-respiratory and infectious diseases (Paranunzio et al., 2019). Rapid urbanization with the growing migrant population, dramatic changes in the natural landscape and unprecedented impacts from climate change create infectious diseases as a major cause of morbidity and mortality (Tong et al., 2015).

Colombo Municipal Council area shows relatively higher exposure level (0.89: higher exposure level) for climate change compared to Kandy Municipal Council area (0.79: higher exposure level) (Udayanga et al., 2020). Rapid urbanization in relatively high-risk areas need special concern because development should be concentrated not only on people and assets but also on increasing vulnerability to climate-change impacts (Garschagen & Romero-Lankao, 2013). The possible climate change impacts and predicted changes on the urban environment of Negombo Municipal Council (NMC) area in stakeholders' perspectives is shown in (Table 7). The stakeholders have ranked in a five scale (Insignificant, Low, Moderate, High, and Severe) to mark against the current level of each impact and possible future scenarios for 10 years, 25 and 50 years horizons on the city (UN-HABITAT, 2011b).

**Table 7. Impact Identification of Negombo Municipal Council (NMC) Area**

| Change in Climate | Possible Impacts | 2010 (Existing) | 2020 (10 year) | 2035 (25 year) | 2060 (50 year) |
|---|---|---|---|---|---|
| Changes in Means | | | | | |
| Temperature | Heat related sickness | Moderate Consequences | High Consequences | Severe Consequences | Severe Consequences |
| | Air pollution concentration & distribution | Moderate Consequences | High Consequence | Severe Consequences | Severe Consequences |
| Precipitation | Increased risk of flooding | High Consequences | Severe Consequences | Severe Consequences | Severe Consequences |
| Sea-level rise | Coastal flooding | Moderate Consequences | High Consequences | Severe Consequences | Severe Consequences |
| | Coastal erosion | High Consequences | Severe Consequences | Severe Consequences | Severe Consequences |
| | Damage to near shore infrastructure | Moderate Consequences | High Consequences | Severe Consequences | Severe Consequences |
| | Salt water | High | Severe | Severe | Severe |

| | | | | | |
|---|---|---|---|---|---|
| | intrusion | Consequences | Consequences | Consequences | Consequences |
| Changes in Extremes | | | | | |
| Extreme rainfall & Tropical cyclone | More intense flooding | High Consequences | Severe Consequences | Severe Consequences | Severe Consequences |
| | Land degradation | Low Consequences | Moderate Consequences | High Consequences | Severe Consequences |
| | Damage to infrastructure (esp. transport infrastructure) | Moderate Consequences | High Consequences | Severe Consequences | Severe Consequences |
| Changes in Exposure | | | | | |
| Biological Changes | Vector impact on health | Moderate Consequences | High Consequences | Severe Consequences | Severe Consequences |
| | Vector impact on agriculture | High Consequences | Severe Consequences | Severe Consequences | Severe Consequences |
| | Loss of bio-diversity | Moderate Consequences | High Consequences | Severe Consequences | Severe Consequences |

Source: After UN-HABITAT (2011).

The overcrowded populations with rapid urbanization in Sri Lanka are vulnerable to climate change impacts and make additional stresses on urban services and public health services. The deepening stress on the water resources are experiencing in major cities in Sri Lanka mainly due to ever increasing demand for human needs and also due to impacts of natural disasters including the climate change. Urban households generally consider water quantity which is more important than its quality even contaminated water supplies during droughts.

Although the urban households are better off than their rural counterparts, the community living in poor urban areas can be among most life-threatening environments. Rapid urbanization and rural-urban transmigration pushes more and more people into the major cities in Sri Lanka while pushing more poor urban people living in hazard-prone areas in major cities with exposure and vulnerability to climate and disaster risk. The risk of urban poor who are located in urban slums in Sri Lanka often in the most hazardous face serious risk from extreme weather events. They have no strength to withstand more extreme conditions and least able to afford preventive measures.

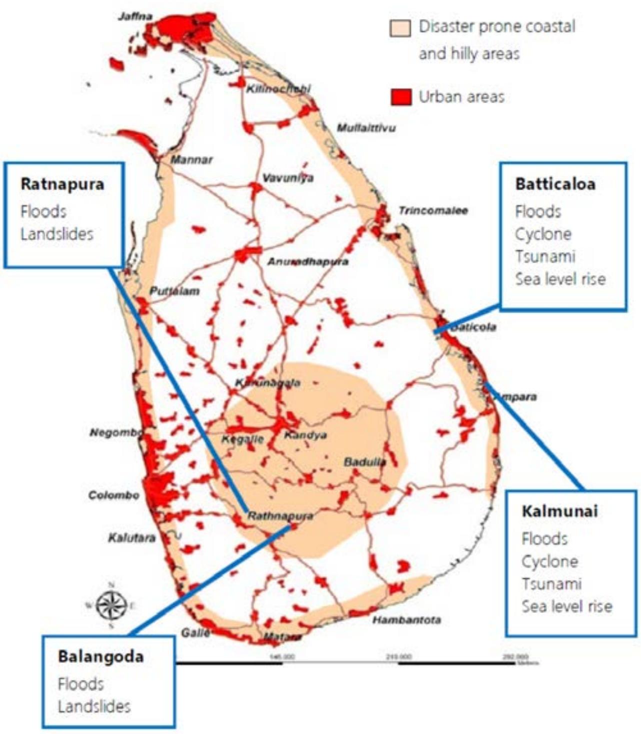
## 4. Environmental Resilience to Urbanization and Changing Climate

### *4.1 Disaster Resilient Cities*

Urbanization and climate change cause natural disasters within urban spaces directly and indirectly. The urban disaster risks are increasing in Sri Lanka with high population density and concentrations of vulnerable people in urban areas together with intensification of adverse impacts of climate change. Urban planners and policy makers have shifted towards inclusion of disaster risk reduction in development practices with the increasing frequency of disasters induced by climate change. Disaster resilient city minimize disasters by building resilience to adverse environmental changes including climate change. The Disaster Resilient City Development Project in Sri Lanka attempted to develop disaster resilient cities and townships in disaster prone regions of Sri Lanka to adapt to climate change, and mitigate its risks (Ministry of Environment, 2012). The concept disaster resilient city aims to develop the urban resilience, the ability to overcome natural disasters particularly climate change that the urban areas face. Resilience is the ability to reduce the impact, damage, or stress inflicted on a city and the ability to recover the city to its previous or better state (Park et al., 2021). Global Platform for Sustainable Cities (GPSC) of the World Bank insist that the urban resilience should go hand in hand with environmental sustainability and developing countries have to transform cities into inclusive and resilient hubs of growth (https://www.worldbank.org/en/news/immersive-story/2018/01/31/3-big-ideas-to-achieve-sustainable-cities-and-communities).

The current concerns of urban development continue to deserve priority attention with the increase of natural and human-made disasters with rapid urbanization. The overall urban development has to be redesigned as the country becoming more vulnerable climate change with overusing renewable resources. The Ministry of Social Services in Sri Lanka established National Disaster Management Centre (NDMC) in 1996 for disaster resilience and providing relief to victims of disasters. National statement on climate resilient cities and support the climate change adaptation activities were validated at the National forum on “Climate Resilient Action Plans for Coastal Urban Areas in Sri Lanka” (UN-HABITAT, 2011). Climate resilient action Plans for Coastal urban areas of Sri Lanka (CCSL) was carried out in Negombo Municipal Council (NMC) and Batticaloa Municipal Council (BMC) areas in order to enhance multi-stakeholder resilience to climate change (Hettiarachchi & Weeresinghe, 2014). The Disaster Mitigation pilot project of United Nations Human Settlements Program (UN-Habitat) in partnership with the Ministry of Local Government and Provincial Councils, Urban Development Authority (UDA) and the Disaster Management Centre implemented city-wide up scaling in disaster prone four municipal council/local authorities (MC/LAs) in Kalmunai, Batticaloa, Ratnapura and Balangoda, under the city development plans for sustainable disaster resilient and healthy cities and townships (Map 5) (https://www.fukuoka.unhabitat.org/projects/sri_lanka/detail20_en.html). However, the involvement of local government in disaster resilience in Sri Lanka is very much reduced as central government is holding the legislative power by the country's Disaster Management Act (Malalgoda et al., 2013).

Urban planning and development in Sri Lanka draw attention for climate change impacts and related disaster risk in cities as well as urban ecosystems components of resilience framework for cities. Removal of vegetation and climatic changes can possibly increase the vulnerability of an urban areas and its coping capacity in Sri Lanka. Therefore, understanding of the broad issues regarding urban fringe zones, urban ecosystems and climate change, and inclusion of these issues have to be included in the overall urban planning process. Efficient urban disaster management on threat of heavy rainfalls causing urban floods in many parts of Sri Lanka is considered for the implications of climate change. Re-planting and restoration of degraded mangrove areas considered for mitigating flooding and erosion in the lagoon and the coastal areas in the vicinity of coastal cities during hurricanes and storms while supporting nesting and reproduction for fish and birds. Land use planning under the disaster resilience of urban planning can minimize the damage caused by increased flooding in urban areas (Park et al., 2021). The Town and Country Planning of the Disaster Mitigation pilot project of United Nations Human Settlements Program (UN-Habitat) in Sri Lanka has emphasized a need to invest in ecosystem based integration of Disaster Risk Reduction (DRR) initiatives (Hettiarachchi & Weeresinghe, 2014). Well-managed ecosystems are more effective in reducing disaster risk mitigating the impact of most natural hazards for the communities in the aftermath of a disaster (Sudmeier-Rieux et al., 2006).




**Map 5. Development of Disaster Resilient Cities in Sri Lankan**

Source: http://www.unhabitat.lk

Transition from unutilized urban land to urban forest in Sri Lanka attempts to assure cities with urban green tree cover and provide environmental services by promoting the capacity of ecosystems. Enhancement of multi-stakeholder resilience and culminate in a multi-purpose green belt were aimed by the "UN-HABITAT Climate Resilient Action Plans for Coastal Urban Areas" (Hettiarachchi & Weeresinghe, 2014). Batticaloa Municipal Council has established 12 km in length of multi-purpose green belt to restore mangrove eco-systems and coastal bio-diversity in protecting the lagoon and coastal areas https://fukuoka.unhabitat.org/programmes/ccci/pdf/SRL4_Climate_Reslient_Action_Plans.pdf. Green areas are highly resilient and are more able to cope with and systematically manage climate change impacts in vulnerable urban areas (Park et al., 2021). Climate and disaster resilient urban planning and development in Sri Lanka is focused on pro-poor resilience mechanisms for the most vulnerable populations in urban centers. Climate Resilient Action Plans of Coastal Areas of Sri Lanka (CCSL) developed action plans for building disaster resilient cities in coastal areas of Sri Lanka. Under the Climate Resilient Adaptation Strategies & Supporting Action Plans CRASSAPs) of this project established a 12 km long multi-purpose green belt to protect the lagoon and coastal areas, restore mangrove eco-systems and coastal bio-diversity in Batticaloa Municipal Council (BMC) area where large number of poor urban dwellers have become vulnerable (https://fukuoka.unhabitat.org/programmes/ccci/pdf/SRL4_Climate_Reslient_Action_Plans.pdf). The design of the multipurpose green belt resilience to multi-disaster situations in Batticaloa Municipal Council (BMC) area, facilitate the community activities through spatial re-arrangements, biodiversity enhancement of coastal eco-systems, protection of coastal beaches from sudden wind and wave processes, and transfer of economic benefit to local community https://fukuoka.unhabitat.org/programmes/ccci/pdf/SRL4_Climate_Reslient_Action_Plans.pdf. The impacts of urbanization and climate change is a growing challenge to urban planners in urban forest planning process with rapid expansion of urban centers in Sri Lanka. The Disaster Resilient City Development Strategies for Sri Lankan Cities Project selected Kalmunai Municipality with 99,634 total population in 2012 due to the lack of land use development plan for the city particularly based on urban forestry and also the vulnerability of the city to multiple disasters including storm surges, cyclones, flooding and tsunami (https://www.fukuoka.unhabitat.org/projects/voices/sri_lanka/pdf/Website_Article_DRR_Dorawela_Oya_May%202014_Final.pdf)

*4.2 Sustainable Urbanization*

Sustainable urbanization includes the social, economic and ecological characteristics. Sustainable urbanization is designed with resilient habitat for existing populations considering social, economic, environmental impact, without compromising the same experience for the future generations. Sustainable urbanization was endorsed at the Habitat III conference held in 2016 and developed efforts in achieving the Sustainable Development Goals during the climate change. UNDP adopted Sustainable

Urbanization Strategy in 2016 support for sustainable, inclusive and resilient cities in the developing countries (Kazak, 2018). Sustainable urbanization respond to rapid urbanization in developing countries and its consequences that are relevant to achieving the SDGs in cities and urban areas for sustainable development (UNDP, 2016b). The urban based crisis-ridden economic development has underscore the need to pay attention to urbanization thus overall urban metabolism has become totally unsustainable (UN HABITAT, 2012). It is difficult to interpreted sustainable urbanization without climate change related themes. Sustainable urbanization taking urgent action to combat climate change and its impacts is critical to achieve the Goal 13 of Agenda 2030 (UNDP, 2016b). Adaptation actions in the context of accelerating climate change patterns should be incorporated into the process of urban planning for sustainable urbanization (Kazak, 2018). The level of urbanization are closely related to levels of income and performance on human development indicators (UN HABITAT, 2012). The people inhabited in sustainable cities are dedicated to manage water, food, energy, and other inputs as well as waste and pollution with minimum environmental impact while meeting their present needs without sacrificing the ability of future generations (Chan, 2017). Urban development planning becoming increasingly intertwined with ecosystem management and disaster management with the increasing risks and impacts of climate change. Sustainable urbanization is one of the efforts to reduce ecological footprint in urban areas and addressing biodiversity, disaster preparedness and climate change adaptation as recognized and endorsed at Rio+20 (https://www.un.org/en/chronicle/article/addressing-sustainable-urbanization-challenge).

Sustainable urbanization has become an urgent practice in Sri Lanka in response to the significant loss of important ecosystem services with degradation and depletion of natural ecosystems, and improve resilience to climate change impacts in urban areas. Protection and restoration of forests, trees and green areas in urban centers are drawing the attention to create healthy, resilient and sustainable urban environment. Urban forestry create balance between the conservation of natural ecosystems in urban planning and facilitate multiple resource users of biological diversity in farming, forestry, fisheries and many other fields. Green infrastructure that would improve the sustainability of urban ecosystems could cut about 40 percent of the total $CO_2$ emissions without changes in urban lifestyle (Hegazy et al., 2017). From a sustainability point of view, ecological properties are significantly high in green cities compared to the compact cities. The Dulumadalawa Forest Reserve and Hanttana forest in Kandy Municipal Area form two natural water reservoirs of capacity 74,000 m3 and 6,000 m3 as the main catchment provide 10% of the city’s drinking water ensuring continuous supply of throughout the dry season as well (Ministry of Defense and Urban Development, 2014). Urban forest turn urban landscapes into urban ecosystems contribute to mitigation and adaptation of climate-change impacts by providing services and facilities enhancing their sustainability (Salbitano et al., 2016).

The adaptive capacity and impacts of urban forests are influenced by biophysical considerations and also the human dimensions. Urban trees connected to human activities and infrastructure coupling natural processes and human processes influence development. The Goals of Agenda for Sustainable

Development in 2030 concern sustainable cities and community well-being and climate actions. Green mechanisms is a great effort in urban design for sustainable urbanization in order to enhance the quality of life of urban communities (Hegazy et al., 2017). Supply of drinking water in major cities in Sri Lanka has become a deepened stress on the water resources mainly due to ever increasing demand for human needs and also due to impacts of man-made and natural disasters including the climate change. Urban forests help in storing water in soil profiles which increase resilience to drought exacerbated by climate change. The existing storm-water and sewer systems in the urban areas in Sri Lanka are often inadequate to handle peak flows in impervious surfaces dominating urban cores with rapid urbanization. Urban forest trees often decrease the amount of storm-water runoff by capturing and storing rainfall in the canopy and, reduce sediment and pollutants through the roots improving water quality before reaching urban water streams. Trees in urban forest absorb gaseous pollutants and intercept particulate matter including dust and smoke in the urban areas. Rehabilitating and re-connecting productive green spaces by urban forestry and urban agriculture throughout the cities reduce surface flows and enhancing infiltration reduces urban flood risks while contributing substantially to urban household nutritional needs. Urban Forest in home-gardens return a multitude of environmental services and economic benefits to the urban households continuously. Green roofs combined with urban agriculture turned into urban forests reduce urban heat islands and cool the city heat created by climate change impacts. Urban agriculture through food on rooftops produce part of the food requirements for growing urban communities in a more sustainable manner (Chan, 2017). Maintaining the food security of rapidly growing urban populations is greatly affected by climate change, which is a main challenge for an active and healthy urban life. The Sri Lanka Climate Fund (SLCF) under the Ministry of Mahaweli Development and Environment, restores abandoned paddy lands to a crop producing areas and provides resources for households to start their urban home gardens, as market based instruments to deal with urbanization challenges and mitigate climate change (https://cdkn.org/resource/integrating-urban-agriculture-and-forestry-into-clima). Integrating elements of urban forestry, urban agriculture, and agroforestry is a multifunctional approach to improve food security and nutritional status, and sustainability of urban landscape (Clark et al., 2013).

Natural and man-made disasters in cities increase with rising inequality and poverty, generating tension and conflicts in urban areas. Integrated urban forestry institutionalized with urban land-use plans and development actions reduce disaster risks and challenges of climate change impacts on urban environment, vulnerability and poverty. Development of "'Forests for Sustainable Cities'' through landscape planning and management under the Ecosystem Conservation and Management Project (ESCAMP) addresses issues to inspire and advance the conservation and management of urban ecosystems in Sri Lanka. The project help the people to better understand the value of forests in urban surroundings, to the health, economies and well-being of the urban communities (https://www.escamp.lk/forests-vibrant-ecosystems-essential-life-earth/). Urban sustainability and regeneration initiatives are driven by the urban development of the smart city with greater environmental stewardship by emerging ecosystem of urban digital technologies (Evans et al., 2019). Kesbewa Urban Council together with Urban Development Authority, Ministry of Agriculture, and Climate Change Secretariat has developed Kesbewa urban development plan (2013-2030) for sustainable urbanization to extend urban agriculture, urban forestry and eco-parks to achieve food sovereignty and promote food production as a climate change adaptation strategy (Kekulandala at al., 2012). Urban green spaces is a key component of urban sustainability enriching human life by providing social and psychological benefits and improving the quality of life of the city dwellers (Rostami et al., 2015).

*4.3 Greening the Cities*

Greening the cities develop a high proportion of forested land within the city borders. Greening city spaces are advised by UNDP to create and manage urban protected areas and implement green infrastructure solutions (UNDP, 2016b). Greening the cities in Sri Lanka help to mitigate negative impacts of unplanned and rapid urbanization creating pockets of forests, landscapes and green areas in the main urban areas thus make them more resilient to the climate changes. Rapid urbanization and migration to cities create land more precious, and convert urban green and public spaces to residential housing and businesses (UNDP, 2016b). Green elements including street trees, gardens and parks support the connectivity creating a network which allows ecological processes tackling environmental challenges, including climate change in urban areas (Grădinaru & Hersperger, 2019). Green spaces mitigate the impact of urban heat islands and improve air quality through the uptake of pollutants and reduce of energy costs for the cooling of buildings (Froese & Schilling, 2019).

Kandy city in Sri Lanka covers 28.53 $Km^2$ with 150,000 residence living population where 15 percent of the land and has been designated as three forest reservations, the UdwattaKalle Rainforest Reserve, Dulumadalawa Sanctuary and Hantanne Forest Area (Ministry of Defense and Urban Development, 2014). Udawattha Kele is an urban forest located in Kandy city in Sri Lanka which was declared as a sanctuary in 1938 under the forest department. Colombo city area in Sri Lanka had maintained a good rate of per capita green space which is used to evaluate the environmental sustainability, satisfying the UN, WHO and EU standards until 2011 (Li & Pussella, 2017). Shading by vegetation of urban green areas and forests keeps the temperature tend to equalize between urban areas to neighboring areas by acting as a solar radiation interceptor that reflects and absorbs radiant energy temperature (Kazak, 2018). Urban forestry has become a valuable part of urban life helping the urban dwellers for physical and mental health, better community cohesion, livelihood development and improved quality of life. Urban forests in public spaces reduce stress and improve the mental and physical health as well as the well-being of the people in urban areas. Rumassala forest range of 20 hectare with many species of flora that are commonly found in the Himalayan region of India, belongs to the Galle Municipal Council area attracts local and foreign tourists. The Municipal Council area covers extent of 1742.4 hectares with recorded 96,836 resident population and 56 persons/hectare of the population density (Ministry of Defense and Urban Development, 2014). Green spaces provide with physical, social, mental, spiritual, and emotional states of harmony within healthy urban environments to achieve livable cities and the well-being of urban dwellers to achieve main goals of sustainable urban policy (Rostami et al., 2015).

Association between percentage green space and the population density particularly the low income city dwellers are critical in the utilization within densely built urban environments in Sri Lanka. Unauthorized occupation of low income city dwellers in urban green areas including traditional forest and natural conservation areas and fertile agricultural lands, and climatic changes have increased the vulnerability of an urban areas for natural disasters and its coping capacity. Colombo city area is not presently maintaining its green spaces a quantitative measurement where the per capita value of green space 7.16m$^2$ recorded in 2015 is below the WHO standard of 8m$^2$ (Li & Pussella, 2017). Greening city is asses based on environmental indicators and enhance the understanding and decision-making on environmental performance. Implementing “the Urban Vision” by the government of Sri Lanka was aimed at improving connectivity and “Green City” initiatives in the Colombo metropolitan and its suburban cities (Ministry of Environment, 2012). Greening cities need to be planned, designed, and developed to lessen the environmental effects and resilient to the climate change impacts while promoting green economy of the cities to realize a sustainable future (https://www.un.org/en/chronicle/article/addressing-sustainable-urbanization-challenge). Urban agriculture as an urban greening strategy increase food security and foster income generation and poverty alleviation while adapting climate change (Froese & Schilling, 2019). The Cabinet of Sri Lanka in 2014 approved the proposal for Urban Forest Resort Project with an extent of about 11 acres in Sri Jayewardenepura Kotte owned by the Urban Development Authority to cater both local and foreign tourists (https://www.dgi.gov.lk/news/cabinet-decisions). Urban planning with green spaces improves the environmental quality and serve as catalysts for bring people together, increase public congregation and interaction (Rostami et al., 2015). Urban tree planting program with native species withstand climate changes. A city wide Tree Planting Campaign with native trees have been proposed by the Federation of Environmental Organizations (FEO) in both public and private lands in the greater Colombo area creating resilient and sustainable urban landscapes. Commencement of tree planting in a large land area available at the urban public palaces is planning in the first week of July 2020 with the seasonal rains (https://feosrilanka.org/projects/greening-the-city-of-colombo/).

### *4.4 Other Environmental Resilience Strategies*

#### 4.4.1 Limiting $CO_2$ Emission

Urban forests and trees together with other strategies for mitigation and adaptation of climate change improve the atmospheric carbon dioxide (CO2) sequestering ability and function as long-term carbon sinks. Urban trees absorb carbon dioxide in the air and transform carbon dioxide into products based on carbon through photosynthesize. According to Sugathapala and Jayathilake (2012), among the different absorbents of carbon dioxide from the atmosphere, trees are the best absorbent compared to soil and sea (Phytoplankton) in urban areas. They have estimated the number of trees from different species

(Mahogany-685995, Robarosia-685995, Kottamba-685995, Acacia-1371990, Teak-914660 and Mara-914660) required to sequester emitted CO2 to reduce $CO_2$ emission (50352.05 ton $CO_2$) annually through urban forestry in Pettah division of Colombo city in Sri Lanka (Table 8).

**Table 8. Requirement of Number of Trees to Absorb CO2 Emission**

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| Name of the tree Species | Tree Age | Number of Trees | Area of trees (ha) | Annual Sequestration rate (Kg/Yr) | Carbon Sequestered (Kg) (C x F) |
| Mahogany | 20 | 685995 | 343 | 20 | 13719905 |
| Robarosia | 20 | 685995 | 343 | 20 | 13719905 |
| Kottamba | 20 | 685995 | 343 | 20 | 13719905 |
| Acacia | 20 | 1371990 | 457 | 10 | 13719905 |
| Teak | 20 | 914660 | 392 | 15 | 13719905 |
| Mara | 20 | 914660 | 392 | 15 | 13719905 |
| Total amount of Carbon Sequestered (t) | | | | | 13719.09 |
| Total amount of CO2 Sequestered (t) x 3.67 | | | | | 50352.05 |

Source: Sugathapala and Jayathilake (2012)

Increase of the average green area per person under the urban planning can reduce urban emissions and enhance climate change mitigation and adaptation benefits (Dulal, 2017). A study has suggested urban vegetation design for physical comfort in urban environment in Colombo where 80% of air pollution is due to vehicular emission (http://www.climatechange.lk/Documents/Project_Terminal_Report.pdf). However, dedication of lands for trees are least competitive in urban core areas due to the high competition for non-tree-based land uses, and required also to sort alternative remedial measures.

4.4.2 Reducing Land Surface Temperature

Urban forests strengthen cities adapt to climate change impacts particularly the increasing heat waves and rising temperatures. The relationship between urban green coverage and the household perceptions regarding temperature change in Matara city shows that the Wald value of 18.798 (significance value of 0.000 and Odds value of 0.067). The households who are living in the high green cover areas have positive perception of cooler temperatures (Ranasinghe & Hemakumara, 2018). Many studies have highlighted the ability of urban forest to improve thermal comfort associated with its tree canopy reducing temperature and regulating microclimate (Jamei. & Rajagopalan, 2017). The increasing trend of the $R^2$ values of regression analysis indicates that the spatiotemporal variations of Land Surface Temperature LST in Colombo Metropolitan Area in Sri Lanka is significantly ($p < 0.001$) strongly negatively correlated with Normalized Difference Vegetation Index (NDVI) ($R^2$ = -0.0942) in 1997, ($R^2$ = -0.2588) in 2007 and ($R^2$ = 0. 3529) in 2017 as the area became more urbanized (Ranagalage et al., 2017). Middel et al. (2015) have shown in a study that a linear relationship between percentage of tree canopy over and near ground air temperature, and reduction of air temperature percentage increase in canopy cover. The Normalized Difference Vegetation Index (NDVI) in the Colombo Metropolitan Area (CMA) in Sri Lanka values ranged from -0.74 to 0.84 in 1997, -0.36 to 0.77 in 2007 and -0.25 to 0.81 in 2017 where both wetland areas and cultivated lands had high NDVI values (Ranagalage et al., 2017). Vegetation of urban forests reflect more heat than absorb heat and allows heat to be transferred upwards into the atmosphere through the process of transpiration (Chan, 2017).

The urban trees provide shade below the canopies avoiding sunlight reaching the surface and intercept greenhouse-gas-emitting from fossil fuels and other sources in urban areas, cooling the local environment. Vegetation abundance urban green space offers significant potential to retain and enhance carbon stocks and help adapt to climatic extremes, such as heat waves by counteracting urban heat island effects in controlling land surface temperature (Dulal, 2017). Carbon sequestration remove $CO_2$ that can retain heat by the vegetation of trees reduce heat of the microclimate directly and indirectly. The roof temperatures and indoor heat gains with turf roof is at a minimum compared to the bare roof slab tops and tile roof roof-tops. According to a study conducted in Colombo urban area in Sri Lanka shows that the green roof record the minimum highest slab top temperature ($37^0$C) compared to the bare roof slab top ($61^0$C) and tile roof roof-top ($63.6^0$C). The minimum highest indoor temperatures is recorded under the green roofs ($32.7^0$C) compared to the tile roofs (34.50C) and bare roofs (35.90C) (Halwatura, 2013). Urban forests reduce the cost of energy needed to cool buildings in urban areas by adapting to higher temperatures and reducing greenhouse gases emissions through carbon dioxide sequestration. Perera et al. (2013) have recommended that the development of Local Climate Zones (LCZs) of Colombo city areas should be limited to open low-rise ($1.56^0$C change) or large low-rise ($0.79^0$C change) areas and mixed developments with in-between plenty of green space. According to FAO, under well managed urban forests, the air temperatures could reduce by up to $8^0$C ($14.4^0$F) and reduce the air conditioning cost in urban areas by around 40 percent (https://www.eco-business.com/news/un-plans-vast-urban-forests-to-fight-climate-change/).

4.4.3 Controlling Urban Heat Island Effect

The Urban Heat Island (UHI) effect magnify the heat stress in urban areas as the temperatures continue to increase due to climate change (Oleson et al., 2013). Urban forest not only greening the urban areas but also reduce Urban Heat Island (UHI) effect fostering carbon sequestration. Trees of properly planned urban forests connect urban biodiversity to surrounding forests and ecosystems, and address the

Urban Heat Island (UHI) impacts caused by urbanization and climate change. Tree plantings and improving green space under urban forestry in Sri Lanka influence the lives of city dwellers by reducing Urban Heat Islands (UHI) even though it is quite difficult to make climate mitigation claims and calculations. Useful empirical insights undertaking UHI control measures and introducing vegetation in cities are included in the strategic plan to address urban heat (Wong et al., 2017). Tree canopy of urban forests offset the Urban Heat Island (UHI) effect due to changing climate and keep the cities cooler thus reduced energy costs for cooling purposes. A study suggest that the greenery or vegetation can be used as Urban Heat Island Effect (UHI) mitigation strategy in Colombo, Sri Lanka by influencing the existing microclimatic condition. Green roofs 100 percent, green roofs 50 percent, green walls 50 percent and combination of all options, reported a reduction of day time peak temperature in $1.87^0$C, $1.79^0$C, $1.76^0$C, $1.86^0$C and $1.9^0$C, respectively. Thus, the greenery and vegetation would improve the human thermal comfort by reducing air temperature and reflected radiation (Herath et al., 2018). Green roofs are considered as the most suitable Green Infrastructure (GI) in urban areas with limited open spaces (Berardi et al., 2014). High density green areas as green infrastructure help mitigate the problem of the UHI and reduce the thermal stress as it does not heat up as much as the built-up area (Kazak, 2018).

### *4.5 Institutional and Policy Setting*

#### 4.5.1 Popularizing Urban Forestry

With the growing awareness of climate change and environmental protection the relationship between urbanization and greenhouse emissions has become a heated topic in rapid urbanization process in Sri Lanka. Development of educational programs popularize urban forestry among school children in urban schools build their behavioral patterns and attitudes to be more environmentally friendly and concerned in reconciliation of climate change impacts by the new generation. Children in urban schools in Sri Lanka engage in wide range of activities in the area of climate change, biodiversity, and waste reduction. Almost all the government schools concentrated in urban areas in Sri Lanka have facilities for the choice of studying sciences up to grade 13 compared to the rural schools (Ministry of Sustainable Development, Wildlife and Regional Development, 2018). School children are more resilient in the face of hardship and are more likely to adapt well with climate change impacts with favorable peer relationships. Planting trees and agricultural crops in gardens of urban schools in Sri Lanka not only serve as a biodiversity hub and enhance resilience to environmental changes but also educate and spread their knowledge to preserve and restore urban ecosystems required for sustainable urban development. One Earth Urban Arboretum with over 500 different varieties of rare and endemic trees created a tiny forest as an educational facility by Dilmah a private tea company in Moratuwa city in Sri Lanka. They regularly conducts educational workshops creating an awareness amongst the school children and urban population on the importance of urban forests (https://www.dilmahconservation.org/initiatives/sustainability/one-earth-arboretum.html).

Strengthening and supporting the children for tree planting in urban schools to cope with risks and adversity associated with climate change draw attention of their families and the communities.

Community Based Disaster Response Teams (CBRDTs) of UN HABITAT in Sri Lanka enhanced community awareness of climate change impacts and disaster preparedness, demonstrating best practices including tree planting and created social harmony and community to be motivators in effective decision making to build urban resilience (UNDP, GEF/SGP) (2016). Educate the public on the thermal benefits of trees and create incentives for the urban people to engage in urban forestry as they have limited understanding of the importance of the urban forest (Middel et al., 2015). Promotion of urban forestry facilitate the urban dwellers to grow fruits and vegetables in their own home gardens increasing food security and reducing food transport, thus reducing greenhouse gas emissions to the urban environments. According to the regulations of Urban Development Authority of Sri Lankan, in each land plots of urban residential zones should keep at least 35 percent of open space as rear space or front space which are used for home gardening which improve urban green coverage and tree planting in urban area (Ranasinghe & Hemakumara, 2018). The UN Habitat- and RUAF-supported program cultivated total 410 ha with home gardens in Kesbewa urban area by around 30 percent of its population for both home consumption of food and income generation while reducing the estimated GHG emissions by 4133 tons/year (Mohamed & Gunasekera, 2014).

4.5.2 Developing Policy Support

Environmentally sound policies is a powerful instruments contributing to sustainable urbanization. The implementation of disaster risk reduction caused by rapid urbanization and climate change in urban areas in Sri Lanka need sufficient policy and institutional approaches in addition to the technical methods and tools. As a signatory to the UN Framework Convention on Climate Change (UNFCCC) ratified on 23 November 1993, Sri Lanka is committed to addressing the threat of climate change by increasing the resilience of the people and ecosystems (Sri Lanka UN-REDD Program, 2017). Climate change is a top priority in policymaking and must be realized by urban initiatives of CO2 reductions. Sri Lanka intended to reduce GHG emissions by 7 percent compared to 2010 as a base year, by 2030 achieving 4% from energy and percent from other sectors through the Intended Nationally Determined Contribution (INDC) (https://www.climatelinks.org/sites/default/files/asset/document/Sri%20Lanka%20Fact%20Sheet%20-%20rev%2010%2012%2016_Final_0.pdf).

Greenhouse gas emissions reduction through urban forestry is an important strategy in sustainable urbanization thus identifying possible enhancing or restricting conditions to be considered in policy actions. The integration of Disaster Risk Reduction (DRR) in Town and Country Planning Ordinance is considered beneficial in multi-hazard risk assessments for resource security and adoption of non-structural and structural mitigation measures in planning and development activities (Hettiarachchi & Weeresinghe, 2014). The urban development policies and institutions need to undertake action to create more sustainable urban forestry and to better adapt to climate change and environmental extremes in order to develop more sustainable human settlements. Strengthening policy and institutional capacity is vital for improving urban climate resilience in cities that recognize urban climate change risks and impacts through carefully design urban planning and developing appropriate urban forestry system. The National Physical Planning Policy and Plan (NPPP&P) which was adopted in 2007 emphasized the urban center development while protecting environmentally sensitive areas such as forests, wildlife habitats and areas prone to natural disasters in urban areas (UN-REDD Programme, 2012). The Government of Sri Lanka acknowledges the role of urban forestry under the forestry sector as a key climate change mitigation strategy through the Intended Nationally Determined Contribution (INDC) in 2016 for the investment in environmental conservation projects (Sri Lanka UN-REDD Program, 2017). ‘‘Forests for Sustainable Cities’ under the Ecosystem Conservation and Management Project (ESCAMP) was implemented in 2018 by the Forest Department, and the Department of Wildlife Conservation, in Sri Lanka to influence the national planning agencies and other stakeholders to create green infrastructure compatible with the urban ecosystems (https://www.escamp.lk/forests-vibrant-ecosystems-essential-life-earth/)

The Statement 29 (2003) of the amendment to the National Agriculture Policy (NAP) include sustainable urban agriculture programs to ensure the food security through environmentally friendly concepts. The main criteria of the 2007 amendment (Statement-17) was to promote urban agriculture and home-gardening with main emphasis on enhancing household nutrition status and income earnings of the city dwellers (Ministry of Environment, 2012). Governmental policy for the establishment and expansion of home gardens in urban settings was also included in several recent programs namely: ‘‘Api Wawamu Rata Nagamu’’ (Let us grow, and uplift the nation) in 2007; ‘‘Deyata Sevana’’ (Tree Planting Program) in 2010; ‘‘Divi Neguma’’ (Livelihood Development) in 2013 in order to reduce costs of living and limits the food imports, enhanced food security, and maintenance of environmentally friendly agriculture methods using modern technologies (Mattsson, 2013). The National Agricultural Policy (NAP) of 2007 promoted urban agriculture not only to enhance household nutrition and income but also to conserve water resources, and efficient water management and soil moisture retention (UN-REDD Programme, 2012).

## 5. Conclusions and Policy Implications

Urbanization in Sri Lanka and exposure of major cities to climate change are changing the ecological consequences and the patterns of the process of urban ecosystem development are in transition. Risks of vulnerability of urban areas in Sri Lanka with urbanization and climate change are complex, dependent and dynamic on wide range and diverse set of factors. Level of urbanization and alteration of urban ecosystems and impacts of climate change have adversely affected the urban areas thus urban dwellers. Disaster resilient cities, sustainable urbanization, greening the cities, and institutional and policy setting related to urban forestry are emerging multifunctional strategies presently addressing multiple challenges of urbanization and climate change as well as an interdisciplinary approach to increase urban resilience. Urban forestry strategies have become a vital importance incorporating urban planning, land use management and addressing mitigation and adaptation of climate change impacts with rapid urbanization. Specific urban forestry adaptation plans is recommended with comprehensive and integrated urban land use planning for the mainstreaming of climate change considerations. The association of disaster resilient city, sustainable urbanization, greening the cities and other urban forestry strategies should be manifested in urban planning, and development of salient policies at the city level can counteract the adverse impacts of climate change in the transition of sustainable processes of urbanization.

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