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# Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy

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ABSTRACT

Incorporation of strategic green infrastructure into urban settings has a potential to mitigate climate change, urban heat island (UHI) effect, flood risk and subsequent increase in quality of human life in general. UHI induces through low surface albedo, building geometry and absence of greenery and it deteriorates the thermal comfort and well-being of city dwellers and occupants. This study examined the implication of urban green infrastructure on enhanced microclimatic condition in tropical urban perspective while evaluating the best suitable strategy by modeling a designated site with ENVI-met microclimatic software (V4). The calibration procedure of ENVI met has been undertaken through a real ground monitoring process and the software modeling was done for selected urban setting. The model was firstly validated by reconciliation of observed in-situ measurements with simulated values. *R*-squared ($R^2$) values for three different surface types such as asphalt, cement and grass were 0.91, 0.96, 0.88 for near ground (0m) and 0.78, 0.81, 0.92 for 1.5 m, respectively. The parametric studies verified that ENVI-met model can be effectively utilized to improve urban micro-scale thermal conditions in tropical Sri Lanka. The numerical simulation model of ENVI-met was used to generate micro-climatic data for the selected area of Colombo metropolitan region with six greening design scenarios such as prevailing UHI condition (T1), trees in curbsides (T2), 100% green roofing (T3), 50% green roofing (T4), 50% green walls (T5) and a combination (T6) of above mentioned green strategies (trees in curbsides + 50% green roofs + 50% green walls). Temperature reductions obtained from all green strategies were compared with existing UHI (T1) scenario during peak temperature in given time. The temperature reductions accomplished by T2, T3, T4, T5 and T6 green infrastructure options compared to T1 were 1.87 °C, 1.76 °C, 1.79 °C, 1.86 °C and 1.90 °C, respectively. It can be concluded that strategic design of urban greenery can effectively enhance the urban environment and outdoor thermal comfort in tropical Sri Lanka.

## 1. Introduction

The present world population is 7.5 billion and it is currently (2017) growing at a rate of around 1.11%per year and it is estimated to reach 10 billion by 2056. In addition, 6 billion live in less developed countries and 1.2 billion live in more developed countries including 54.7% (2017) of the world's population living in urban areas (UN DESA, 2017; PRB, 2014). As predicted by UN, 60% of the future world population of 8.5 billion will be categorized as urban population by 2030 (UN, 2015) and the number of cities with population of over one million in 2016 was 512 and it is expected to increase by approximately 30% into 662 by 2030 (UN DESA, 2017; Mirzaei and Haghighat, 2010). Concentration of sophisticated resources, commercial assets, beneficial socio-economic and environmental conditions and modern infrastructure will encourage people to move into a single, favorable place which is called as urbanization. Urbanization can bring both positive and negative consequences to human, society, economy and natural and built environment. With the process of endless development and anthropogenic interventions occurred with urbanization and industrialization, can bring formidable challenges originated from both Urban Heat Island effect (UHI- defined as a city or metropolitan area that is significantly warmer than its surrounding rural areas due to anthropogenic activities) and climate change.

The Intergovernmental Panel on Climate Change (IPCC) has developed heat island intensities varying in the range of 1.1–6.5 °C (IPCC, 2014).The city of Medellin (Colombia) recorded positive daytime UHI of 7.0 °C, followed by Tokyo (Japan), Nagoya (Japan), Sao Paulo (Brazil), and Bogota (Columbia) (> 5 °C) (Peng et al., 2012). The

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average temperature in the urban microclimate can be increased in the range of 1–12 °C warmer than the surrounding area in larger cities having over one million population. Further, Smaller cities where the population below 1 million is less vulnerable for heat islands compared to larger cities. Major reasons which instigate the UHI are low surface albedo, building geometry and orientation and lack of greenery within the micro-climate (Taha et al., 1988; Taha, 1997). However, basically UHI occurs when naturally available vegetated surfaces (such as grass and trees) are replaced with non-natural heat absorbing, non-reflective, water-resistant impervious surfaces (such as concrete, asphalt) made with anthropogenic materials which absorb high percentages of incoming solar radiation (Wijeratne and Hulwatura, 2016; Taha et al., 1988; Taha, 1997). Moreover, UHI intensities are affected by factors such as wind speeds, cloud cover, season, city and population size, and time of the day (Arnfield, 2003).

This UHI can directly influence on decreasing thermal comfort and healthiness of city dwellers and occupants. Impacts such as deterioration of the conditions in living environments, increment of energy consumption can be directly occurred due to UHI. Further, UHI can augment air conditioning demand (Rosenfeld et al., 1993), enhanced air pollution (Hogrefe et al., 2004) and heat-stress associated mortality and illness (Sailor and Fan, 2002; Changnon et al., 1996; Knowlton et al., 2004). It is revealed that 70 000 deaths were occurred due to a summer heat wave in Europe, 2003 (Robine et al., 2008).

Recently, UHI became a significant predicament and measures that have been taken to mitigate through urban planning where different urban design options can enhance urban air quality and outdoor thermal comfort by reducing surface temperatures (Emmanuel et al., 2007). Mitigation measures that can be used to reduce UHI are manipulating urban structure (dimensions of the buildings and spaces between them, street widths and spacing), increasing urban cover (fractions of built-up, paved, vegetated, bare soil and water) and regulating urban metabolism (heat, water, and pollutants due to human activity) (Stewart and Oke, 2009).

Increasing urban shading with greenery is a successful option (Galenieks, 2017; Park et al., 2017; Zölch et al., 2016) as trees can mitigate the air temperature by evapotranspiration. Trees can intercept incoming solar radiation and preventing it from penetrating into street canyons, thus providing shade and cooling benefits (Matzarakis et al., 1999). Cooling effect of the urban vegetation depends on the foliage density and cooling capacity of the plant (Tan et al., 2010). Besides trees are utilizing a considerable amount of solar energy for the process of photosynthesis and as a result significant fraction of radiation will be retained instead of releasing to the atmosphere which would cause extra heating (Chandramathy and Arch, 2014). Researchers have proven that photosynthetically active radiation was reduced by 94% just penetrating 5 m into the canopy of Puerto Rican wet forest (Johnson and Atwood, 1970) and global radiation was reduced by 53% just penetrating 6 m into the canopy of a Malaysian rain forest (Yoda, 1974). Vegetation has the ability to reduce air temperature up to 5 °C by the evapotranspiration and its shading process (Akbari et al., 2009). Furthermore, trees help to reduce $CO_2$ through carbon sequestration and Ozone precursor levels in air, so it can reduce the greenhouse gases (GHG) of surrounding micro-climate directly and indirectly. Most cities are designed with vegetative surfaces in terms of urban forestry such as trees on curb sides, trees in centre-median (Tran et al., 2017; Kenawy et al., 2010; Akram et al., 2008), living green roofs (Getter and Rowe, 2006), green walls, green façade and turf areas (turf the paving, turf the parking areas, turf the urban gardens/parks). Average maximum daytime temperature could be reduced from humid cities like Hong Kong by 8.4 °C, City of Athens by 10 °C and Riyadh by 3.4 °C and Moscow by 1.7 °C by using vertical greenery (Alexandri and Jones, 2008; Santamouris et al., 2001).

Sri Lanka is also experiencing excessive day time temperatures in cities with industrial, commercial and domestic activities with a huge population and continuous constructions. Colombo is the main commercial metropolitan in Sri Lanka with a recent continuous development and it reports extensive temperature increments and extreme thermal insecurities inside the city. Hence this preliminary study will evaluate the feasibility to mitigate the UHI through vegetation installation by computer simulation with the adaptive use of a numerical simulation model software named ENVI-met (and LEONARDO) developed by Michael Bruse, of the University of Bochum, Germany (Elnabawi et al., 2013; Ozkeresteci et al., 2003; Huttner et al., 2008; Kittas et al., 2015; Jeong et al., 2015; Nice, 2011). Moreover, this paper explores the contributions of designed urban green strategies for its thermal comfort effects in order to enhance the awareness and affinity to use green alternatives in urban settings in tropical Sri Lanka. This research was conducted (a) to envisage the validity and feasibility of ENVI-met software in urban micro-climatic modeling in tropical Sri Lanka and (b) to identify the best possible green infrastructural strategies to maintain enhanced microclimatic conditions in tropical urban context to mitigate existing UHI.

## 2. Materials and methods

Methodology of the research is comprised of a case study with a field assessment and a simulation study.

### 2.1. Study area

Colombo Metropolitan Region (CMR) is located on the Sri Lankan West coast in lowland region at 6°56′N, 79°50′E with 1 m elevation from mean sea level and 5.6 million inhabitants approximately in metropolitan area. CMR is extending about 100 km in the North–South and 30 km in the East–West directions with a typical warm–humid tropical climate which is classified as Af (Tropical rainforest climate) in accordance with Koppen–Geiger climate classification (Kottek et al., 2006). Most of the city is classified as LCZ3 (48.1%), LCZ2 (8.9%) and LCZ8 (23.7%). LCZ1 (0.3%) and LCZ4 (1%) form a very small fraction of Colombo's built fabric (Perera and Emmanuel, 2007). The CMR climate is affected by Asiatic monsoon and existing high temperatures and humidity values (Fig. 1) are creating an inconvenient thermal environment throughout the year (Johansson et al., 2004). Some research studies on UHI issues had reported that CMR had temperature intensities ranging from 0.09 °C to 4.4 °C over the selected 'rural' areas (Perera et al., 2012).

### 2.2. Calibration of ENVI-met

Initial software calibration was completed in the premises of Civil Engineering Department, University of Moratuwa, Sri Lanka (6.7969°N, 79.9018°E) to test the feasibility of ENVI-met numerical model for tropical Sri Lankan micro climatic conditions. Three thermal sensitive receptors were installed in different surfaces that are made with materials comprised of diverse albedo values such as asphalt, cement and grass. Temperature variations were monitored throughout two successive warmest days of August 2016 (29th and 30th) by using automatic Graphtec data logger (GL240) for 48 h in five minutes intervals under free running mode as establishing the receptor knobs in two different heights (0, 1.5 m) along each pole.

Same locality was modelled inside the simulation software after the configuration (Fig. 2) and the building case study was calibrated to validate the simulation software. Simulation was conducted through numerical micro-climate model ENVI – met by using hourly ambient climatic data from Colombo, meteorological weather department. Scatter distribution diagram was prepared to(a) monitor temperature measurements (b) validate the accuracy and (c)test the suitability of model with acquired $R^2$–Coefficient of determination values to standardize the ENVI–met model.