IDENTIFYING POSSIBLE PLANNING INTERVENTIONS TO CONTROL THE INCREASE OF LAND SURFACE TEMPERATURE

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KEY WORDS: Land Surface Temperature [LST]; Urban Heat Island [UHI]; Impervious Surface [IS]; Green Area [GA]; Planning interventions

ABSTRACT

The focus of this research is to identify the relationship among Land Surface Temperature (LST) impervious surface (IS) and Green area (GA) in an urban area. The scholars and professionals discuss the solutions to control land surface temperature as it leads to urban heat island and other micro climatic effects, however, there are limited scholarly works to confirm the relationship between LST and IS as well as LST and GA. Thus, the research objectives are, to verify the relationship between LST and IS and LST and GA and evaluate the capability of introduced planning regulations to reduce rising land surface temperature issue. Quantum Geographical Information System (QGIS) based tools like MOLUSCE helped to predict the land use and remote sensing knowledge had used to assess the level of LST, IS and GA in a series of time periods including future predictions. Once the relationship between the three factors were identified and predicted for future scenarios, it is further aimed to identify how to intervene this situation by changing the GA, particularly by means of imposing green roof concept implemented by the Sri Lankan Government in 2017 (Nila Haritha Sri Lanka). The simulations under four scenarios were carried out using ENVI-met V4 open source software. Accordingly, the Nila Haritha Program will not be enough to mitigate the increasing LST in the study area. Thus, it is essential to introduce and implement best planning interventions to control this disastrous situation. This research was conducted in an urban precinct in Sri Lanka, but can be applicable to any context to determine the possible planning interventions to control increasing land surface temperature issue.

1. INTRODUCTION

At present about 50% of world population live in urban areas and the prediction is that 65% of population will live in urban areas by 2030 (United Nations, 2011). The consequences are already predicted by scholars, namely, land use changes due to the high migration (Zha, et al. 2003) high use of urban energy systems and CO_2 emissions (Ihara, et al, 2008), urban sprawl (Amarawickrama, Singhapathirana and Rajapaksha, 2015) increase of natural disasters (Wickramathilake, et.al 2017) and urban heat island (UHI) phenomenon. Senanayake , et.al., (2008) emphasis the need for adapting less carbon and less use of energy, especially by controlling the building sector. Senanayake, et.al (2013) and Tennakoon and Gunawardena (2017) point out the need of reducing the impact of UHI by exploring and employing sustainable mitigation measures. Scholarly thinking and planning practices in most cities are now being oriented towards sustainable development (Meetiyagoda, 2018).

This discourse leads to introduce a National Policy called “Nila-Haritha Sri Lanka” in 2017. This policy contains a regulation that is at least 50% of the roof area of all buildings of government sector constructions should be covered with suitable plants. As the regulation will enforce only to new constructions, the consequences are not yet understood. At the same time, scholarly works limitedly available to justify this regulation or its consequences. In this background, this research aims to spatially identify whether a land surface temperature rising problem exists in the Sri Lankan context and whether the introduced regulation is sufficient to reduce the identified level of land surface temperature.

The case study of this study was selected from Colombo Metropolitan Region as that is the most urbanized and sprawled city in Sri Lanka (Amarawickrama, Singhapathirana and Rajapaksha, 2015). To be specific, the case study area comes under Sri Jayawardhanepura Kotte Municipal Council, as it is declared as administrative capital where high concentration of government sector buildings is located. The need of conducting spatial analysis for this nature of research was understood and remote sensing methods were used to analyze the level of land surface temperature including future predictions. To understand the implications of new regulation, ENVI-met V4 simulations were incorporated. The next sections of the paper will provide theoretical background, the methodology adopted and a comprehensive discussion about the findings of the empirical study.

2. OBJECTIVES

With the above background two main objectives were set for the study;

3. To find out the influences of green coverage and the impervious surfaces on land surface temperature
4. To critically evaluate the capability of newly introduced "Nila Haritha Sri Lanka" program to regulate the land surface temperature.

3. LITERATURE REVIEW

Memon et al. (2008) define land surface temperature (LST) as "thermal emission of landscape "surface" including the top of the canopy for vegetated surfaces as well as other urban or rural surfaces". This is determined by solar radiation and other substrate atmospheric conditions, such as soil moisture. LST is temperature measured in air close (1m) to the earth surface. The rise of land surface temperature in urban areas creates an uncomfortable living environment. Memon et al. (2008) confirm that LST can be measured with satellites over large spatial and temporal scale by using remote sensing. Peng et al. (2008) mention that if the runoff coefficient of land surface is greater than 0.6, such impervious surfaces have low capacity to natural ground water recharge. Impervious spaces are hardened, paved and structured surfaces. Mullaney (2015) list the materials contributed to have impervious surfaces in relation to buildings, roads and parking lots, namely, concrete, bricks, tiles, asphalt, bitumen and so forth.

Some scholars compared the level of LST and IS and identified higher mean LST of IS than green spaces (Wong and Yu, 2005 and Ranagalage et al. 2018). Mullaney, et.al (2015) study the spatial temporal variation of UHI effect of percentage IS area and elevation on LST in India and found a positive relationship between LST and percentage of IS area. However, this research does not consider the effect of green area in relation to this issue. Morakinyo, et.al (2017) stress the need of improve green space coverage over impervious surface to mitigate urban heat island. According to Takebayashi and Moriyama (2007) increasing GA limits the IS and decrease the LST. However, it is identified larger parks do not have advantages over smaller green areas in cooling effects (Cheung et al. 2015). According to Oke (1982) Kim and Baik (2004) and Memon, et.al (2008) the urban planning and design interventions can control the increasing LST condition through factors such as the GA and the IS. As stated by Morakinyo et al. (2017), this condition is controlled by a biological and metabolism process of absorbing the solar heat which results in evaporating water. However, it is not practical for high-density cities to control the high LST condition by demolishing the existing IS or by converting the valuable lands into GA. Hence the best solution suggested by Morakinyo et al. (2017) is to shift the green cover to rooftops.

4. MATERIALS AND METHOD

4.1 Case Study

Sri Jayawardhanapura Kotte is the administrative capital of Sri Lanka (Figure 1). The area has a population of 107,508 people (Department of Census and Statistic, 2017). The area covers a total of 7 square miles, making the population density over 38,560 per square mile. The geographic location of Sri Jayawardhanapura Kotte extends from 6°55′N 79°55′E. When considering the geographical perspective, it is mix of land and water (160-acre Beira Lake). Sri Jayawardhanapura Kotte is located in the tropical monsoon climate under the Köppen climate classification. This area is characterized as heavy rainfall and relatively constant, warm temperature and humidity. It has an extended period of heavy rainfall from May to August and October to January, which is affected by the monsoon. Rainfall in the city averages around 2,500 millimetres (98 in) a year. The dry period is from January to April, and the average LST in the daytime is in the range of 25-35◦C and the weather is rough and unstable during this period.

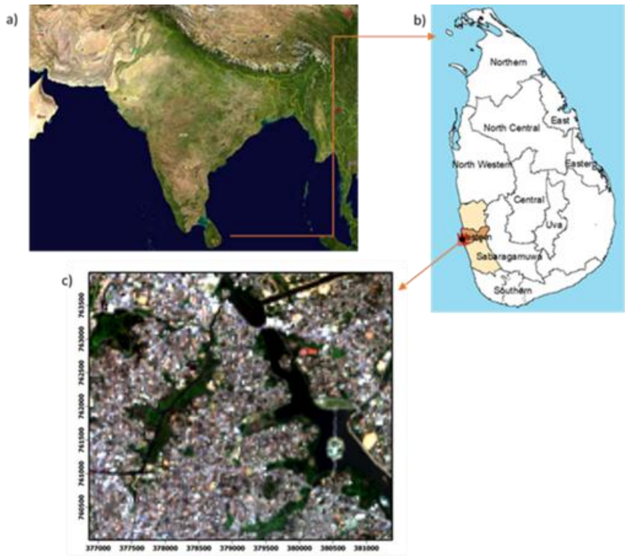

Figure 1: Location of the Study Area: (a) Map of South Asia (Google earth); (b) Location of Sri Jayawardhanapura Kotte; and (c) Landsat 8 Image Displayed in a False Color Composite (bands 5, 4, and 3) (17th February 2018) (https://earthexplorer.usgs.gov/).

4.2 Satellite Images

The Landsat images with less than 10% cloud coverage were taken in the dry season; 13th March 1995 (Landsat 5 TM), 4th March 2005 (Landsat 5 TM) and 17th February 2015 (Landsat 8 OLI/TIRS) (https://earthexplorer.usgs.gov/) (Table 1) were selected for this study to calculate LST, and NDVI from 1995 to 2015 period.

Table 1: Description of the Landsat Images Used

Landsat Data for three time periods				
Sensor	**Acquisition Date**	**Time** GMT	Local	**Season**
Landsat 5 TM	13th March 1995	04:18:38	09:48:38	Dry
Landsat 5 TM	4th March 2005	04:18:38	09:48:38	Dry
Landsat 8 OLI/TIRS	17^{th} February 2015	04:54:05	10:24:05	Dry

4.3 Normalize Different Vegetation Index (NDVI) Calculation

The NDVI is a very important variable for understanding urban climate. "This variable derived from remote sensing data by using the reflectance in the red (RED) and near-infrared (NIR) portions of the electromagnetic spectrum. The NDVI map produced had a value ranging from -1 to +1. Larger NDVI values indicate vegetation, small positive value represents bare soil or built-up areas and negative or close to zero values indicates water" (Ranagalage, et.al 2018). Equation 1 gives the method of NDVI calculation.

Equation 1:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

4.4 Quantifying LST

The best LST quantifying method is extracting temperature using the specific equipment. However, due to lack of facilities and time limitation the LST was quantified with the help of thermal bands of Landsat images. LST is the brightness temperature of the land surface and it's not the real temperature on the surface but has a strong relationship with the air temperature. The equation 2 explains the method of LST calculation.

Equation 2:

$$LST = \frac{T\beta}{1 + (\lambda * T\beta / p) \, In\varepsilon}$$

Tβ - Satellite brightness temperature in degree Kelvin.
λ - Wavelength of emitted radiance.
P - h * c / ϑ (1.438 * 10-2 mk)
ϑ = Boltzman constant (1.38 * 10-23 J/k)
h= Planck's constant (6.626 * 10-34 Js)
c= Velocity of light
ε - Land surface emissivity estimated using the NDVI

4.5 QGIS MOLUSCE Tool

MOLUSCE is a plug-in of QGIS software. MOLUSCE tool has the capability to predict land use changes in the future. This prediction depends on past years land use data. This is not the exact future Land use; however, the predictions are in line with the past changes of the land use.

4.6 ENVI-met V4

“ENVI-met has the capability to simulate the surface, plant, atmosphere interactions within or around a complex urban geometry making it a commonly used tool for modeling different urban atmospheric processes including wind flow, turbulence, urban microclimate, pollutant dispersion, radiation fluxes, and soil temperatures” (Morakinyo et al. 2017). The model is freely available at http://www.envi-met.info. The Data (building, water bodies, and green areas) were abstracted from Google earth images for this study.

4.7 Simulation

Based on the LST of the study area, few samples representing high LST, medium LST and low LST were selected for the simulations. Three types of simulations were created to achieve the objective; they are 50% green roof coverage in government buildings (following the “Nila Haritha Sri Lanka” guidelines), 100% green roof coverage in government buildings and 100% green roof coverage in all buildings with area more than $1000m^2$.

A summary of the method undertaken during the study is given in table 2.

Table 2: Summary of the method

Main Stages of this Research	Descriptions of Variables.
Identifying design related controllable factors.	As discussed in the literature review section, following urban design related controllable factors affect the LST. ***Green area*** (Takebayashi and Moriyama, 2007; Memon, Leung, and Chunho, 2008) ***Impervious surface*** (Takebayashi and Moriyama, 2007; Memon, Leung, and Chunho, 2008)
Identifying the relationship between Green area and impervious surface.	Dependent Variables – Green Area Independent Variables – Impervious Surface
Identifying relationship between Green Area, Impervious surface and Land Surface Temperature.	Dependent Variables – Land Surface Temperature. Independent Variables – Green Area. Impervious Surface
Finding out the possibility of reducing LST through the strategic planning intervention (Consider green roof practices programme 2017 in Sri Lanka)	Dependent Variables – Land Surface Temperature. Independent Variables – Green Area. Impervious Surface

Multiple regression analysis and simulations were undertaken for above different combinations of dependent and independent variables to achieve the set objectives.

5. RESULTS AND DISCUSSION

5.1 Land Use/Land Cover Change

The land use/ cover classifications had an overall accuracy of 92%, 96% and 93% and Kappa value of 0.86, 0.91 and 0.87 for 1995, 2005 and 2015 years respectively. To certify the accuracy of assessment, 300 reference points representing 60% of training samples were selected from all land use classes. The Google Earth images and real color satellite images were used as reference data to assess the accuracy of classified maps. Figure 2 displays the derived land use/land cover maps and the LST maps.

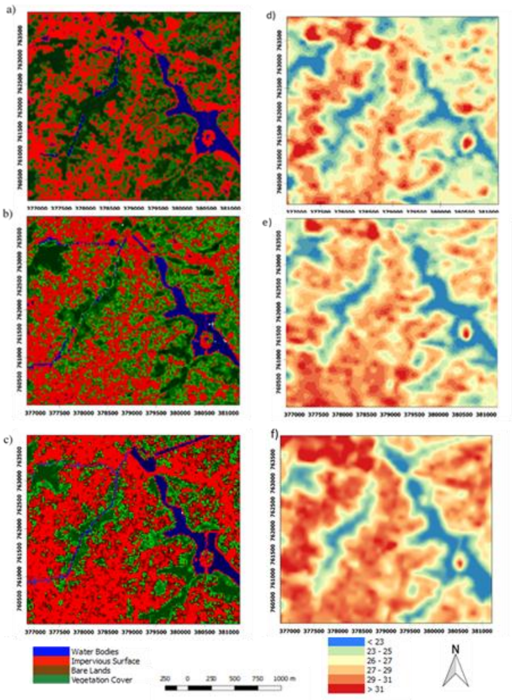

Figure 2: Land Use/ Cover Maps and LSTs in Sri Jayawardhanapura Kotte area: a) Land Use/Cover in 1995, b) Land Use/Cover in 2005, c) Land Use/Cover in 2015; d) LST in 1995, e) LST in 2005 and f) LST in 2015

According to the classification, impervious surface has an annual growth rate of 32.3% from 1995-2005 and 49.7% from 2005-2015 period. Green areas show an annual growth rate of -3.8% from 1995-2005 and -68.9% from 2005-2015 periods. Table 3 displays these annual growth rates for the analyzed period.

Sri Jayawardhanapura Kotte has been undergoing rapid urbanization during the past three decades. The Impervious Surface (IS) has increased by 323.29 ha during the 1995-2005 period and 497.52 ha from 2005-2015 periods. The increasing trend of IS area is highest from 2005-2015 compared to 1995-2015.

Table 3: Details of the land use/land cover changes

Land use/ Cover	1995 Area (ha)	%	2005 Area (ha)	%	2015 Area (ha)	%
IS	1087.47	39.3	1319.76	47.8	1817.28	65.7
GA	1275.12	46.1	1236.78	44.7	547.56	19.8
Water	165.08	6.0	130.86	4.7	185.67	6.7
Barelands	240.03	8.6	78.3	2.8	215.16	7.7
Total	**2767.7**	**100.0**	**2767.7**	**100.0**	**2767.7**	**100.0**

The Green Area (GA) shows a rapid decreasing trend during the research time period. The GA has decreased by 1275.12 ha during the 1995-2005 period and it has decreased by 1236.78 ha from 2005-2015. The decreasing trend in GA is highest from 2005-2015 compared to 1995-2015. Table 4 displays the land use/land cover changes during analysed time periods.

5.2 LST Distribution

In 1995 the LST ranged between 21 ^{0}C and 30 ^{0}C, with a mean value of 23.14^{0}C. In 2005, LST ranged between 21 ^{0}C and 35 ^{0}C, with a mean LST of 26.10^{0}C. In 2015, LST ranged between 21 ^{0}C and 36 ^{0}C, with an increasing mean LST of 27^{0}C.

Figure 3 shows the changes in the mean LST, a segment of GA and IS for the considered time period. The highest mean LST was recorded in low green areas. The pattern of IS showed a compatibility to the mean LST pattern during the three time periods. The average GA segment was in a decreasing trend of 46.1%, 44.7%, and 19.8 %, respectively, while there was an increasing trend in IS from 39.3% in 1995, 47.8% in 2005 and 65.7% in 2015. The regression analysis showed a strong positive relationship between the mean LST and fraction of IS and a strong negative relationship between mean LST and fraction of GS. Additionally, the relationships (the mean LST and the fraction of IS and GA) were statistically significant ($p < 0.001$) in 1995, 2005 and 2015.

$Y = 0.163X1 - 0.162X2 + 32.884$ (1995)

$Y = 0.1639X1 - 0.1678X2 + 32.160$ (2005)

$Y = 0.1831X1 - 0.187X2 + 33.385$ (2015)

According to the analysis there is a strong positive relationship between LST and IS. Further LST and GA have a strong negative relationship. However, bare lands and LST have a weak positive relationship and water and LST have a weak negative relationship. Therefore, bare land and water bodies were neglected in the generated equations.

Table 4: Land use/ cover changes 1995-2005, 2005-2015 and 1995-2015.

Land use/ Cover	**1995-2005** Land use/ cover changers (ha)	Annual Growth Rate	**2005-2015** Land use/ cover changers (ha)	Annual Growth Rate	**1995-2015** Land use/ cover changers (ha)	Annual Growth Rate
Impervious surface	323.29	32.	497.52	49.7	729.81	72.8
Green area	-38.34	-3.8	-689.22	-68.9	-727.56	-72.7
Water bodies	-32.22	-3.2	54.81	5.4	22.59	2.2
Bare lands	-161.73	-16.1	136.89	13.6	-24.84	2.4

*Annual growth rate ha/year

5.3 Land Use Prediction for 2025 and 2035

Land use prediction maps of Sri Jayawardhanapura Kotte showed rapid urbanization. The Impervious Surface (IS) will be increased by 2076.61 ha from 2015-2025 and it will be increased 2216.09 ha from 2015-2025. The annual gain rate of IS will be 12.2 (ha per year) and it will be increasing to 37.2 ha per year.

The Green Area (GA) shows a rapid decreasing trend during both time periods. The GA will decrease by 113.04 ha during the 2015-2025 period and it will decrease 325.8 ha from 2025-

2035. The annual gain rate of GA will be 11.3 Ha per year. Table 5 displays the predicted land use/cover changes for 2025 and 2035 periods.

Table 5: Land Use/ Cover Change 2015-2025, 2025-2035 and 2015-2035

Land use/ Cover	**2015-2025**		**2025-2035**		**2015-2035**	
	Land use/ cover changers (ha)	**Annual Growth Rate**	**Land use/ cover changers (ha)**	**Annual Growth Rate**	**Land use/ cover changers (ha)**	**Annual Growth Rate**
Impervious surface	250.2	25.0	122.31	12.2	372.51	37.2
Green area	-212.76	-21.2	-113.04	-11.3	-325.8	-32.5
Water bodies	-65.6	-6.5	-9.18	-9.1	-74.78	-7.4
Bare lands	-26.5	-2.6	-0.09	-0.009	-26.59	-2.6

*Annual growth rate ha/year

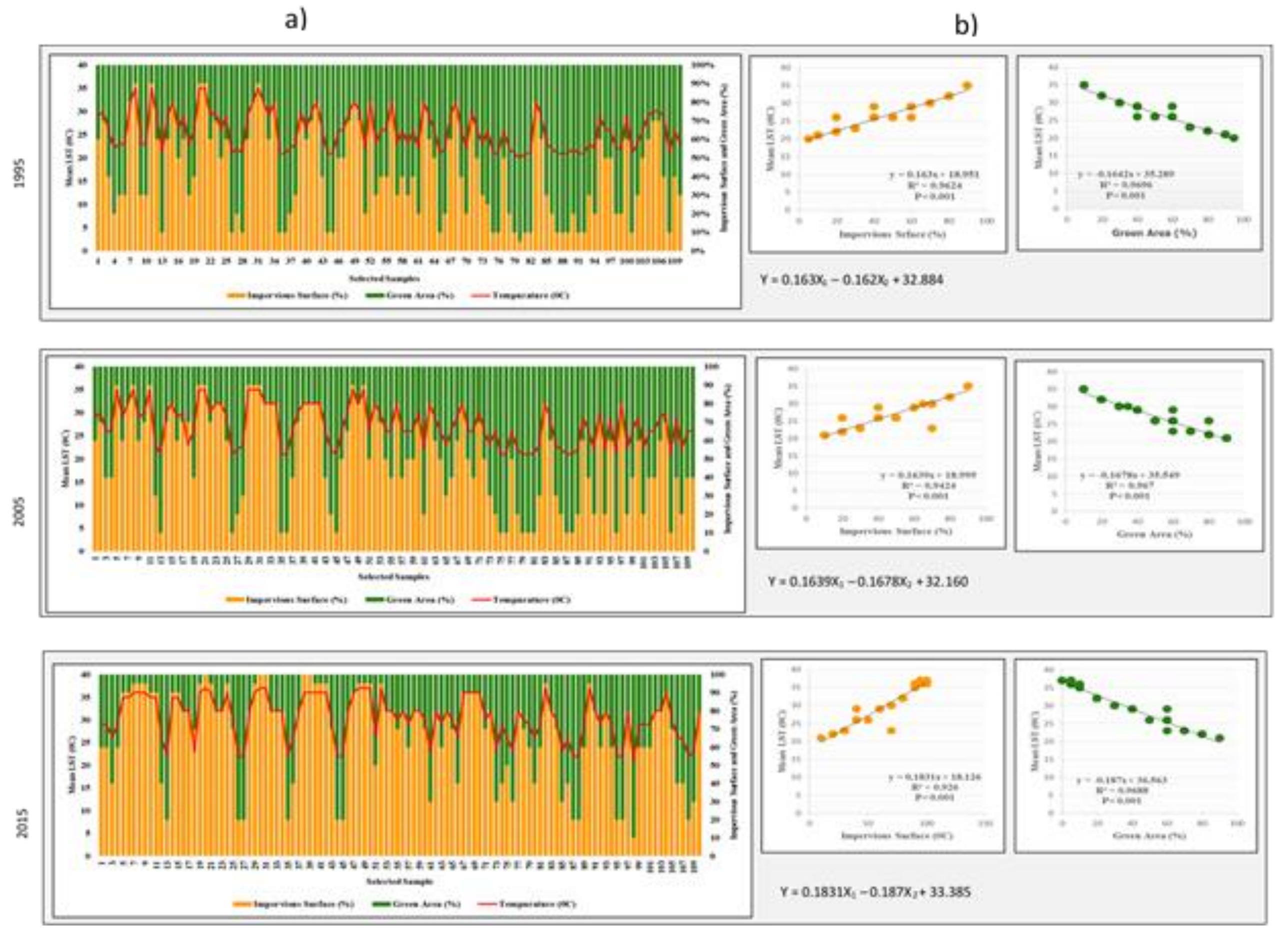

Figure 3: (a) Spatial Pattern of Mean LST, a Fraction of IS and GA. (b) Scatter Plots between Mean LST and Fraction of IS and GA in Sri Jayawardhanapura Kotte Area in 1995, 2005 and 2015.

5.4 Evaluation of Exiting Planning Intervention

With the help of ENVI met V4, LST simulations were undertaken and it took approximately 30 hours for generating a result (Figure 4). The first six-hours results were neglected based on the research done by Emmanuel et.al. 2007. This model cannot be used to calculate temperature or any other data of solid things.

According to the "Nila Haritha Sri lanka" program, green roofs will be introduced to the government buildings initially. Thus three types of simulations (scenarios) were undertaken representing 50% green roofed government buildings, 100% green roofed government buildings and 100% green roofed buildings with area greater than $1000ft^2$.

The scenario of 50% green roofed government buildings or 100% green roofed government buildings couldn't affect in controlling LST. However, the scenario of all >1000 ft^2 buildings covered in green was effective in controlling LST. Figure 5 displays the relationship between green roof coverage and LST.

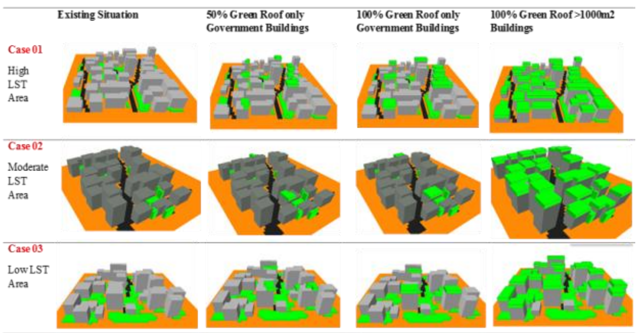

Figure 4: Simulations Representing High LST, Medium LST and Low LST

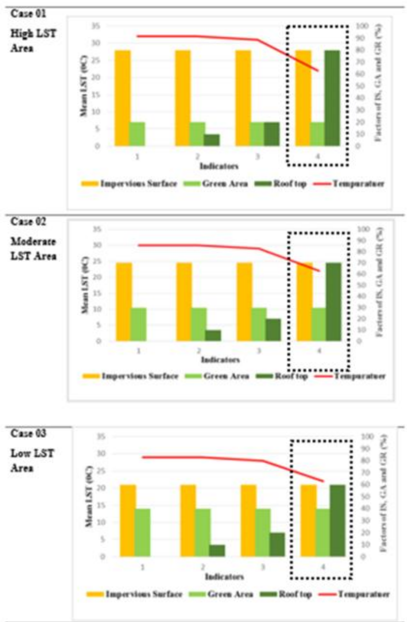

Figure 5: Case 01, 02 & 03- LST Change According to the Four Scenarios within 24hours

Thus the Nila Haritha Sri lanka concept will not be a solution for the rapidly changing LST in the study area. Further the same results could be obtained to any part of Sri Lanka indicating that the Nila Haritha Sri Lanka concept will help to control the increasing LST. It indicates there should be proper evaluation mechanism and proper planning intervention prior to launch just surface solutions to the emerging delinquent of increase of surface temperature.

6. CONCLUSION

This study was undertaken with the objectives of finding out the influence of green coverage and the impervious surfaces on land surface temperature and to critically evaluate the capability of newly introduced "Nila Haritha Sri Lanka" program in regulating the land surface temperature. The research was conducted in the capital city of Sri Lanka which is currently facing unexpected increase of land surface temperature. The time series analysis from 1995 to

2015 showed that rapid increase of LST in the study area. The mean LST of 23.14^{0}C (1995) increased to 27^{0}C (2015) due to impervious surface and green area change. According to the land use prediction undertaken for 2025 and 2035 years, the impervious surface will be increased from 65.71% (2025) to 75.03% (2035) while green area will be decreased from 19.8% (2025) to 2.43% (2035). The observation of LST increasing trend depends on the rapidly decreasing green area in Sri Jayawardhanapura Kotte. The results of the regression model showed that there is a strong positive relationship between LST and IS and a strong negative relationship between LST and GA.

Considering those relationships, the increase of the green area is essential in controlling LST of the study area. However, the area is at its peak urbanization since it is located in Colombo district with higher demand for urbanization. Therefore, the most appropriate way of increasing green is introducing new green growing techniques to the area. One of the methods is green roofs.

In 2017 Sri Lankan Government has started to practice green roof program under the "Nila Haritha Sri Lanka". This program promoted green roof only for government buildings. According to ENVI-met simulation results, it is not enough to control LST in Sri Jayawardhanapura Kotte area. According to the simulation results, it will be possible to control LST if all rooftops greater than 1000 square feet practice green roofing. However, with the existing situation and the conditions of the impervious surfaces, it is not practicable to convert all the rooftops to green roofs. The policy makers and urban planners need to seriously think about this relationship and try to give some supplementary practicable mechanisms to overcome the increase of LST for controlling possibilities of occurring urban heat islands in Sri Lanka in near future.

ACKNOWLEDGEMENTS

A special thank goes to the Conference and publications Support grants, University of Moratuwa, Sri Lanka.

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