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Research Article

Do natural landscapes contribute to reducing Land Surface Temperature (LST)? A case study from Muthurajawela wetland, Sri Lanka

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Abstract

Microclimate regulation is one of the most significant ecosystem services provided by wetlands. The present study attempted to investigate the cooling effect provided by Muthurajawela, a coastal Ramsar wetland using Remote Sensing and GIS. The variation of Land Surface Temperatures (LST) over different Land Use Land Cover (LULC) categories of natural (water bodies, marsh, thick vegetation, grassland) and anthropogenic (built-up areas, coconut cultivations and bare lands) areas was investigated in 2015 and 2020. Parameters including Satellite Brightness Temperature, Normalized Difference Vegetation Index, Proportion of Vegetation and Land Surface Emissivity were calculated along eight transects starting from the center of the water body and extending up to 5 km from the boundary of the wetland. The results revealed that LST over areas under natural land cover (2015 - mean 25.04ºC; 2020 - mean 23.36ºC) were significantly lower than that of areas under anthropogenic influence (2015 - mean 26.52ºC; 2020 - mean 26.22ºC). The lowest increase of LST was over the water body and the highest was over the built-up areas indicating the buffering capacity of wetlands. As air temperatures are highly linked to LST, our findings suggest that wetlands contribute to lower atmospheric temperature and offer cooling effects during dry months. As wetlands could contribute to decreasing atmospheric temperature, at least in a local scale, it is important to conserve these ecosystems as a possible adaptation option to reduce climate change driven heating effects.

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Introduction

Land is one of the most valuable natural resources which provides many basic needs of humans, including habitats. On the other hand, natural lands, together with living and non-living components which are interacting with each other, act as ecosystems to offer a wide array of benefits, the Ecosystem Services (ES). The ES appear in many different ways and can be classified into provisioning, regulating and maintenance, cultural and supporting services which help the human communities and the environment (Gern et al., 1994; Haines-Young and Potschin, 2013; Biggs et al., 2016). Studies on the impacts of human alterations on regulating services of ecosystems are rare. For instance, the focus on temperature regulation provided by natural habitats has been poorly documented. In the context of climate change and rising atmospheric temperatures, investigations on temperature regulations by nature present meaningful insights, especially in order to mitigate impacts (Clarkson et al., 2013; Mclnnes and Everard, 2017). For instance, the ES related temperature regulation and cooling are vital in energy conservation and urban planning (Inostroza, 2014; Kong et al., 2016; Scholz et al., 2018). Land use plays a major role in shaping the natural environment in an area. Population expansion and urbanization have demonstrated a rapid increase in the recent past (Cao et al., 2019; Athukorala et al., 2021; Nath, 2021). Increasing population, unplanned urban growth and unsustainable human interferences which result in significant changes in land use could affect natural ecosystems (Alberti and Marzluff 2004, Estoque and Murayama 2016). For instance, changes of LULC such as built up areas, impervious surfaces and vegetation cover can alter Land Surface Temperature (LST) (Tran et al., 2016; Pal and Ziaul 2017). The different LULC categories and conversions of land cover present many impacts and disparities on the LST (Weng et al., 2007).

The present investigation fills this research gap by exploring the temperature variation along a land use gradient in a coastal area. This study attempts to quantify the impacts of different LULC categories on Land Surface Temperature (LST) in Muthurajawela wetland and its surroundings in Sri Lanka. Muthurajawela is one of the largest coastal wetland in the country and has experienced increased developmental pressure in the last few decades with significant changes in LULC in the area (Zimar et al., 2020; Athukorala et al., 2021; Egresi et al., 2021). To present an account on how different LULC could affect LST, this study involved a detailed analysis of temperature variations starting from the wetland and the marshes (natural areas) and moving to the surrounding areas up to the city, including the barren land, agricultural areas and the city (anthropogenic areas) using Geographic Information System (GIS) and Remote Sensing (RS) as a tool.

Material and Methods

Study area

Muthurajawela marsh is the largest coastal wetland in Sri Lanka (Dissanayake et al., 1982) and is situated in a highly urbanized area. The wetland is located in ($70^0$3'N, $79^0$55'E) between the Negombo lagoon to the north, Kelani river to the south and spreading inland up to Ragama and Peliyagoda in the Gampaha district (Khanh and Subasinnghe, 2018). The marsh covers an extent of 6,232 ha and forms a coastal wetland ecosystem together with the Negombo lagoon. The average annual rainfall of the area is around 2000-2500 mm with the majority received from the Southwest monsoon season (Bambaradeniya et al., 2002). The marsh is rich in aquatic and terrestrial biodiversity. The government of Sri Lanka has declared an extent of 1777ha as a sanctuary in July 1996 and is governed under the Department of Wildlife Conservation (DWC), Sri Lanka.

Methodology

To conduct this study, eight transects were identified starting from the waterbody as the centre and expanding towards the settlement areas. Each transect, therefore, extends over different land uses of natural and anthropogenic origin (please refer to Figures 1 and 2).

Satellite data

Radio metrically corrected level 1 collection 2 data of Landsat 8 satellite were used and data were obtained from the United States Geological Survey (USGS) through the Earth Explorer website (http:/earthexplorer.usgs.gov/). Landsat 8 is the most recently launched Landsat satellite and carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). Cloud free satellite data on the 08th of January 2015 and 13th of January 2020 were used considering the same season for the present study.

Calculation of land surface temperature

LST is calculated using GIS and Remote sensing techniques. The Landsat 8 TIRS sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. The OLI and TIRS measure the radiance of the Top of Atmosphere (TOA). The detailed step by step procedure for LST calculation is given below.

TOA spectra radiance

The following equation was used to convert the Digital Numbers (DN) to the spectral radiance (Lλ) using the radiance scaling factors (Rongali et al., 2018).

Conversion of TOA radiance:

$$L\lambda = MLQcal + AL \quad (1)$$

where

Lλ	=	Spectral radiance (W/(m2 * sr * µm))
ML	=	Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata)
AL	=	Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata)
Qcal	=	Level 1 pixel value in DN

Top of atmosphere brightness temperature

The TIRS of the satellite image was converted from the spectral radiance to the Brightness Temperature (BT) using the following equation (Reddy and Manikiam, 2017).

Top of atmosphere brightness temperature in (^{0}C):

$$BT = K2 / \ln (K1/ \ln(L\lambda)) -273.15 \quad (2)$$

Where:

Lλ	=	TOA spectral radiance (Watts/(m^2 * srad * µm))
K1	=	Band-specific thermal conversion constant from the metadata

		(K1_CONSTANT_BAND_x, where x is the thermal band number)
K2	=	Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

Normalized Difference Vegetation Index (NDVI)

The NDVI is widely used as an indicator to analyze the vegetation and the biomass of an area using multi spectral satellite images. The NDVI value ranges from -1 to +1. The lower values of NDVI indicate none or less vegetation areas and higher values indicate high vegetation areas. The NDVI is used as a factor for LST calculation (Ogashawara and Bastos, 2012; Fils et al., 2017).

Calculating the NDVI:

$$NDVI = (NIR-R)/(NIR+R) \quad (3)$$

where:

NIR	=	Near Infrared Band
R	=	Red Band of the satellite image

Proportion of vegetation

The proportion of vegetation represents the amount of vegetation in the area; the proportion of vegetation was calculated using the NDVI data (Reddy and Manikiam, 2017).
Proportion of vegetation:

$$Pv = (NDVI-NDVImin / NDVImax-NDVImin)^2 \quad (4)$$

Land Surface Emissivity (LSE)

Land surface emissivity is an indicator of the inherent efficiency of the transformation of the above surface heat energy in the radiant energy; the emissivity depends on the profile, moisture and the observation conditions (Sobrino et al., 2001). The LSE is a significant parameter in obtaining the satellite imagery-based LST. There are several methods of obtaining the LSE. The NDVI based Emissivity Method is used for LST estimations from the Landsat images (Oluseyi et al., 2009; Estoque et al., 2017; Sekertekin and Bonafoni, 2020;). The LSE calculation for this study is shown below,

$$\text{Emissivity } E = 0.004 * Pv + 0.986$$

Land Surface Temperature (LST)

There are several algorithms available to calculate LST, for this study the LST was calculated for the Muthurajawela wetland and surrounding area by using the following equation (Rajendran and Mani, 2015; Suresh et al., 201,; Jesus and Santana, 2017;Wijerathne et al., 2018; Ranagalage et al. 2019).

Calculate the LST:

$$LST= BT / 1 + W * (BT / P) * \ln (E)) \quad (5)$$

where:

BT	=	At satellite temperature
W	=	Wave length of emitted radiance (11.5 um)
P	=	h* c/s (1.438*10^-2mk)
h	=	Planck's constant (6.626* 10^ - 34)5)
e	=	Velocity of light (2.998 * 10^ 8 m/s)

Identification of temperature extraction points

There are multiple buffer lines marked from the outside boundary of the wetland at 500m intervals up to 5km. The intersection points of buffer lines and 8 transects were obtained and LST was extracted (Figure 1 and 2) for those featured points. The extracted temperature was categorized over the Land Use and Land Cover (LULC) types, and after that, the extracted temperature (^{0}c) was analyzed on a temporal and spatial basis for the study area.

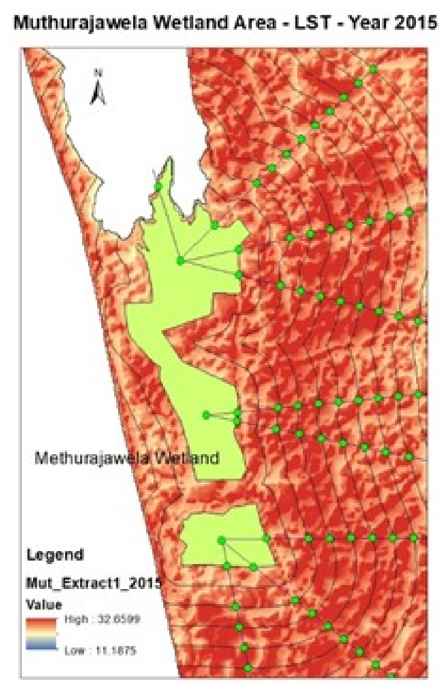

Figure 1. Map of LST derived from 08th of January 2015 satellite image and LST extraction points.

Land use and land cover classification

Analysis of Remote Sensing images of an area utilizes two techniques, which are object-based image analysis and pixel-based image analysis (Blaschke, 2010). The object-based method uses a selection of segments of image and pixel-based method uses the values of pixel to classify the images (Yagoub and Kolan, 2006).In this study, the multi temporal satellite images with 30m pixel resolution were used to analyze the LULC changes in the Muthurajawela marsh wetland area.

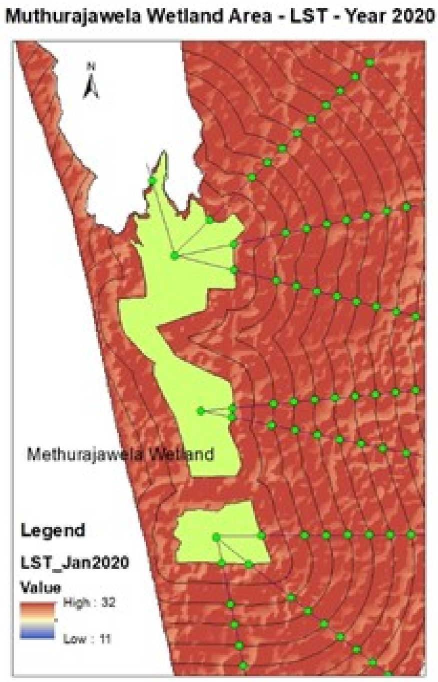

Figure 2. Map of LST derived from 13th of January 2020 satellite image and LST extraction points.

To achieve this, the Iso Cluster unsupervised classification was performed using ArcMap (Version 10.8). This technique utilizes a combination of functionalities of clustering and maximum likelihood classification tools. Unsupervised classification allows identification of pixels automatically according to its pixel values, post identification and categorization in to several classes (Rozenstein and Karnieli, 2011). All the satellite images were classified into 7 classes; water bodies, bare lands, open areas and thick vegetation/forests as natural areas and, agricultural areas, paddy / moderate vegetation areas and settlement areas of the city as anthropogenic areas. The Google earth pro software was utilized for the ground verification of the LULC categories. The identified LST extraction points and the LULC categories of those points were analyzed using Microsoft Excel.

Correlation analysis

The correlation analysis was carried out for the LST over LULC categories against the distance from the center of the wetland for the years 2015 and 2020.

Statistical analysis using t-test

The two-tailed t-test was used to determine whether there is a significant difference between the average values of data on LST for the natural and human interfered basis. The T-test formula is shown in equation (6).

T- test (t) value $$t = \frac{\bar{x}1 - \bar{x}2}{\sqrt{(S^2\left(\frac{1}{n1} + \frac{1}{n2}\right))}} \quad (6)$$

$\bar{x}1$ and $\bar{x}2$ are the average value of the two data sets, S is the standard error, n1 and n2 are the number of observations of each data set.

Results

The spatial and temporal distribution of the LST along transects

The calculated LST for different transects are shown in Figure 3. Muthurajawela wetland faces anthropogenic impacts based on its location especially being closer to the Katunayake International Airport and the capital of Sri Lanka; These anthropogenic impacts can be evident from the LST interpretations. It can be observed that along transects; the temperature is increasing slightly towards the outbound (Figure 3). Transect number seven goes slightly away from the International Airport, and after some distance from the populated area, some vegetated and paddy areas can be observed. Hence the trend line shows a slight decrement. Further, the transects were grouped into three categories, where average LSTs for the transects one, two and three (T1, T2, T3) show a clear temperature increment. These transects lie in highly populated areas. The transects (T4 and T5) go through the main land, where there are some vegetated areas that can be observed after 3-4 km from the wetland. Up to that distance, the temperature shows an increment and afterwards, the LST shows a decrement. The same scenario can be observed with the Transects (T6, T7 and T8) refer to Figure 4.

The land use and land cover pattern

The LST over LULC for the year 2015 is presented in Figure 5 and Table 01 for the year 2020 is presented in Figure 6. The maximum LST (30.9 ^{0}C) was observed over the settlements and the minimum LST (22.01 ^{0}C) was recorded over the water bodies in the year 2015. The highest range of LST difference was observed over the settlements (5.38 ^{0}C) and the lowest range of LST difference was observed over the agricultural areas (1.45 ^{0}C) for the year 2015. The LST over LULC for the year 2015 is presented in Figure 7 and Table 1. The maximum recorded temperature was 30.41 ^{0}C over settlement areas and the minimum was recorded at 22.67 ^{0}C over the water bodies in the year 2020. The highest % difference of temperature was recorded over settlements (24%) for the year 2020. The LULC analysis revealed that LULC has an impact on the LST. The Figure 7 shows that there had been significant differences between study years. The LST difference is high for the thick vegetation between 2015 and 2020. For this study, the LULC type was identified as Natural and Anthropogenic, and for the year 2015, the mean LST for natural areas was recorded as (25.04 ^{0}C) while that for and anthropogenic areas was recorded as (26.52 ^{0}C). For the year 2020, the mean LST for natural areas was recorded as (23.36 ^{0}C) and anthropogenic areas were recorded as (26.22 ^{0}C).

The Spatial and temporal distribution of the LST along transects.

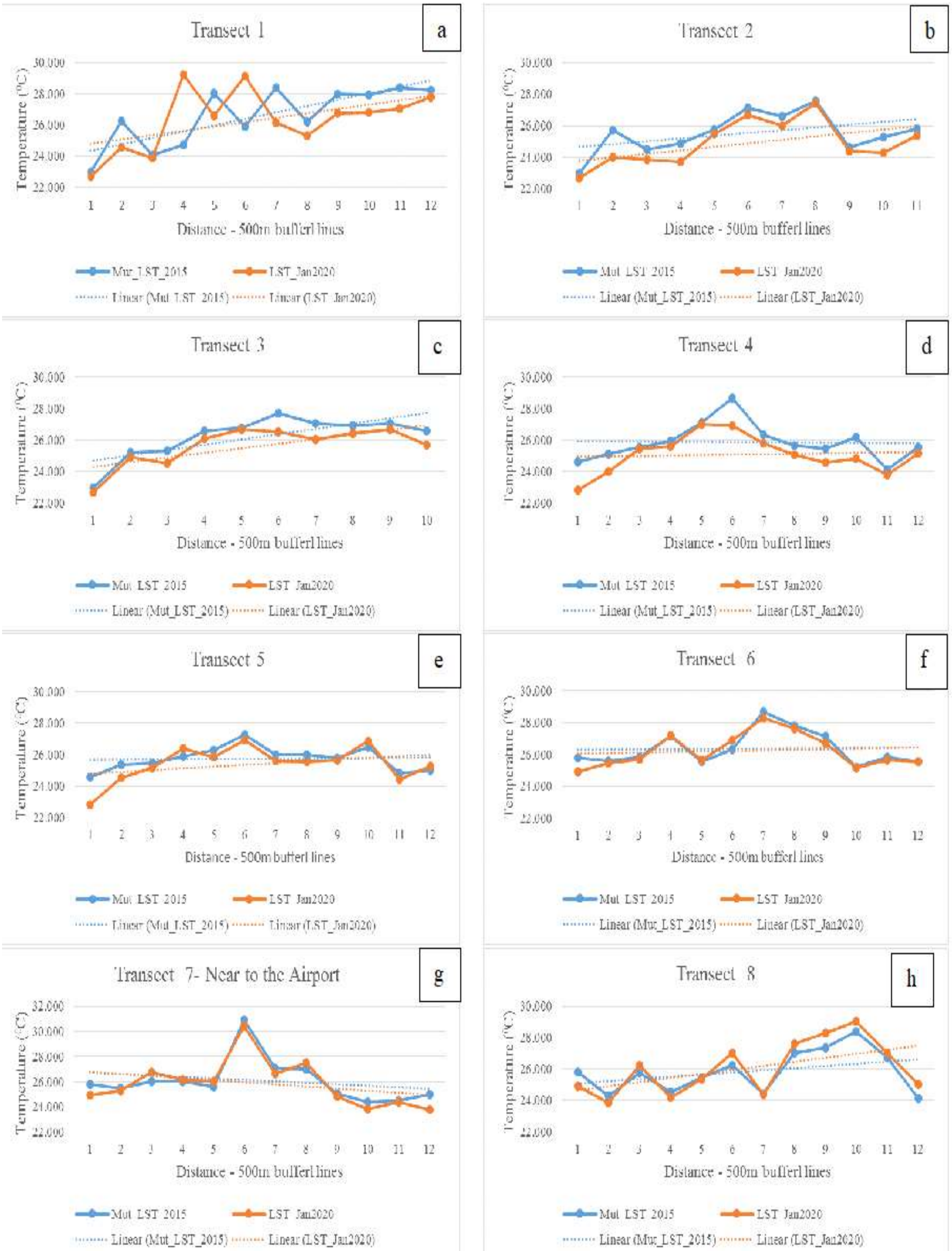

Figure 3. Land Surface Temperature difference along transects which extends over different land uses (a-h)

Average temperature along transects

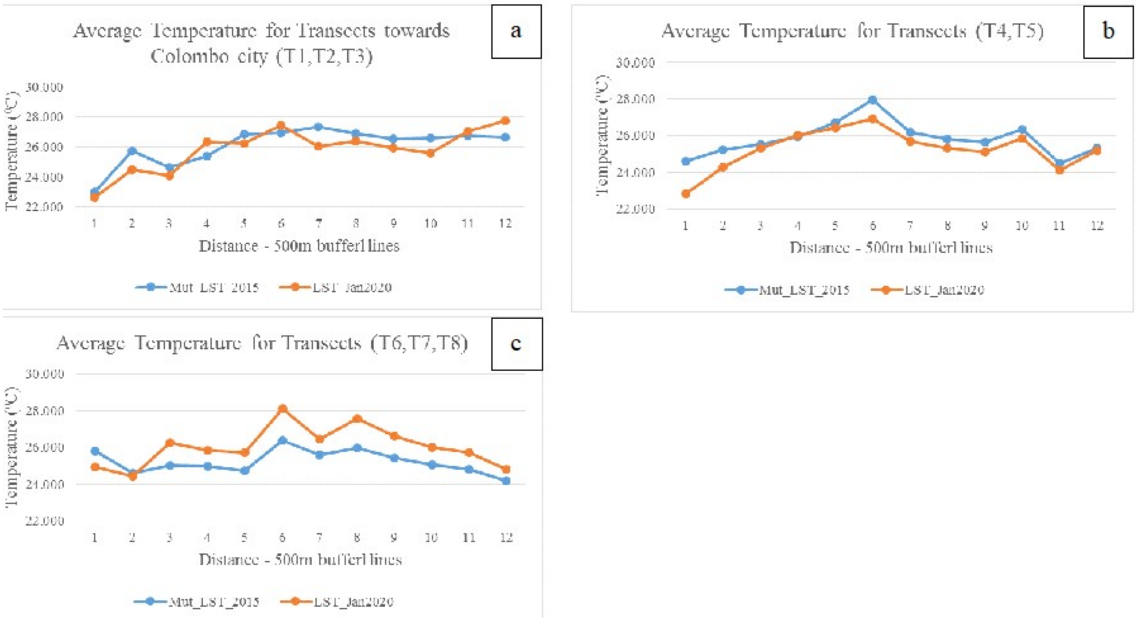

Figure 4. Average temperature along transects (a-c)

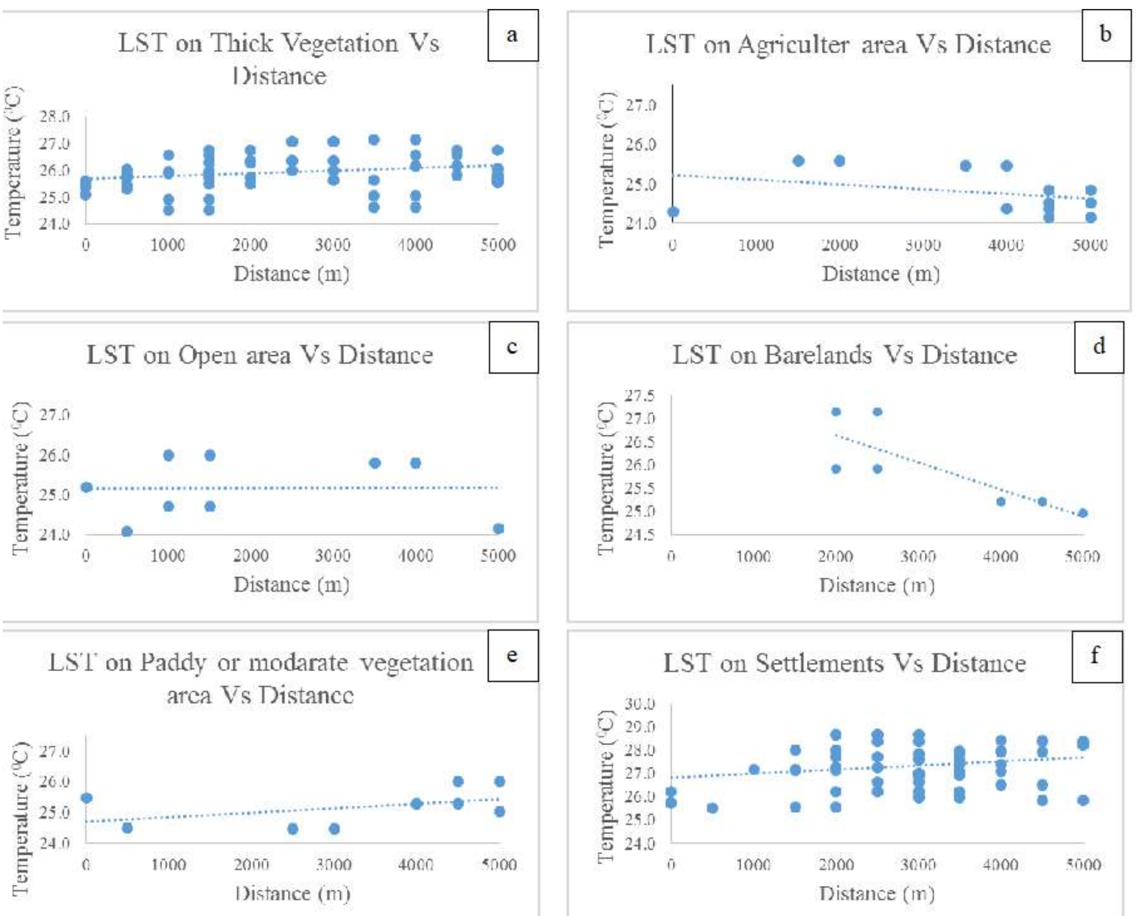

Figure 5. LST variation over different LULC types in the year 2015 (a-f).

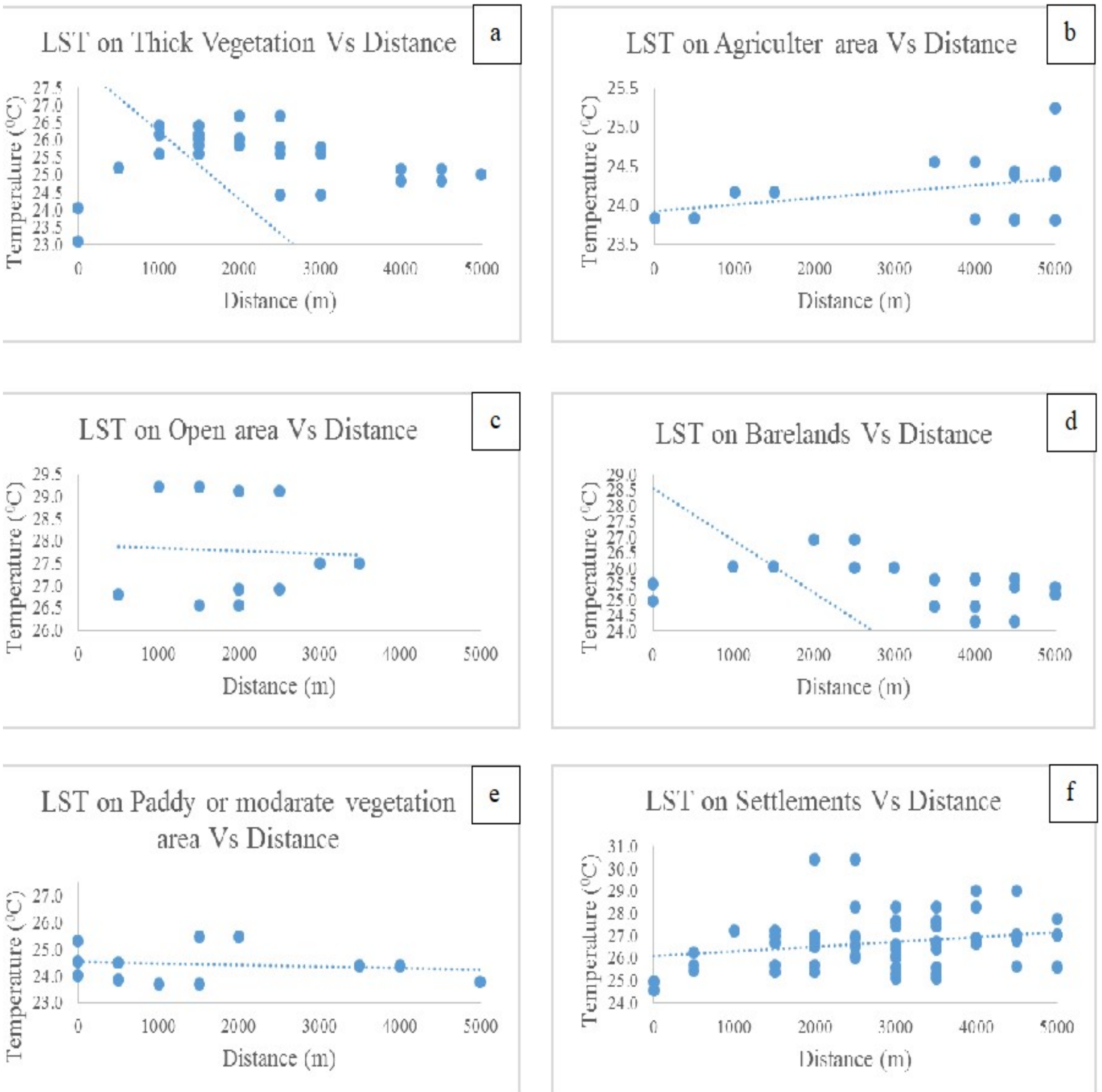

Figure 6. LST variation over different LULC types in the year 2020 (a-f).

Table 1. Minimum and maximum LST for the years 2015 and 2020.

LU LC	Type	Year 2015		Difference		Year 2020		Difference	
		Min	Max	Max-Min	%	Min	Max	Max-Min	%
1	Water bodies	22.01	24.59	2.59	12%	22.67			
2	Bare Lands	24.97	27.14	2.17	9%	24.29	26.91	2.62	11%
3	Open Area	24.08	25.99	1.92	8%	26.56	29.20	2.64	10%
4	Thick Veg -Forests	24.52	27.13	2.62	11%	22.82	26.68	3.86	17%
5	Agriculture area	24.14	25.59	1.45	6%	23.81	25.24	1.44	6%
6	Paddy and Moderate Vegetation	24.45	26.00	1.56	6%	23.71	25.49	1.78	7%
7	Settlements	25.53	30.90	5.38	21%	24.56	30.41	5.85	24%

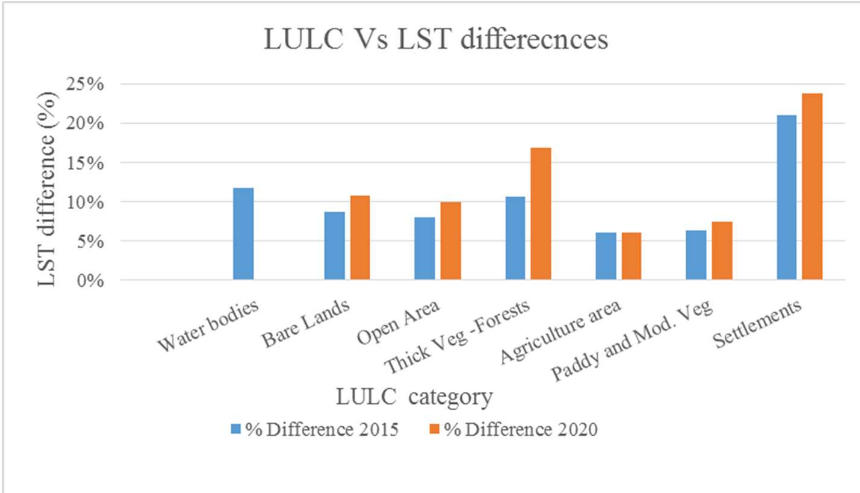

Figure 7. LST difference (%) and LULC categories.

Table 2. Mean and standard deviation of the land surface temperature for the year 2015.

Categories of natural areas	Mean Temp	Std. Dev	Categories of human interfered areas	Mean Temp	Std. Dev
Water bodies	22.33	0.59	Open areas	25.16	0.77
Bare Lands	25.93	0.90	Agriculture area	24.78	0.56
Thick veg or forest	25.94	0.71	Paddy or Moderate veg	25.16	0.62
			Settlements	27.32	1.14
Natural areas	25.04		**Anthropogenic areas**	26.52	

Table 3. Mean and standard deviation of the land surface temperature for the year 2020.

Categories of natural areas	Mean Temp	Std. Dev	Categories of human interfered areas	Mean Temp	Std. Dev
Water bodies			Open areas	27.77	1.15
Bare Lands	23.10	7.71	Agriculture area	24.22	0.41
Thick veg or forest	23.63	6.61	Paddy or Moderate veg	24.43	0.67
			Settlements	26.74	1.16
Natural areas	23.36		**Anthropogenic areas**	26.22	

The two-tailed t-test was carried out for the study to identify the impacts of LST on natural and anthropogenic areas. For both the years of 2015 and 2020, the calculated p-value is less than 0.05 ($p < .05$). Therefore the null hypothesis can be rejected at 95% confidence level and, there is a significant difference of LST on natural and anthropogenic areas for both the years 2015 and 2020.

Discussion

Muthurajawela wetland is a complex ecosystem with waterscapes and landscapes (CEA, 1994). Due to increased developmental activities the wetland is currently facing escalated alternations in its components with distinct episodes of land use changes (Dahanayaka et al., 2013). The recent construction of the Colombo to Negombo Express way (opened to the public in 2013) and expansion of the road network and support services with more economic opportunities (RDA, n.d), have further increased the human encroachments. In addition, the Bandaraniake International Airport and the Katunayaka Export Development Zone, have provided many socio-economic advancements, and which have contributed to change in the physical environment. Even though it is difficult to understand the drivers of such LULC changes, the impacts are visible in many parts of the world (Li et al., 2010). In Muthurajawela land use changes, fragmentation and habitat loss have been rampant (Alahakoon et al., 2018).

Our study demonstrates the variation of the LST on anthropogenic and natural habitats along with different LULC categories. For both years under the study, the maximum LST was observed over the areas of anthropogenic influence (settlements) measured as

30.9 ^{0}C in 2015 and 30.41 ^{0}C in 2020 with the maximum yearly temperature difference recorded as 21% in 2015 and as 24% in 2020. Similarly, the mean annual LST on natural areas were significantly lower in both the years: natural areas as 25.04 ^{0}C vs. anthropogenic areas as 26.52 ^{0}C in 2015 while in 2020 natural areas 23.36 ^{0}C vs. anthropogenic areas 26.22 ^{0}C. The minimum temperature recorded over the water bodies for 2015 and 2020 were 22.01^{0}C and 22.67 ^{0}C, respectively.

The findings of the present study underline the importance of water, wetlands and vegetation in providing the "cooling effect" (Chang et al., 2007). This validates that wetland and vegetation impact profoundly on the temperature. There are lower temperatures over such natural areas obvious, when compared to the city. We argue with these results that the ecosystem services generated by natural ecosystems (Zhang et al., 2020) could be a possible mitigatory measure to combat climate change-induced temperature increase. Growing evidence suggests that regulatory services provided by wetlands and vegetation are among the forefronts of making cities and settlements healthy and livable (McPhearson, 2015; Säumel, 2016; Orimoloye, 2020). However, an additional concern derived from this study is the increasing threats of habitat degradation and alternation which will affect the health of ecosystems impairing their ability to provide ES (Ntshane and Gambiza, 2016; Soh, 2019).

There is growing public attention to increased temperature and related issues, including health and socio-economic implications. For instance, elevated temperatures in cities would demand more electricity and power for cooling (Dissanayake et al., 2019). Some researchers also suggest that the cooling effect of wetlands can be used against "Urban Heat Island effect" (Sun et al., 2012).

Nevertheless, to overcome the limitations in the present study, new investigations are needed with continuous monitoring of LST along natural-anthropogenic habitat gradients and with covering more spatial variances. Evidence-based guidance is urgently required, especially from a policy and practice perspective, to bridge the gap with systematic studies on how to use natural ecosystems to obtain nature's free ecosystem services.

Conclusion

The study findings show that there is a microclimatic cooling effect from the Muthurajawela wetland. Further, it reveals that there is a significant difference in LST between natural areas and anthropogenic areas. The study area is under the influence of urbanization and increment of settlements, In which the wetland act as a cooling island and helps to regulate the temperature in the area.

The micro climatic regulation as ES and cooling effect provide a sustainable solution for energy needs that utilize for cooling devices such as air-conditioning and fans in wetland and its surrounding area during day and night times.

This study had faced several limitations while selecting the satellite images, such as finding the cloud-free images.

It is further observed that there shall be policy solutions and proactive law enforcement need to be taken in place to mitigate the land encroachment and the waste dumping to the Muthurajawela wetland area.

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