Analyse the Surface Temperature Fluctuation in Matara Municipal Council, Sri Lanka by Utilizing Remote Sensing and GIS

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Abstract :*Rapid urbanization, often characterized by unplanned urban expansion, has led to significant reductions in vegetation cover and increases in impervious surfaces such as buildings, pavements, and roads. This phenomenon is particularly evident in the city of Matara, Sri Lanka, which has experienced substantial urban growth over the past few decades. This study employs remote sensing techniques to assess the impact of urban development on urban surface temperature in Matara. This research utilizes pre-processed LANDSAT ETM+ images from Landsat 4-5 level 1, Landsat 7 level 1, and Landsat 8 level 1, satellites, spanning the years 2001, 2008, 2014, and 2021.The study relayed on analyzing thermal infrared (TIR) data to derive Land Surface Temperature (LST), as well as calculating vegetation and built-up indices. Specifically, the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI) were examined to quantify changes in vegetation cover and urban development, respectively. The relationships between LST and these Vegetation and buildup indices are explored to understand the thermal characteristics of the urban environment. Results indicate a consistent annual increase in surface temperature in the heart of Matara city area. While temporal fluctuations in NDVI and NDBI were observed, these changes significant in heart of Matara city area which were not always linear or uniform. The findings suggest that the urban heat effect in Matara could be mitigated by increasing vegetation cover and implementing more sustainable urban development practices. Further, we recommend the implementation of comprehensive urban planning initiatives that incorporate sustainable development principles within the Matara municipal council area. Such efforts should aim to balance urban growth with the preservation and enhancement of green spaces, thereby improving the city's thermal environment and overall livability.*

Keywords: Land Surface Temperature, NDBI, NDVI, Remote Sensing, Urbanization

Introduction

Over time, the number of people has tended to rise. As agriculture flourished, little sedentary communities emerged as more people were born. Some of the people discovered a reason for gathering to form organizations. A few of these settlements later evolved into modern cities. Over the last few centuries, as the population of the world has grown and our economy has become more industrialized, a significant number of people have moved toward cities. This concept is known as urbanization. Urbanization has a significant environmental impact. Because cities only cover a small percentage of the earth's surface, they make up to half of the global population and account for 7%–90% of economic growth, making them the core of anthropogenic activities. Through environmental energy instabilities and a reduction of carbon dioxide storage and bioenergy, urbanization affects climate systems, threatens biodiversity, and has an impact on ecosystem productivity.

Sri Lanka is an island with a tropical climate that is hot and humid all year. The Matara municipal council area is the focus of this analysis. The Matara district has shown an increase in urbanization during the last several years. Things have happened because of the growing population and number of structures. The green environment and the number of trees have both decreased significantly because of urbanization. In addition, urban heat has grown in recent years. Therefore, through this study, it is expected to explore the impact of urbanization on the urban temperature in the Matara municipal council area.

Literature Review

Urbanization consists of the substituting of natural cover with impermeable urban materials, as well as changes in the ecology system and changes in land surface energy.(Fu & Weng, 2017) . Urbanization is happening because of the human-created process, and it has become an effect on biodiversity, climatic changes, and the ecological system. The massive increase of population growth and buildings in cities with the rapid urbanization and because of that the green areas are reduced and increasing the impervious areas(Guo et al., 2012). Nearly 50% of the world's population currently lives in cities, and this percentage will continue to rise, particularly in emerging countries.(Sandamali & Chathuranga, 2020)

Urbanization is an anthropogenic change that affects the local energy balances by causing changes in the surface materials caused by plant reduction, reflectance fluctuation, or soil sealing. This impact is brought about by both the higher electromagnetic wave absorption and the delayed cooling of urban surfaces in comparison to neighboring places. Local dynamic leads to a decrease in humidity levels, a rise in surface temperature, latent heat, as well as a strengthening of sensible heat. The following are the primary causes of UHI (a) the capabilities of construction material to retain heat, (b) anthropogenic heat generation, (c) wind speed change and reduction as a factor of surface roughness, (d) greater solar radiation absorbing from lower reflectivity surfaces, among many others.(de Almeida et al., 2021)

The ongoing change of land from a rural area to an urban area has significant environmental impacts that have yet to be completely investigated. The urban landscape formations and the thermal environment can be significantly altered by urban development. To establish plans for sustainability and to enhance the urban residential environment and things in life, reliable and timely information about the state and patterns of urban heat ecosystems is vital. As a result, creating methodologies and improving the capacity to detect urban expansion as well as the urban thermal environment is a main priority (Guo et al., 2012).

Urban heat is the most significant urban environmental-related problem in the world and numerous areas of the world have become crucial circumstances because of urbanization. Human activities are a major cause of the temperature varying in metropolitan areas. In the urban setting, individuals frequently engaged in non-farming activities including building, commerce, and industry. Land usage and land cover changes in that areas are being influenced by urbanization. Therefore, can’t be ignored and needed to be well prepared for. If not, the environment will impact badly on human life. Because of Urbanization and increasing population, the climate was varying, and urban regions became hotspots due to extreme heat. The people who live in urban areas have critical health threats due to increasing urban heat. Urban heat not only has an impact on people’s health, but it can also raise mortality rates. Because of this urban heat and urbanization, suitable urban planning and proper management can use for the sustainable development of the city.(Halder et al., 2021)

Nowadays large cities and industrial development have resulted in a higher number of surfaces covered in man-made materials like concrete and bitumen. The growth in the use of materials and high thermal mass qualities, as well as the growth of metropolitan areas, have a direct impact mostly on land surface temperature (LST), which causes a rise in the area's sensible temperature. The forest's vegetation cover dictates that temperature of the surface, which varies greatly in urban areas. The temporal change in LST caused by urbanization was examined (YAMAK et al., 2021).

By utilizing satellite remote sensing data can know about the surface heat through the land surface temperature and it can utilize for the analysis of the Urban Heat Islands and this concept is recognized as the Surface Urban Heat Islands (SUHI). LST is based upon several classes of land use/cover/ classifications and how heated the earth's surface is. Global warming and rising global greenhouse gas levels have impacted and created vegetation regions, which has become a serious environmental problem due to fast urbanization and increased development area. Caused of a lack of green areas and thermal variance, the urban region is hotter than the rural place (Halder et al., 2021)

In past years, remotely sensed data with a variety of spatial, spectral, angular, and resolutions have been widely used to analyze urban development and obtain land cover physiological specifications like vegetation relative abundance, built-up index values, and land surface temperature levels, that are reliable indicators of urban ecosystem environments. The growth in construction is the most visible result of urbanization. When the system of urbanization is going to proceed, the areas of Urban Heat Island become larger, and the built-up land cover ratio also increased. These indexes depend on the proportion of developed areas to determine the amount of urbanism, but they ignore the impact of natural vegetation. Because uniquely one band in the thermal infrared range of the Landsat TM detector is placed in the thermal infrared range and it is challenging to retrieve LST when using a thermal separating approach or a widely used divide process, therefore learning further about transmission is crucial.(Guo et al., 2012)

Remote sensing photography is useful for tracking and detecting land use variations often in urban and peri-urban areas has resulted in continuous urbanization. Converting satellite images into a land use map digitally utilizing conventional systems of human interpretation and quantitative picture categorization is a time-consuming procedure. Using satellite images can determine the land surface temperature (LST) on the impact of various degrees of urbanization (Zha et al., 2003).

Land surface temperature has often been determined via remote sensing data, such like thermal infrared (TIR). Thermal infrared information from the earth's surface has been combined with a series of spacecraft and aerial sensors. Thermal infrared sensors can also be utilized to collect emittance data from a variety of surfaces with considerable variation. In ecological research, the study of the urban atmosphere, and the analysis of the urban heat island, emissivity data as well as land surface temperature data can be utilized (UHI). parameters of the environment can be collected, investigated, and modeled using thermal infrared remote sensing. It made it possible to determine land surface temperature which was the significant element in a lot of ecological changes consisting of the urban heat and global warming. The surface temperature is crucial for examining the urban air, also not only for obtaining constrained atmospheric conditions but also for comprehending the environmental variables that people required. (Sandamali & Chathuranga, 2020)

In 1979, Normalize Difference Vegetation Index (NDVI), which Tucker developed, is an estimate of quantity and quality of vegetation. The vegetation index can be used as a basic vegetation indicator that is commonly utilized in numerous parts of vegetation indices by utilizing Near Infrared (NIR) bands and red bands. NDVI is a good indicator of eco-friendly biomass, leaf region index, and instances of formation that ranges from-1 to +1. (Sandamali and Chathuranga, 2021). It was defined by using the equation that is mentioned below. It was based depend on the Near-Infrared band (NIR) and red bands based on the proportion of chlorophyll in vegetation. The NDVI index is often used to distinguish between healthy plants that procreate exceptionally well in the UV Electro Magnetic Radiation (EMR)'s near range. Vegetation index varies according to the type of the Landsat satellite.(Saleem et al., 2020)

NDVI computation for Landsat 5 satellite,

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{Band\ 4} - \boldsymbol{Band\ 3})}{(\boldsymbol{Band\ 4} + \boldsymbol{Band\ 3})}$$

NDVI computation for Landsat 7 satellite,

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{Band\ 4} - \boldsymbol{Band\ 3})}{(\boldsymbol{Band\ 4} + \boldsymbol{Band\ 3})}$$

NDVI computation for Landsat 8 satellite,

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{Band\ 5} - \boldsymbol{Band\ 4})}{(\boldsymbol{Band\ 4} + \boldsymbol{Band\ 5})}$$

The NDBI approach was developed by Zhao.(Zha et al., 2003) Differences that are normalized. The vegetation index can be used to identify metropolitan areas, such as urban or city, where its shortwave infrared sectors have higher reflectivity than NIR regions. NDBI indicator can be utilized to design the area of having more buildings and land use (Halder et al., 2021). For estimating the populations of both the studied area, the NDBI was derived utilizing spectral response values from the NIR bands and Middle infrared (MIR) bands. As well as Normalized Difference Built-up Index. The variance between the SWIR and NIR bands divided by the total of both the bands could be represented by the vegetation index.(YAMAK et al., 2021)

$$\boldsymbol{NDBI} = \frac{(\boldsymbol{SWIR} - \boldsymbol{NIR})}{(\boldsymbol{SWIR} + \boldsymbol{NIR})}$$

Methodology

Study area

The study area was the Matara Municipal Council area in the Matara district in the Southern province of Sri Lanka. Matara district is the second largest city in the southern province.

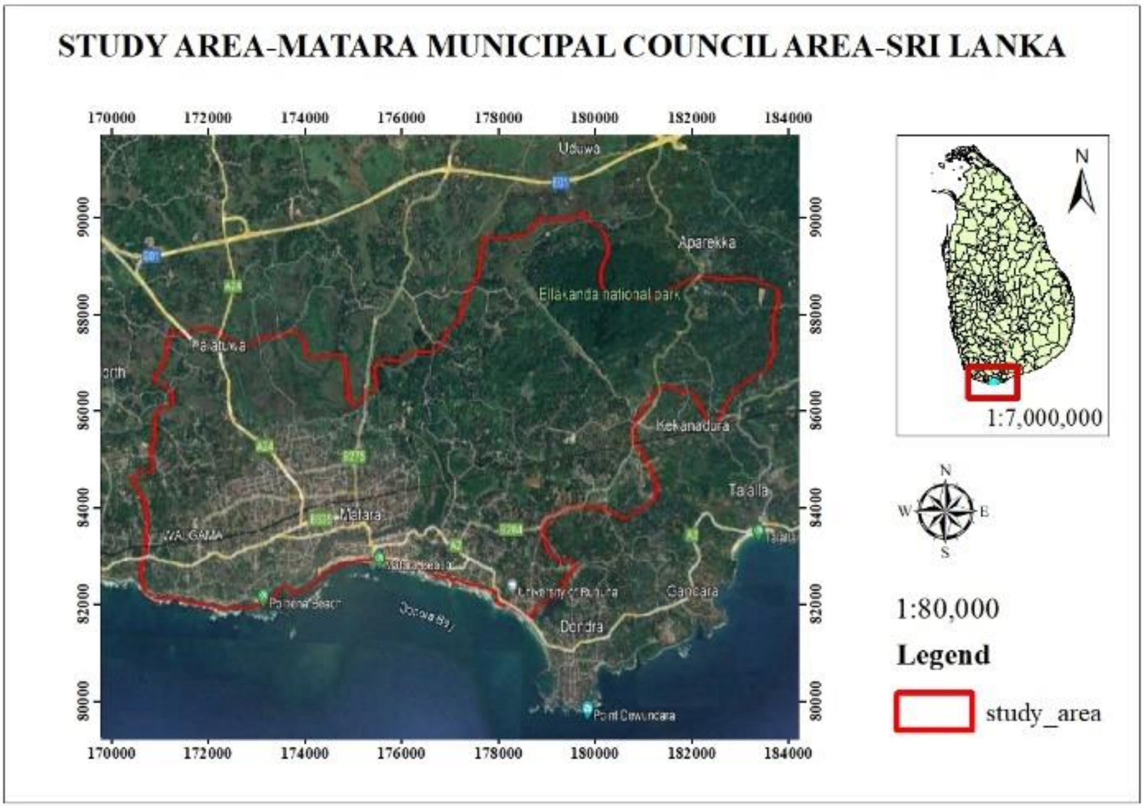


Figure 1: Study Area Map

This study mainly focuses on the preparation of surface temperature maps that vary with built-up layers and vegetation layers. RS data was used for the analysis. Environmental constraints can be collected, investigated, and modeled using TIR Remote Sensing. Landsat images were employed in this investigation since it allows for the estimation of surface temperature, which was obtained from the United States Geological Survey (USGS) via Earth Explorer (http://earthexplorer.usgs.gov).

The following Figure 2 describes the entire workflow of the study.

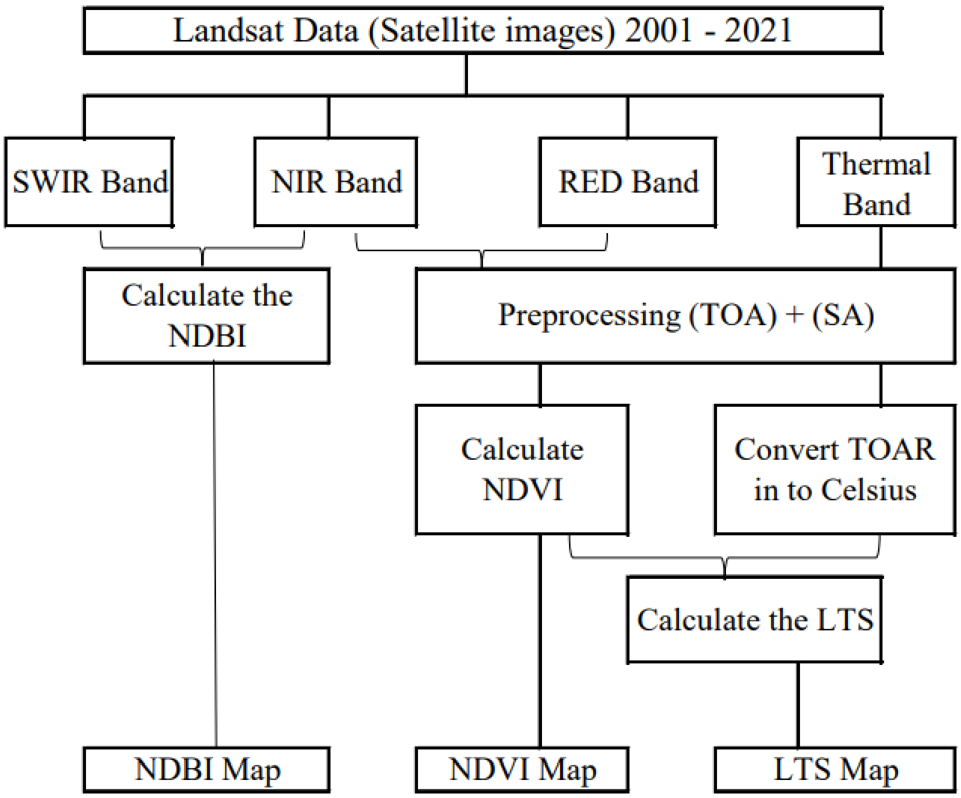


Figure 2: Flow chart of the methodology

Following instructions will have to be adopted by authors of articles when they submit it to the conference:

Image Preprocessing

In the preprocessing, should have to remove the errors and make the corrections. There were two corrections performed in the preprocessing stage. Radiometric correction and geometric correction. Under the geometric correction, Georeferencing and resampling techniques must be used. Furthermore, under the radiometric correction, to account for DN values must also make the necessary corrections.

Conversion of the DN Values into Sensor Spectral Radiance

These processes vary according to the type of satellite, such as Landsat 4-5, Landsat 7, and Landsat 8-9. When considering Landsat 4-5 and Landsat 7, they have the same equation.

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN}\right) * (QCAL - QCALMIN) + LMIN_\lambda$$

Where,

L_λ=Spectral radiance at the sensor's aperture in (watts/ (m2*sr* µm))

Q_{CAL} = Quantized calibrated pixel value in DN

$L_{MIN\lambda}$ = Spectral radiance scaled to Q_{CALMIN} in (watts/ (m2*sr* µm))

$L_{MAX\lambda}$ = Spectral radiance scaled to Q_{CALMAX} in (watts/ (m2*sr* µm))

Q_{CALMIN} = Minimum quantized calibrated pixel value (corresponding to $L_{MIN\lambda}$) in DN

Q_{CALMAX} = Maximum quantized calibrated pixel value (corresponding to $L_{MAX\lambda}$) in DN

When considering Landsat 8-9,

$$L_\lambda = ML * QCAL + A$$

Where:

L_λ = Spectral Radiance (watts/(m2*sr* µm))

M_L = RADIANCE_MULT_BAND_n from metadata

A_L = RADIANCE_ADD_BAND_n from metadata

Q_{cal} = Level 1 pixel value in DN

Conversion of Radiance to Brightness Temperature

These processes also vary according to the type of satellite, such as Landsat 4-5, Landsat 7, and Landsat 8-9. When considering Landsat 4-5 and Landsat 7,

$$Pp = \frac{\pi * L_\lambda * d2}{ESUN_\lambda * COS\theta s}$$

Where:

Pp = Unitless planetary reflectance

Π = 3.14159

d = Earth-Sun distance in astronomical units interpolated from values listed

$E_{SUN\lambda}$ = Mean solar exo-atmospheric irradiances

When considering Landsat 8-9,

$$\rho_\lambda = M\rho * Qcal + A\rho$$

Where:

Pλ = TOA Spectral Reflectance

Mρ = REFLECTANCE_MULT_BAND_N from the metadata

Aρ = REFLECTANCE_ADD_BAND_N from the metadata

Q_{cal} = Level 1 pixel value in DN

Convert to Top of Atmosphere Brightness Temperature in Kelvin

$$T = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)}$$

Where:

T = Top of the atmosphere Brightness temperature in kelvin

L_λ = TOA spectral radiance (watts/(m2*sr* µm))

K_1= K1_CONSTANT_BAND_x, (where x is the specific band number from the metadata file.)

K_2 = K2_CONSTANT_BAND_x, (where x is the specific band number from the metadata file.)

Convert the TOAR in Kelvin to Celsius

$$C \ = (T) - 273\,^{\circ}$$

Where:

C =Brightness Temperature in Celsius

T = Brightness temperature in kelvin

Calculate the Normalized Difference Vegetation Index (NDVI)

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

NDVI values should be in the -1 to +1 range. Positive values represent the vegetated area and negative values represent the non-vegetated area.

Calculate the Proportion of Vegetation (Pv)

$$Pv = \left(\frac{NDVI - NDVI_{max}}{NDVI_{max} - NDVI_{min}}\right)^2$$

Where:

$NDVI_{max}$ = Maximum value of NDVI

$NDVI_{min}$ = Minimum value of NDVI

Calculate the Land Surface Emissivity (LSE)

This process needs to calculate the Land Surface Emissivity (LSE). Pv was given by,

$$\varepsilon = 0.004 * Pv + 0.986$$

Where:

Pv= Proportion of vegetation correction

Calculate the Land Surface Temperature (LST)

Land surface temperature can be obtained by using below equation

$$LST = \frac{BT}{\{1 + w[\left(\frac{BT}{\rho}\right) * ln\varepsilon\lambda\}}$$

Where,

BT = Satellite brightness temperature

W = Wavelength of emitted radiance

P = h*c/s(1.438*10-2mk)

h= Plank’s Constant (6.626*10-34Js)

S= Boltzmann constant (1.38*10-23J/K)

C= Velocity of light (2.998*108m/s)

Results and Discussion

Spatial and Temporal Variation of Land Surface Temperature

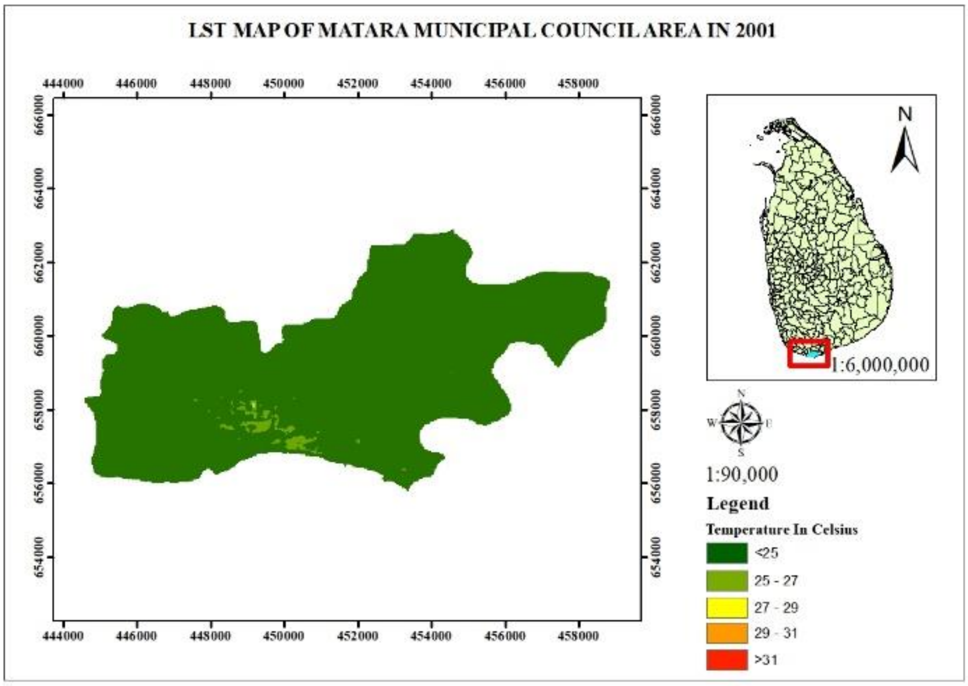


Figure 3: LST in 2001 Dec 27

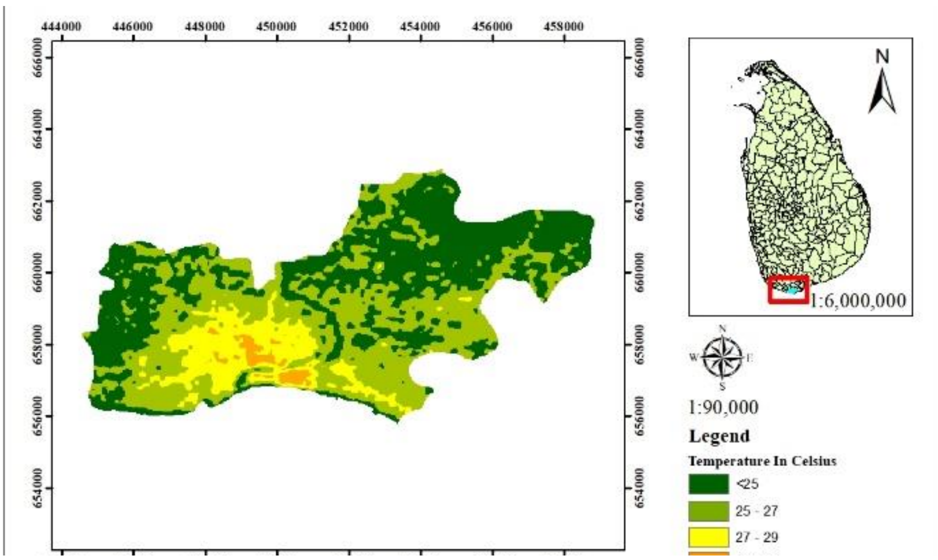


Figure 4:LST in 2008 Dec 27

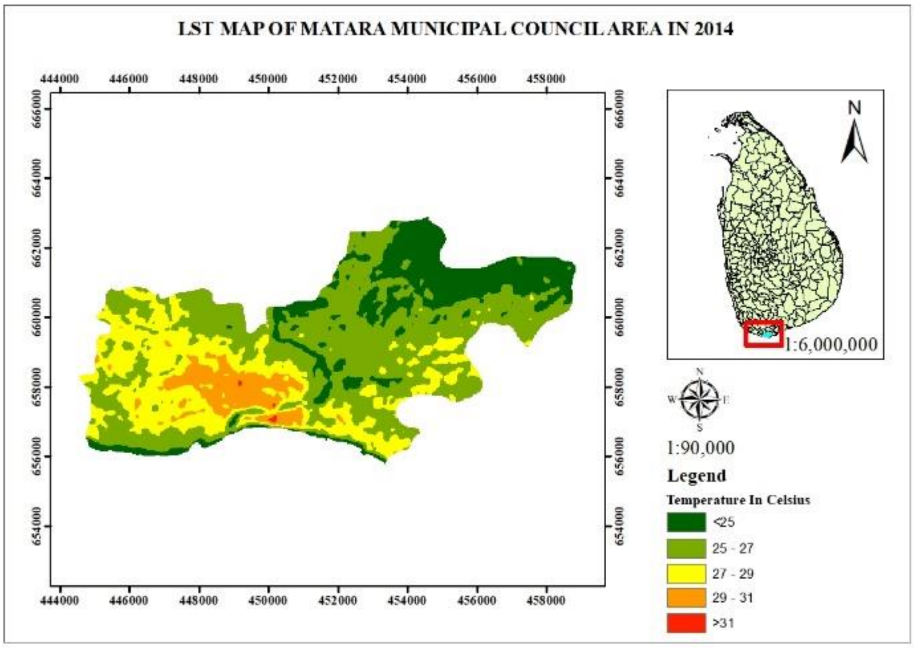


Figure 5: LST in 2014 Feb 06

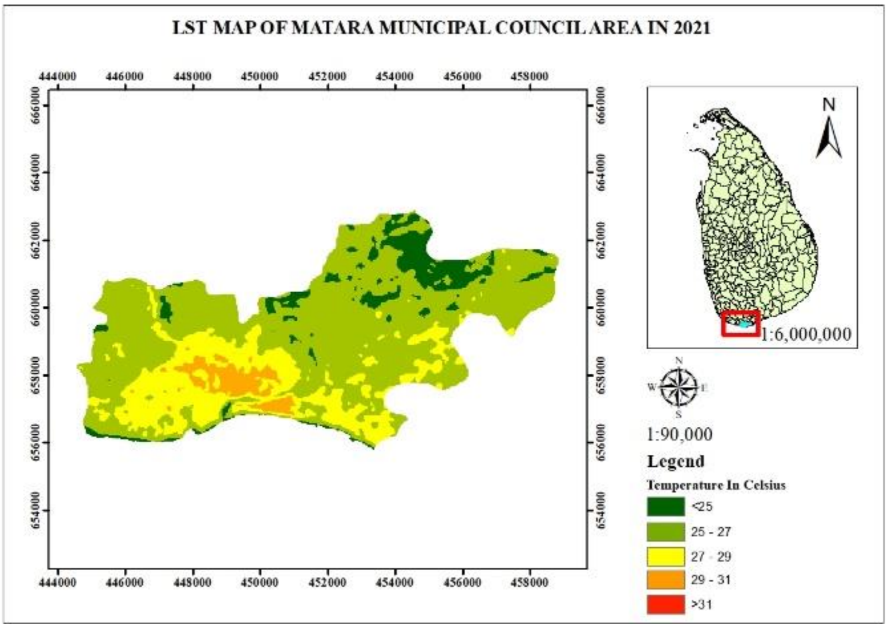


Figure 6: LST in 2021 Dec 27

As depicted in Figure 3, the land surface temperature was below 25°C in the majority of the Matara Municipal Council in 2001. When it comes to 2008, a considerable amount of the Matara Municipal Council has land surface temperatures that range between 25°C and 27°C. Furthermore, a narrow area shows an increase in LST, between 27°C and 29°C. Figure 4 shows the significance increase of LST compared to 2001. According to the figure 5, the most common LST ranges in 2001 steadily declining in 2014. The majority of areas in 2014 appear to be between ranges 25°C - 27°C and 27°C to 29°C. additionally in 2014, the LST in the 29°C –31°C range appears in the city's core area. When 2021 is taken into account, it shows a decline in the lower range of LST and an increase in the higher range.

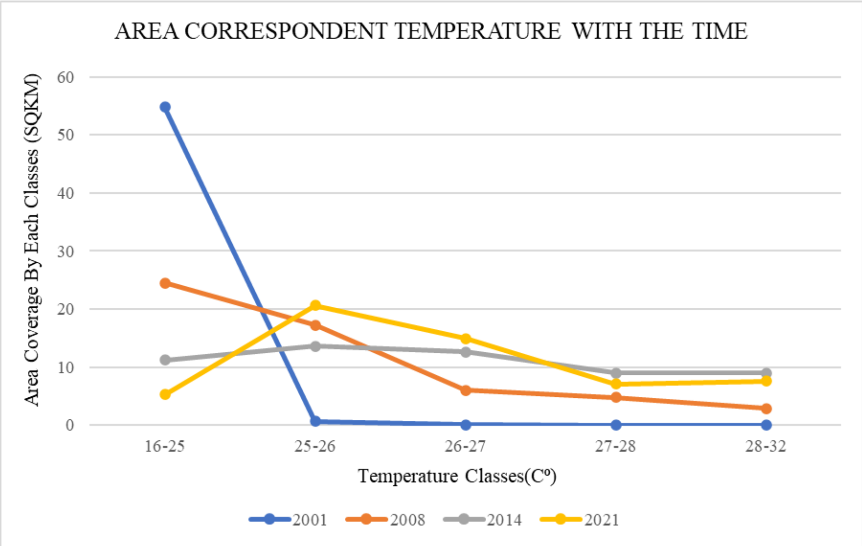


Figure 7: Area correspondent LST with the time

The greatest area correspondent temperature rises over time, as depicted on the graph. In 2001 the highest area corresponded to a temperature range of 16-25 and in 2008 it moved toward up to the 25-26 range finally it approaches 28-32 in 2014 and 2021.Areas with high temperature ranges are increasing, as seen by the four figures above.

The main reason for this can be considered as the large urbanization by centering the Matara Town. In here satellite photos from the years 2001, 2008, and 2021 that were gathered in December of their respective years. However, satellite photos from 2014 were captured in February. Because all the above satellite images were captured in December to February months, it can be considered that all satellite images were in the north-east monsoon duration. For this reason, it can be regarded as the collected satellite photographs under same meteorological circumstances.

Spatial and Temporal Variation of Normalize Difference Vegetation layer

The ideal foundation for identifying vegetation layers is made possible by NDVI. It possesses the capacity to distinguish between different vegetation layers and may also be capable of determining how healthy and green a region is at any time. . Also, for this analysis, select 42 random points considering the vegetation, buildings, and water bodies. Vegetated areas are shown by the NDVI plus values. Same as the non-vegetated areas are shown by the minus values.

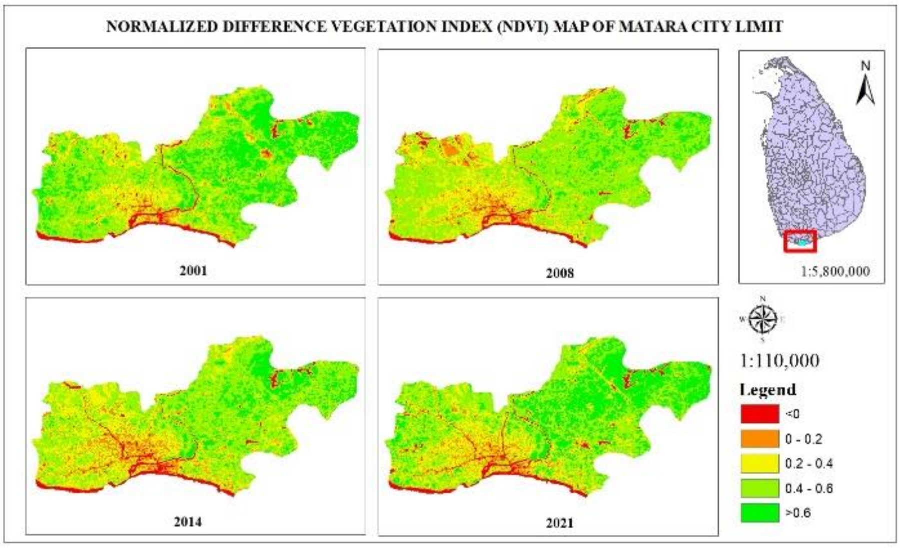


Figure 8 : NDVI map of Matara city limit in 2001, 2008, 2014 and 2021

A large proportion of green space, or vegetation, is depicted in Figure 8 for the Matara district in 2001. Compared to 2001, there was a decline in vegetation in 2008, as seen by the drop in dark green area. In 2008, there was a notable rise in the area of cleared woodland, indicated by the red coloration. Additionally, the town center's dark green area decreased significantly in 2014, while the yellow area significantly increased. The reason for so is that the construction was carried out in tandem with the 2015 Dayata Kirula show. Additionally, by 2021, there is a rise in green space, but overall, there is a decline in green space in Matara's city canter. This is caused by the new development in the city center and the removal of trees.

Spatial and Temporal Variation of Normalize Difference Built up layer

NDBI offers the most effective platform for analyzing and identifying the building layers of a specific area without additional processing steps and time wastage. Furthermore, to get a better idea of the variation of the built-up indexes, it used the reclassify method and divided the groups into two: built-up and non-built-up. Below, a Figure 9 exposes the land area (Sqkm) of built and unbuilt character of the selected area during the past four years (2001, 2008, 2014, and 2021).

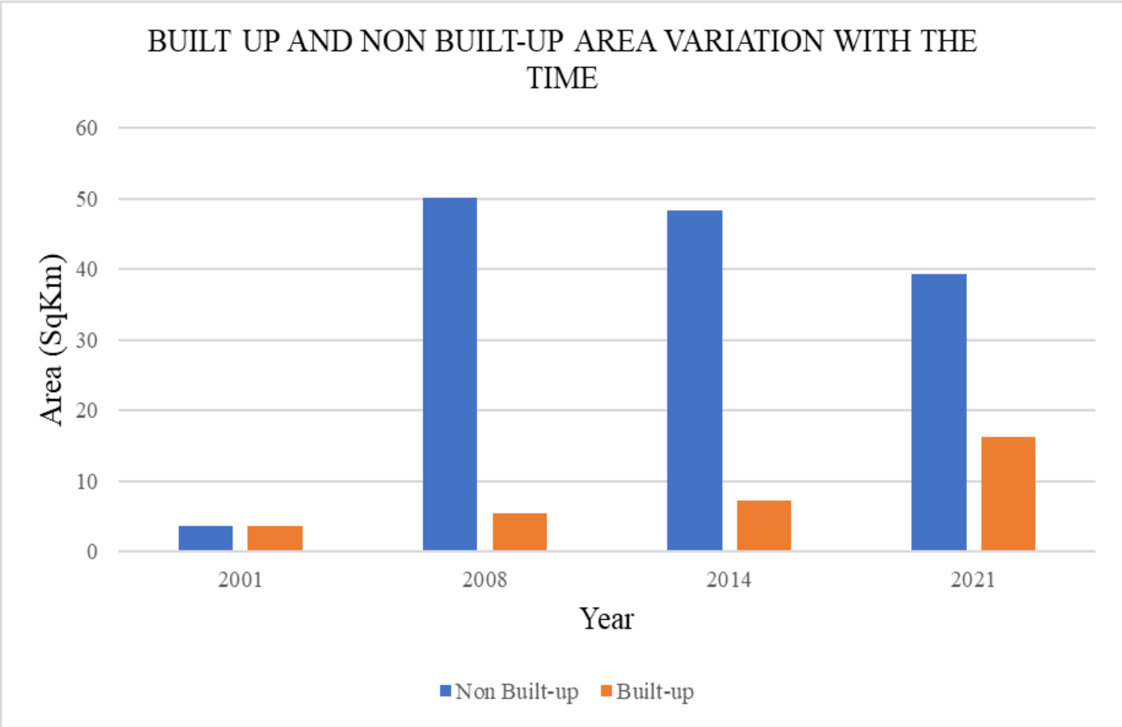
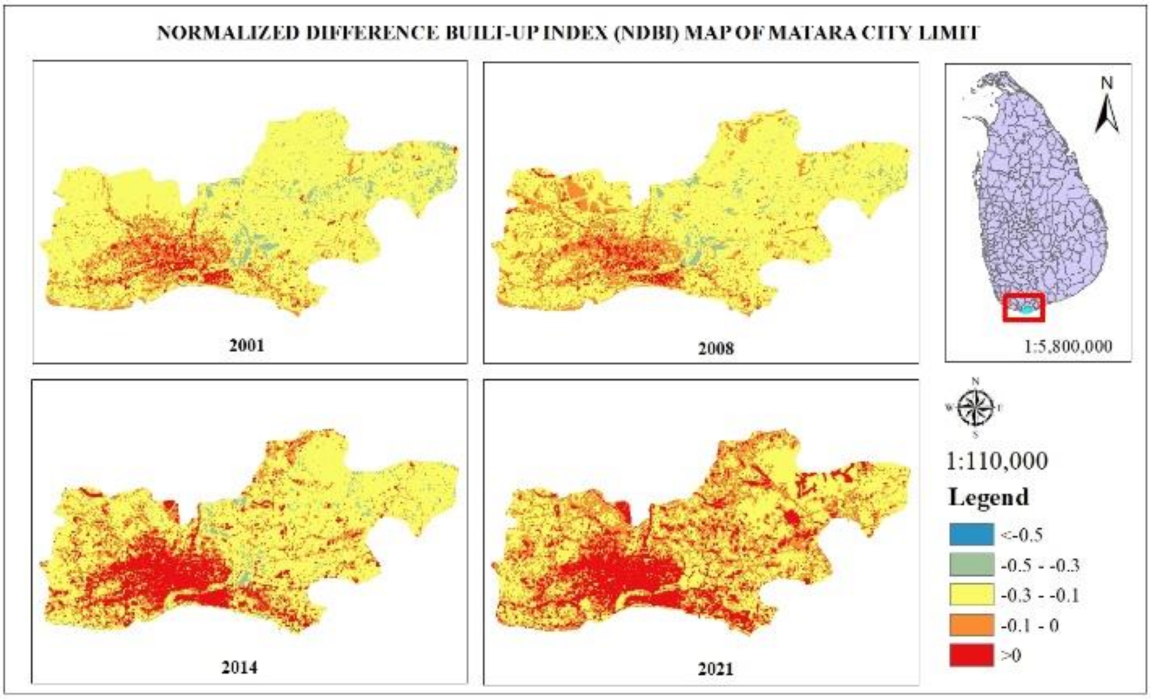


Figure 9 :Built-up and Non-Built-up variation with the time

According to the figure 9, Built-up areas were increased with the time, and non-built-up areas were decreased with the time.

Figure 10 :NDBI map of Matara city limit in 2001, 2008, 2014 and 2021



According to Figure 10, in 2001, the minimum areas consist of the built-ups, which show red color. Non-built-up shows in blue, grey, and yellow colors. When it comes to 2008, it is also similar to the year 2001. Though in 2014, the red color shows the built-up areas, and it was widely expanded up to some level in the center of Matara City due to the construction project of the Dayata Kirula. When it comes to the year 2021, the huge areas consist of built ups.

According to the result, the land surface temperature range of Matara Municipal Council area increased year by year, though when it came to 2014 and 2021, it was getting similar changes in LST ranges because of EL-Nino and La-Nino. Generally, Matara Municipal Council area has been facing huge development at the present. Due to that reason, year by year the surface temperature range of Matara City has been increasing. When considering the spatial and temporal variation of vegetation index and built-up index, it reflects well. As an example, In year 2001, the areas with more built-ups were less than in the year 2021. Because of that, the surface temperature has been increased due to the buildings at the city limit. Further, when considering the vegetation layer variation, it reflects well.

Conclusion and Recommendation

In this study, land surface temperature, vegetation indexes, and built-up indexes in the

Matara municipal council area were analyzed using Landsat ETM+ data. Downloading the Landsat data considering the four years (2001, 2008, 2014, and 2021). When downloading Landsat satellite images, several factors are considered. Some of them are cloud coverage, fluctuation in the monsoon season, and requested Landsat collection. because that can directly impact the results of the studies. This study relates to the temperature. As a result, taking that factor into account can help to mitigate the errors that occurred during the studies. The key bands utilized for this study are thermal, red, SWIR, and NIR. Utilized the Landsat Collection Level 1 data. When preprocessing Landsat images, the method of preprocessing changes according to the type of Landsat. The procedure is the same for Landsat 4-5 and Landsat 7, but it differs for Landsat 8. GIS software is used to prepare maps, and Excel software is used to prepare numerical charts and tables.

Also, Matara District is the city that doesn't have a meteorological station to measure the temperature physically. Due to that, there is no base data set to prove this analysis. It was the Challenging situation to ground truth recorded data. But when considering the results that were taken from this analysis, the surface temperature had been spatial and temporal variation year by year. Other than clearing woodland, there can be other reasons that cause variation of NDVI, such as El-Nino and Lanina situations.

To develop a city, urban heat is one of the most important factors to consider. Therefore, urban heat can rapidly change with urbanization. Through this study, can identify the patterns of how to variate urban heat with urbanization and the impact on Urban Surface Temperature due to urban development. Urban planners play a significant role in urban planning. When considering urban planning, they must know about the patterns of how to change urban heat with urbanization. Through this study, they can mitigate the problems that happen in urban planning. Urban planners can apply this study to identify proper patterns that are suitable for the city in feature development.

It is preferable to obtain released Landsat images with ten-year intervals when using those images. The temperature will then differ significantly. Furthermore, when downloading Landsat satellite images, several factors must be considered. Some of them are cloud coverage, fluctuation in the monsoon season, and requested Landsat collection. because that can directly impact the results of the studies. Furthermore, all the Landsat images must be in same inter monsoon season. Because it was impact to the result of the study. If

Landsat images are used without preprocessing, Landsat collection 1 level 2 data should be used for this study. GIS software was the most suitable platform to analysis of these type of studies. Google Earth software can be used to identify the areas of having more built-up. When preprocessing Landsat images, should apply the specific preprocessing method according to the type of Landsat. Finally recommend when developing the city or urban area, it must consist with Sustainable development and increase the vegetation and green spaces.

Matara District has seen rapid urbanization in recent years. Buildings and the population were directly impacted to the extreme heat in the Matara municipal council area. As a result, when building or constructing roads, use eco-friendly materials and methods. Further, recommend sustainable development for Matara City and increasing green spaces in the city area. By using this analysis data, the future city development of Matara district can be planned. Urban developers can use this data to develop urban areas. This study can be applied to the entire cities of Sri Lan

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