# The Growth of Urban Heat Island Effect Monitored in a Rapidly Developing City of Lombok Island

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**Abstract.** The study aims to monitor urban development around Mataram City and the correlation between Urban Heat Island. Also, analyze the vegetation and built-up changes surrounding Mataram City with Land Surface Temperature (LST) growth. The boundary of the study location is a 25-kilometer radius from the Mataram City centroid. The data used in this research is Landsat 8 Surface Reflectance for the period June-September in 2013, 2019 and 2023 obtained from Google Earth Engine. The Random Forest method is used to obtain land use classification with urban, rice fields, dry land, water bodies, and vegetation. NDBI values are processed from Shortwave infrared (SWIR) and Near-infrared (NIR), NDVI from Near-infrared (NIR) and Red, and LST from thermal bands. The data processing results indicate that Mataram City and its neighboring areas are showing growth, marked by rising NDBI and LST values. This growth is characterized by an expansion of built-up areas to the north, east, and south especially rings 4 and 5, simultaneously by higher NDBI values. Additionally, there is a decrease in vegetation cover, particularly in lowland areas within these rings, leading to a decline in NDVI values. Areas with increased NDBI values also show an increase in LST.

**Keywords**. Urban Heat Island, Land Surface Temperature (LST), Normalized Difference Built-Up Index (NDBI), Normalized Difference Vegetation Index (NDVI), Random Forest.

## 1 Introduction

Surface temperature can increase global temperature because it affects the local climatic conditions of an area. City centers release more heat than rural areas because land that is built up land will absorb solar radiation higher than land that is not built up. The Urban Heat Island (UHI) effect occurs due to temperature disparities between urban and rural areas. Urban areas absorb heat during the day and radiate it at night due to impervious surfaces. Therefore, they are warmer than rural areas which cool down faster at night. [1]. Higher urban density can also influence surface temperatures by affecting the overall level of sunlight exposure and heat exchange between materials.

The impact of Urban Heat Island (UHI) is demonstrated by the expansion of urban areas, elevated surface temperatures compared to surrounding regions, alterations in land cover and use, and pollution. [2]. Anthropogenic activities such as transport, power generation, and various sources of heat contribute to the warming of urban regions. Another factor that contributes to the Urban Heat Island phenomenon is the conversion of natural land into urban areas. [3]. Tropical regions receive ample sunlight consistently throughout the year. However, the presence of the Urban Heat Island (UHI) phenomenon in these areas can have a significant impact on climate change through atmospheric and surface changes, particularly in urban regions. This impact can have adverse effects on human life, especially in terms of comfort, urban air pollution, energy management, and urban planning.

Mataram City is classified as a Special Economic Zone (SEZ) intended for value-added industries. Additionally, it serves as the capital city of West Nusa Tenggara, where the population of Mataram has been consistently increasing every year from 2018 to 2020. The increasing population of Mataram city has the potential to expand the urban area. Urban areas are vital to economic growth with various industrial, commercial, and service activities. For this reason, the special economic zone is set in the city of Mataram.

Urban areas refer to regions where activities other than agriculture take place, with a well-defined arrangement of regional functions that serve as a place for urban settlement, government services, social welfare, and economic activities. Mataram City is one such urban area, with a high population density and various support infrastructure for economic activities. However, this has led to an annual increase in surface air temperature in Mataram and the surrounding areas. It has been recorded that the weather in the city of Mataram and the surrounding area has reached 31-32

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degrees Celsius, which falls into the category of hot temperatures.

This research aims to monitor urban development around Mataram City and the correlation between Urban Heat Island. Also, analyze the vegetation and built-up changes surrounding Mataram City with the growth of land surface temperature.

## 2 Methods

### 2.1 Research Location

This research was conducted by taking 25 kilometers of the surrounding Mataram City as the research location. Mataram is one of the cities in West Nusa Tenggara Province, located in UTM position zone 406465mT to 9051109mU. Mataram covers an area of 61.30 km2, representing 1.3% of the total area of West Nusa Tenggara Province. The study area was created by creating a multi-ring buffer with a radius of 25 km from the Mataram City centroid then divided into five circles (Fig 1). Multi-ring buffer created with a plugin in QGIS software. The ring numbering starts from the Mataram City Centroid, namely ring one and the outermost area is ring five.

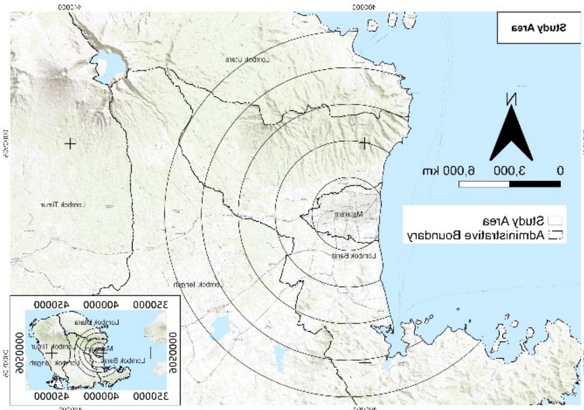

**Fig. 1.** Study Area Boundary Map (Source: Data processing, 2023)

### 2.2 Research Method

#### *2.2.1 Random Forest Land Use Land Cover (LULC) Classification*

Random forest (RF) is a machine learning technique that generates trees, which are then used to generate majority voting (bagging ensemble method). The final output class is determined by a majority vote. The benefit of RF is that it is particularly effective in dealing with the problem of overfitting because the trees or classifiers formed by RF are generated randomly and so are not impacted by overfitting [4]. When inputting data, RF will create subsets of the data as many iterations as are performed. The first subset will create a tree itself (the first tree), the second subset will create the second tree, and so on based on the iterations performed. The tree will produce its classes (class A, class B) and will be voted using majority voting to produce the final class. The accuracy of a random forest model grows with the number of trees until the model begins to converge and no more accuracy gains are obtained. Because each tree in a random forest is trained on a distinct bootstrapped sample of the data, overfitting is reduced [5].

The random forest method is applied for land use classification. The first step is to create training data. The amount of data used for each year is in Table 1. Training data classification into rice fields, built-up land, vegetation, dry land, water body, and urban. Following this, the dataset is split into training and test datasets at a proportion of 80:20. These two data sets must be pre-processed before the actual model is built. The accuracy test of the classification results was performed with a confusion matrix to calculate the overall accuracy value and the Kappa value. The Kappa value indicates the confidence level of the classification results. The target for an excellent kappa value is more than 0.8. The number of trees used for this algorithm is 50 trees. The algorithm employed 50 trees, with the number of trees adjusted to the training data to prevent overfitting. Accuracy results are not always directly proportional to the tree value [6].

#### *2.2.2 Land Surface Temperature (LST) Calculation*

The (LST) was calculated from the Thermal Band 10 using the following formula (i):

$$LST = \frac{T_b}{1+\left(\lambda\, x \frac{T_b}{\rho}\right) x \ln \varepsilon} \quad (1)$$

$T_B$ = temperature brightness in Kelvin
λ = the wavelength of the emitted beam (λ = 10.8 µm, the center wavelength of Landsat 8 Band 10) [7]:
ρ = h × c / s (1,438 × 10-2 m K).
s = the constant of Boltzmann (1,38 × 10-23 J / K).
h = the constant of Planck (6,626 × 10-34 Js).
c = the velocity of light (2,998 × 108 m/s).

In this study, the LST unit value was converted from degrees Kelvin to Celsius (°C) [7]. The LST calculation was based on each Random Forest land use classification. LST values are calculated for each ring to see the change in LST from the Mataram City centroid.

#### *2.2.3 Normalized Difference Buill-Up Index (NDBI)*

The Normalized Difference Built-up Index (NDBI) indicates built-up areas such as buildings, settlements, industries, and roads. The NDBI value can be used to show the urban development of an area and the density of buildings [8]. This index gauges the distinction in reflectance between near-infrared (NIR) and short-wave infrared (SWIR) values to determine development. Developed areas, such as buildings and roads, tend to have lower SWIR reflectance than NIR reflectance, while natural ground surfaces have a smaller difference between these two types of reflectance. The NDBI values are calculated using the following equation (ii):

$$NDBI = \frac{SWIR-NIR}{SWIR+NIR} \quad (2)$$

SWIR = Shortwave infrared
NIR = Near-infrared

Landsat 8 utilizes band 6 to capture SWIR and band 5 for NIR according to source [9]. Negative NDBI values are indicative of water bodies, while NDBI values close to zero are typical of vegetation areas. Built-up areas are detected by positive NDBI values [10]. The NDBI values are calculated for each ring to determine the change in NDBI from the centroid of Mataram City.

### *2.2.4 Normalized Difference Vegetation Index (NDVI)*

The Normalized Difference Vegetation Index (NDVI) is a method of assessing whether green, live vegetation is present on the target surface. The NDVI value is strongly influenced by the chlorophyll content of a plant. NDVI analyses the difference value of surface reflectance that captures near-infrared (NIR) light and the RED band. Healthy, green plants can absorb red light and reflect NIR light. Therefore, areas with good vegetation will have a high NDVI value. The NDVI calculation is linked to the red and near-infrared bands because of the different spectral characteristics of vegetation (iii) [10]:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (3)$$

NIR = Near-infrared
RED = Red

Landsat 8 satellite uses band 4 to capture the red light spectrum and band 5 to capture the near-infrared light spectrum. Negative or close-to-zero NDVI values are detected for areas covered by water. On the other hand, small positive NDVI values are detected for bare soil, and a higher positive NDVI value is detected in vegetation. The NDVI values are calculated for each ring to determine the change in NDVI from the centroid of Mataram City.

## 3 Result and discussion

### 3.1 Land Use Land Cover (LULC) Classification

From the calculation shown in Table 1, the Kappa coefficient of the LULC classification in 2013 was 0.9, LULC in 2019 was 0.99, and LULC in 2023 was 0.83. However, the spatial resolution of the imagery used in the classification is low 30 meters, which is one of the factors in producing these figures. Moreover, the interpretation of the Kappa coefficient by Landis and Koch states that the results fall into the substantial category with a range of greater than 0.80 [11]. In other words, the Kappa coefficient from the accuracy test results on the 2013, 2018, and 2023 LULC classifications is classified as good. For this reason, the LULC classification in this study can be used for further analysis [12].

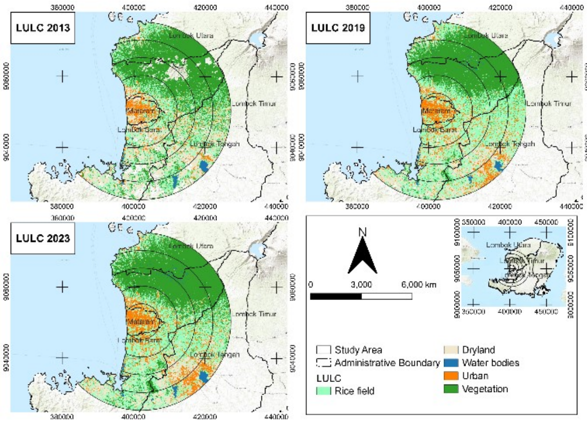


**Fig. 2.** LULC time series distribution (Source: Data processing, 2023)

**Table 1.** Confusion Matrix of LULC

| Year | Sample size | Overall Accuracy (%) | Kappa (%) |
|---|---|---|---|
| **2013** | 415 | 93 | 0,90 |
| **2019** | 401 | 99 | 0,99 |
| **2023** | 418 | 87 | 0,83 |

Based on the map in Figure 1, it can be explained that there are changes in land use every year. The northeast of Mataram City is Mt. Rinjani, the western part of the city borders the sea, and the physiography of the plains is east to south of Mataram City. Land use changes for built-up areas in Mataram City have been expanding towards the north, east, and south. The amount of built-up land is increasing every year. In addition, it is obtained that there is an expansion in the Central Lombok region with a relative position southeast of Mataram City. Vegetation land use is decreasing each year for the plain areas. Vegetation changes have dominated in the lowland areas, except for the Gunung Rinjani National Park area. Land use changes for water bodies are due to differences in reservoir water capacity in that year.

The dominant land use in the study area is shown in Table 2. Ring 1 is dominated by urban areas in all years, ring 2 is dominated by rice fields in all years and rings 3 and 4 are dominated by vegetation in all years. There was a change in the dominance of land use in Ring 5 in 2019, with most land use being rice fields, which were originally vegetation.

**Table 2.** Major land use classification

| Distance (Km) | 2013 | 2019 | 2023 |
|---|---|---|---|
| **0-5** | Urban | Urban | Urban |
| **5-10** | Rice field | Rice field | Rice field |
| **10-15** | Vegetation | Vegetation | Vegetation |
| **10-20** | Vegetation | Vegetation | Vegetation |
| **20-25** | Vegetation | Rice field | Vegetation |

### 3.2 Normalized difference vegetation index (NDVI)

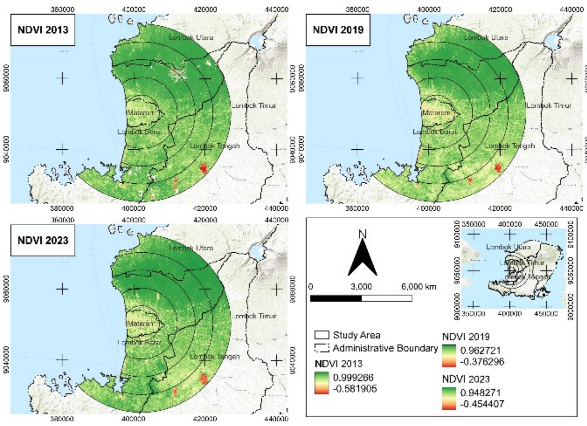


**Fig. 3.** NDVI time series distribution (Source: Data processing, 2023)

The presence of vegetation has a significant role impact on lowering environmental temperatures. It can alleviate the urban heat island (UHI) effect by as much as 24°C. [13]. This cooling effect is because vegetation emits less energy due to evapotranspiration and absorbs less shortwave radiation [14].

The results of the NDVI data processing are shown in Figure 3. From the figure, it can be explained that the maximum NDVI value decreases each year. The maximum NDVI value in 2013 was about 0.99, decreased to 0.96 in 2019, and the lowest value in 2023 was 0.94. The decrease is due to changes in vegetation density in the study area. Dryland use can reduce NDVI values. This can be seen in the southeastern area of Mataram city, which is shown in a yellowish color. This color has a low NDVI value. The use of dry land increased in 2019 and 2023. Dryland and rice fields do not have a cooling effect on the site and do not reflect NIR waves as well as vegetation. The spatial distribution of NDVI shows that high NDVI values are in rings 2 and 3 with 5-15 kilometers for 2013. The color of NDVI is getting fainter, which shows that vegetation density is decreasing in rings 2 and 3 in 2019 and 2023.

However, vegetation is a less potent factor of LST variance, especially when considered over long periods. This is because vegetation undergoes a phenological process, i.e., its growth and development cycle vary with the seasons. For example, [15] found that vegetation only contributes to the surface UHI during the summer and early fall seasons. The seasonal influence of vegetation effects can vary depending on specific local conditions. In this study, this factor was minimized by choosing the same image recording time, namely during the dry season (June-September) for each year. Variations in UHI effects are caused by differences in vegetation types [16]. For example, evergreen vegetation may be a more robust indicator of LST/UHI than deciduous vegetation. However, the study site has only two seasons, the dry season, and the wet season. Vegetation can be used to explain the UHI phenomenon, but it is not an absolute parameter and needs to be combined with other parameters [15].

### 3.3 Normalized difference built-up index (NDBI)

Urbanization and the conversion of natural land to built-up areas are the primary factors that contribute to the urban heat island effect (UHI). This phenomenon occurs due to the high prevalence of non-permeable surfaces, which prevent water vapor from escaping. Consequently, heat from the sun is trapped, leading to a significant increase in temperature in urban areas compared to their rural counterparts.

Under cloudless skies, arid urban surfaces can reach temperatures as high as 88°C, while vegetated areas with low moisture can be as cool as 18°C under the same conditions. [17]. Dark-colored materials in narrow city streets retain more of the sun's energy, exacerbating the UHI effect. [18]. Extensive research has been conducted to identify urban growth patterns and evaluate their impact on the UHI effect in cities. Figure 4 has shown that urban growth can lead to significant increases in the UHI effect and that it is important to manage urban growth in a way that minimizes this impact.

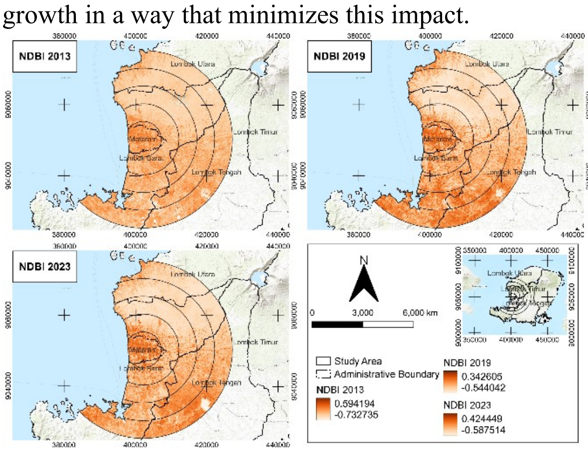


**Fig. 4.** NDBI time series distribution (Source: Data processing, 2023)

The results of the NDBI data processing are shown in Figure 4. Based on the map, it can be explained that the maximum NDBI value fluctuates, but the spatial distribution shows that the wider the area, the greater the NDBI value. This area is on the southeast side of Mataram city. Apart from that, based on the NDBI value, it can be explained that the City of Mataram, which is in ring 1 of the study area, experienced an expansion in the NDBI value, which is indicated by a higher value in orange. Expansion is radial from the city

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center. The spatial distribution of NDBI shows that high NDBI values are in ring 1 with 0–5 kilometers for 2013, shown in solid orange. In 2019 and 2023 high NDBI values extending to rings 4 and 5 (10-25 kilometers) are shown in dark orange.

### 3.4 Land surface temperature (LST)

The spatial distribution of the Land Surface Temperature (LST) can be seen in Figure 5. The map shows that the range of minimum and maximum values is quite large. The minimum value ranges from 24-25oC and the maximum value ranges from 59-64oC. The maximum value does not represent the whole area, but only one object. On the map, it can be explained that there is an expansion of LST values in the study area. The expansion of LST values is shown in Mataram City's center and the study area's southeast area (Praya District, Lombok Tengah Regency). Even though these two areas are urban areas that are rapidly- developing, currently most of their buildings have bright-colored roofs. The choice of roof material is an important consideration, as dark-colored roofs absorb more heat while lighter colors reflect it. Implementation of the green roof concept that has been established by the local government of Mataram City can prevent surface temperature heating.

The northern region of the study area does not indicate an expansion of LST value (Figure 4). This is due to the physiographic shape of the mountains near Mount Rinjani National Park. The area is a protected area where no urban development is allowed, and it borders the sea and is narrow. Unlike the northern region, the southeastern region tends to have a flat physiography that allows land conversion into built-up areas.

The expansion of LST values can be seen by comparing the values each year. In 2013, LST values tended to be dominated by ring 1, with the main land use being urban areas. Quite drastic changes are shown in ring 4 and ring 5 by comparing each year. In 2013, ring 4 and ring 5 of LST values still tend to be yellow and orange. Meanwhile, in 2019 and 2023, the LST values show drastic color changes to red.

The average LST of each ring is shown in Figure 5 which can be explained that the first ring 0-5 kilometers from the city center point has the highest value compared to the outer ring. By comparing each ring area in the same year, the farther the area from the city center shows the lower the average LST value. The result also shows that in 2019, Mataram City and the rural area surrounding it showed the lowest LST between the period of 2013 to 2023.

The LST values cannot represent all areas due to the presence of clouds at the study site which must be removed for the data to be representative. The LST values obtained only represent the dry season of the year with the time intervals of September 2013, 2019, and 2023.

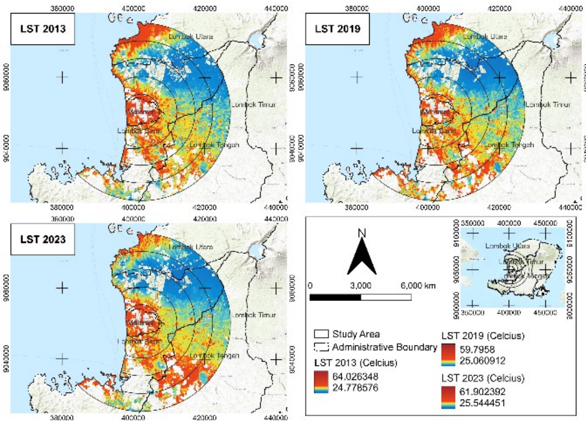


**Fig. 5.** LST time series distribution (Source: Data processing, 2023)

### 3.5 Urban heat island growth

Urban Heat Island (UHI) intensity is typically measured as the temperature difference between urban and rural areas. To accurately assess UHI, some researchers recommend using landscape classification systems that consider urban and local climate zones. This approach enables the analysis of temperature differences between different zones and provides a more comprehensive understanding of UHI intensity. [19]. In this study, the urban climate zone of Mataram City is in the surrounding area represented by every circle, namely parts of North Lombok, West Lombok, and Central Lombok.

According to the LST measurement, the region within the first ring of Mataram City exhibits higher Land Surface Temperature (LST) values as compared to its surrounding areas. This leads to the Urban Heat Island (UHI) phenomenon, which is characterized by a temperature disparity between urban and rural regions. The distribution of UHI is not only found in Mataram City but also occurs in Praya District, located southeast of Mataram City, indicated by the red LST color (Fig 5). The Praya District of Central Lombok Regency shows an increase in LST values from 2019 to 2023 compared to 2013. Praya District, as the capital of Central Lombok Regency, also experienced a transition from natural land to built-up areas. These built-up areas are associated with roads forming a linear pattern for residential and commercial sectors [20]. Praya District is an area with high levels of development but still falls within a region with low income. Praya District supports Lombok City and is located along the main road. It is reasonable that the increase in built-up land use follows a linear pattern along the road [21].

Mataram City holds a strong appeal for urban tourism. The supporting facilities, including a total of hundreds of five-star hotels, have consistently increased [22]. The surge in hotel development is naturally accompanied by the construction of supporting infrastructure. The allure of urban tourism undoubtedly attracts a diverse range of both local and international tourists. This sector certainly requires built-up land to operate. This situation propels changes in built-up land

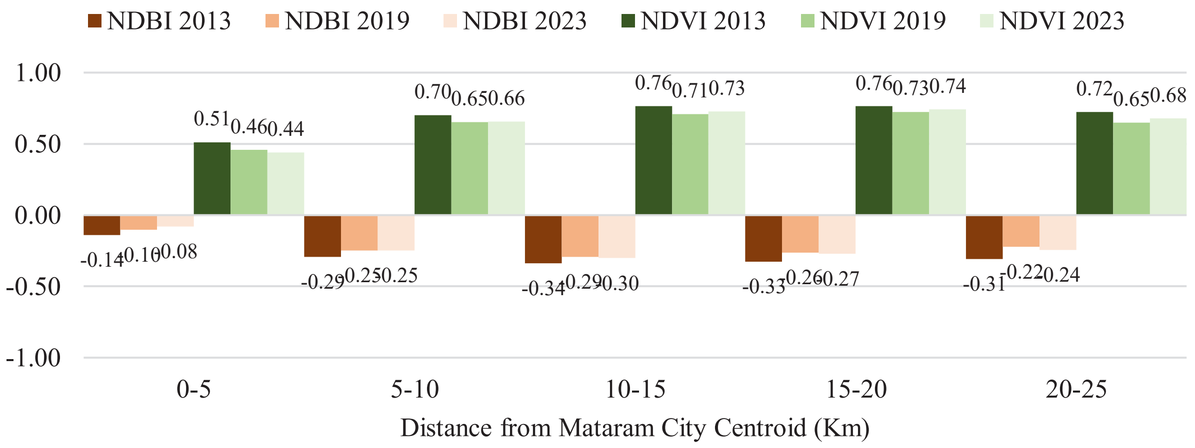


**Fig. 6.** Average NDBI and NDVI 2013, 2019, and 2023

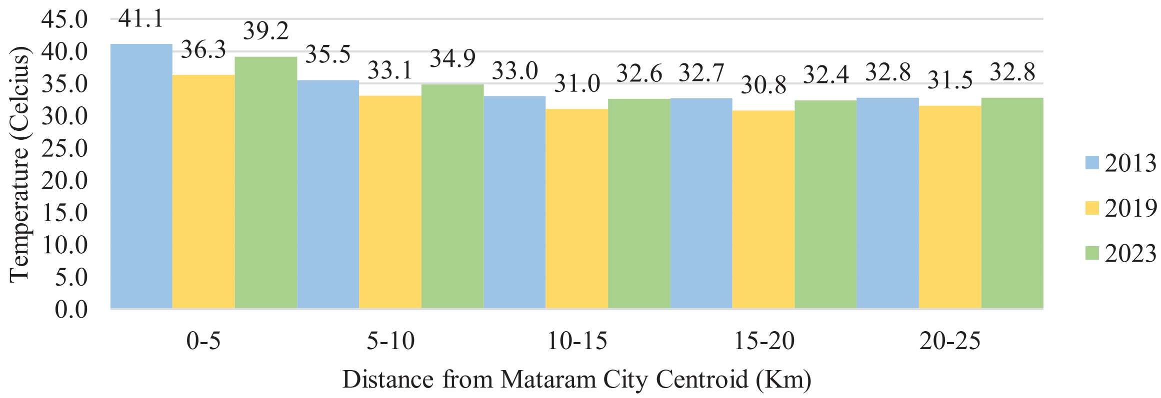


**Fig. 7**. Average Land Surface Temperature 2013, 2019, and 2023

use. The areas surrounding Mataram City, have their charm due to the various central service facilities available in the city of Mataram. The services and facilities in these centers stimulate population movement and contribute to various other economic resources flowing into Mataram City.

Based on the graph (Fig 6), it can be explained that the trend of built-up land density in the study area is increasing each year. This is indicated by the Normalized Difference Built-Up Index (NDBI) shifting towards positive values. The NDVI values decrease each year, shifting towards negative values. This condition represents a decreasing vegetation density. Both phenomena trends occur for all five rings in the study area.

Studies have shown that there is a significant inverse correlation between NDVI and NDBI. NDBI has a direct impact on the LST value. This is because built-up areas produce extra heat and contribute to the urban heat island effect. The highest temperature of LST is observed when NDBI is high. A higher NDVI indicates lower temperatures. Vegetation cover has a significant impact in alleviating the urban heat island phenomenon [23]. Other common factors that influence urban heat islands are vegetation, seasons, built-up areas, population density, and water bodies. The LST value is a function of each factor that affects the urban heat island.

## 4 Conclusion

The analysis of Land Use and Land Cover using Random Forest Classification shows annual changes in land use in Mataram City and its surrounding areas from 2013, 2019, to 2023. The city of Mataram and its surroundings are showing urban growth characterized by increasing NDBI and LST values. The area around Mataram City that is currently showing the most rapid growth is Praya Sub-district, which is in ring four and ring 5. The land change occurred with an increase in the built-up area towards the north, east, and south in Ring 4 and Ring 5, associated with an increase in NDBI values. Meanwhile, there was a decrease in the area covered by vegetation, especially in lowland areas in Ring 4 and Ring 5, which is associated with a decrease in NDVI values. Areas with increased NDBI values observed an increase in LST.

## 5 Recommendation

One solution for mitigating the Urban Heat Island (UHI) phenomenon is to create roofs designed to reflect more sunlight and have high thermal emissivity, known as Cool Roofs [24]. Cool roofs are a term used to refer to roof coatings that can reflect sunlight, thus reducing overall air temperature. The choice of roof material is an important consideration, as dark-colored roofs absorb more heat while lighter colors reflect it. Most buildings in Mataram City currently use bright-colored roofs, while only some educational buildings still have dark-colored roofs.

The primary issues with high heat reflectance roofs are the high paint cycle costs and the extensive maintenance required due to being under variations in the weather [25]. To improve performance, suitable technology design for roof types and local climate conditions is required. Cool roof materials can be made from various substances such as asphalt, tile, metal, membranes, modified bitumen, and roof coatings [26]. The effectiveness of cool roofs is determined by the 'albedo' present in the roof material, which is the ability to absorb or reflect light, influenced in part by the roof color. Cool roofs can also reduce CO2 and other electric emissions associated with AC usage, but the light reflection on the roof due to high albedo values can create glare.

Implementing the concept of green roofs is one way to incorporate architecture into a building to reduce temperature rise in an environment. The continued growth and development of Mataram, particularly after it became a Special Economic Zone, has resulted in a deficiency of green spaces within urban areas. As a solution, multiple building contractors have begun constructing residential areas centered around the concept of green roofs. A green roof is essentially a roof surface that is covered in vegetation and growing materials, which are planted across waterproof membranes and layered accordingly [27]. The term green roof is also known as an eco-roof. Buildings adopting the green roof concept are specially designed and integrated. With these green roofs, a drainage system can be established across the roof surface to channel water from the plants. Most buildings in Mataram have not yet embraced the green roof concept; only a few settlements have implemented it, such as the Green Asia residential area in Sikumbang, West Lombok Regency.

The local government of Mataram City has initiated the promotion of the "1 House 1 Tree" program and the green roof concept, which aims to increase the prevalence of green roof settlements to prevent surface temperature heating. Considering that Indonesia is a country located along the equator, certain months experience extremely hot weather. Given the functions and benefits of green roofs in reducing indoor temperature levels, it is highly recommended to implement the green roof concept.

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## References

1. P. Mwangi, F. Karanja, P. Kamau, Analysis of the Relationship between Land Surface Temperature and Vegetation and Built-Up Indices in Upper-Hill, Nairobi. Journal of Geoscience and Environment Protection, **6**, 1-16 (2018)
2. X. Li, Y. Zhou, S. Yu, G. Jia, H. Li, W. Li, Urban heat island impacts on building energy consumption: A review of approaches and findings. Energy, **174**, 4017–419 (2019)
3. Y. Yamamoto, Measures to mitigate urban heat islands. NISTEP Science & Technology Foresight Center (2006)
4. P. Danoedoro, S.H. Murti, Land Cover/Land Use Classification of Landsat-8 OLI Data Using the Random Forest Method (in bahasa). Jurnal Penginderaan Jauh Indonesia, **3**(1), 1–7 (2021)
5. B. Rimal, L. Zhang, H. Keshtkar, N. Wang, Y. Lin, Monitoring and modeling of spatiotemporal urban expansion and land-use/land-cover change using integrated Markov chain cellular automata model. ISPRS International Journal of Geo-Information, **6**(9), 288 (2017)
6. F. Cánovas-García, F. Alonso-Sarría, F. Gomariz-Castillo, F. Oñate-Valdivieso, Modification of the random forest algorithm to avoid statistical dependence problems when classifying remote sensing imagery. Computers & Geosciences, **103**, 1-11 (2017)
7. R.C. Estoque, Y. Murayama, Monitoring surface urban heat island formation in a tropical mountain city using Landsat data (1987–2015). ISPRS Journal of Photogrammetry and Remote Sensing, **133**, 18–29 (2017)
8. T. Mahesti, K.D. Hartomo, S.Y.J. Prasetyo, Application of the Random Forest Algorithm in Analyzing Surface Temperature Changes in the Salatiga City Area (in bahasa). Jurnal Media Informatika Budidarma, **6**(4), 2074–2085 (2022).
9. N. Kikon, P. Singh, S.K. Singh, A. Vyas, Assessment of urban heat islands (UHI) of Noida City, India using multi-temporal satellite data. Sustainable Cities and Society, **22**, 19–28 (2016)
10. X. Zhang, R.C. Estoque, Y. Murayama, An urban heat island study in Nanchang City, China based on land surface temperature and social-ecological variables. Sustainable Cities and Society, **32**, 557–568 (2017)
11. J.R. Landis, G. G. Koch, The measurement of observer agreement for categorical data. Biometrics, **33**(1), 159-174 (1977)
12. M. Kusuma, P. Susongko, Y. Arfiani, Validation of the Instruments of Learning Readiness With E-Learning Using Rasch Modeling To Empower Technological Content Knowledge (Tck). Jurnal Pena Sains, **6** (2019)

13. Z. Tan, K.K.L. Lau, E. Ng, Urban tree design approaches for mitigating daytime urban heat island effects in a high-density urban environment. Energy and Buildings, **114**, 265–274 (2016)
14. J.P. Kim, J.M. Guldmann, Land-use planning and the urban heat island. Environment and Planning B: Planning and Design, **41**(6), 1077–1099 (2014)
15. F. Yuan, M.E. Bauer, Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. Remote Sensing of Environment, **106**(3), 375–386 (2007)
16. B. R. Luz, J.K. Crowley, Spectral reflectance and emissivity features of broad leaf plants: Prospects for remote sensing in the thermal infrared (8.0–14.0 μm). Remote Sensing of Environment, **109**(4), 393–405 (2007)
17. L.M. Gartland, Heat islands: understanding and mitigating heat in urban areas. Routledge (2012)
18. P. Shahmohamadi, A.I. Che-Ani, K.N.A. Maulud, N.M. Tawil, N.A.G. Abdullah, The impact of anthropogenic heat on formation of urban heat island and energy consumption balance. Urban Studies Research, 2011 (2011).
19. I.D. Stewart, T.R. Oke, Local climate zones for urban temperature studies. Bulletin of the American Meteorological Society, **93**(12), 1879–1900 (2012)
20. B. Evangelista, B.I.W. Utary, Implementation of Central Lombok Regency Government Policy on Regional Spatial Management (in bahasa). Jurnal Pendidikan dan Konseling (JPDK), **5**, 3835-3844 (2023)
21. S. Hartati, Development Inequality Analysis Between District and Identification of the Leading Economic Sector. International Journal of Multicultural and Multireligious Understanding (IJMMU), **8**, 442-450 (2021)
22. R. Kurniansah, M.S. Khali, Availability of Tourism Accommodation in Support of Urban Tourism as a Tourism Attraction in Mataram City, West Nusa Tenggara Province. Jurnal Bina Wakya, **1**, 39-44 (2018)
23. M.S. Malik, J.P. Shukla, S. Mishra, Relationship of LST, NDBI and NDVI using landsat-8 data in Kandaihimmat watershed, Hoshangabad, India. Indian Journal of Geo-Marine Sciences, **48**, 25-31 (2019)
24. V.R. Khare, A. Vajpai, D.A. Gupta, Big picture of urban heat island mitigation strategies and recommendation for India, Urban Climate, **37** (2021)
25. M. Seifhashem, B. Capra, W. Milller, J. Bell, The potential for cool roofs to improve the energy efficiency of single storey warehouse-type retail buildings in Australia: A simulation case study, Energy and Buildings, **158** (2017)
26. H. Elnabawi, Mohamed, A. Alhumaidi, B. Osman, R. Alshehhi, Cool Roofs in Hot Climates: A Conceptual Review of Modelling Methods and Limitations. Buildings, **12**, (2022)
27. Y. Rahayu, Green Roof Concept Analysis and Simple Design Modeling. Vitruvian, **10**(1), (2020)