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The Impact of Urban Green Space on The Urban Heat Island Phenomenon – A Study Case in East Jakarta, Indonesia

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Abstract

The urban heat island (UHI) phenomenon has grown disastrous in many major cities across the world, including Jakarta. The more cities worldwide that suffer this scenario, the faster global warming will occur, making it a global concern that has to be given priority. The goal of this study was to determine the distribution of UHI in each region and how land use planning may mitigate it. East Jakarta was found to have the highest UHI in Jakarta. The method of this study used spatial analysis, which consists of land surface temperature (LST) and normalized vegetation difference index (NDVI) using GIS. The analysis results showed that the area with the highest LST and the widest coverage of UHI in East Jakarta is in Cakung where the temperature has increased to 4°C, while the area with the lowest LST and the narrowest coverage of the UHI area is Cipayung. Meanwhile, Cipayung has the most urban green space and urban forest, making up roughly 5.6% and 1.96% of its area, while Matraman has the least, making up 1.09% of its area without any urban forest. Therefore, there are no areas in East Jakarta that meet the requirements of 10% urban forest and 30% green space. However, the region with the lowest UHI distribution is Cipayung, which has the greenest urban area. It shows how the presence of urban forests, affects the distribution of UHI in metropolitan areas.

1. Introduction

City climate is the result of the interaction of natural factors and anthropogenic factors which cause climate differences in the city and the surrounding area, due to the varied physical surfaces resulting in varying surface behavior patterns in terms of radiation, absorption, evaporation, and release of heat (Bokaie et al., 2016; Hassan et al., 2021). Two factors affect the city's climate, namely natural factors, and anthropogenic factors. Natural factors are divided into two scopes, namely the macro scale caused by latitude and the meso scale caused by land topography and water bodies, while anthropogenic factors consist of urban surface materials, as well as air pollution and emissions from transportation and industry (Sanger et al., 2016). However, the most important causes of urban climate change are changes in land use and population growth through urbanization (Atasoy, 2020; Bokaie et al., 2016; Song et al., 2020; Buchori et al., 2022; Dewa et al., 2022).

Cities are the centers of global development, increasing environmental change on a global scale in a number of ways, including through changes in land use and cover, which will have an impact on raising the average anomaly of land surface temperature in urban areas (Li et al., 2021; Mohammad & Goswami, 2022). Jakarta is the nation's capital which has a strategic location. According to (Rahmawati et al., 2018), urban development activities in Jakarta, which act as the capital and the center of government, economy, and industry, will affect decreased environmental quality. The decline in environmental quality is marked by increasing air pollution and the occurrence of urban heat islands (UHI). Microclimate change in urban areas is one of the triggers for the phenomenon of global warming.

The risk of uncontrolled urban expansion is what causes the UHI phenomenon (Mirzaei, 2015; Mirzaei et al., 2012). Cities would still face the issue of rising temperatures even if the global climate stays the same (Hassan et al., 2021). The UHI phenomenon tends to have a greater impact on areas dominated by built-up land, so the UHI phenomenon has become a scourge in many cities in the world, including Jakarta. This is because the rate of global warming will increase rapidly (Rushayati & Hermawan, 2013). Then this will cause a significant decrease in environmental quality, resulting in a decrease in the productivity of urban communities. One alternative to addressing the UHI problem in the city is to build urban green spaces containing vegetation types that have large carbon absorption capabilities because trees can reduce the temperature by direct shading or evapotranspiration (Yang et al. 2005).

Based on studies by (Saputra et al., 2021), the calculation of LST in Jakarta produces a different value every month, with the highest LST value in the eastern part of Jakarta. The contributing factors to the cause of UHI in Jakarta are due to increased CO2 emissions and the expansion of urban areas (Rushayati & Hermawan, 2013; Wati & Fatkhuroyan, 2017). According to Lee et al. (2015), Green space in urban areas is considered a solution to control urban problems in urban planning. However, the problem that is becoming a hot issue in Jakarta now is the lack of green areas in urban forests, city parks, and green belts. The quality of life in urban areas can be measured by the amount of green space they have (Wright Wendel et al., 2012).

The urban greening program in Indonesia has been regulated in Law number 26 in the year 2007 which instructs local governments to plan the development of urban green space with a target amount of 30% of each area. Article 29 paragraph 1 states that public green space is a green area that is owned and managed by the local government and utilized for the benefit of the community, whether in the form of city parks, urban forests, cemeteries, or green belts. According to the study by Setiowati et al. (2022), there are 3,474 hectares of green space in Jakarta, making up 5.3% of the city's total urban green space, which is still low because Jakarta hasn't been able to reach the established urban green space ratio standard of 30%.

Therefore, this study aimed to examine the impact of the presence of urban green spaces on urban heat island phenomenon to provide sustainable land management direction to support spatial planning. This is important because in the future, the population will keep growing and the demand for land will continue to increase, but in terms of land conditions is limited. By looking at settlement patterns as the basis for land sustainability, the study result is expected to help provide an overview of the character and future of urban areas, especially in terms of sustainable land use. This study is needed because there are no studies related to urban heat islands on a region scale in Jakarta, because most studies related to urban heat islands and urban green space have been carried out on the wider scale of the DKI Jakarta as a province. This is because land use in each region is different with different population growth, so the study case with a smaller scope is needed to design efficient urban planning in accordance with changes in the surrounding microclimate.

2. Data and Methods

2.1. Study Area

The research location is in East Jakarta, the largest area in Jakarta, with an area of 188 km^2 or 28.4% of the total area of Jakarta, with a population of 3,056,300 people and a population density of 16,550 people/km^2. Administratively, the city of East Jakarta consists of 10 districts that showed on Figure 1, namely Pasar Rebo, Ciracas, Cipayung, Makasar, Kramatjati, Jatinegara, Duren Sawit, Cakung, Pulo Gadung, and Matraman. The district is in the eastern part of Jakarta and is bordered by North Jakarta to the west, South Jakarta to the southwest, and West Java to the east.

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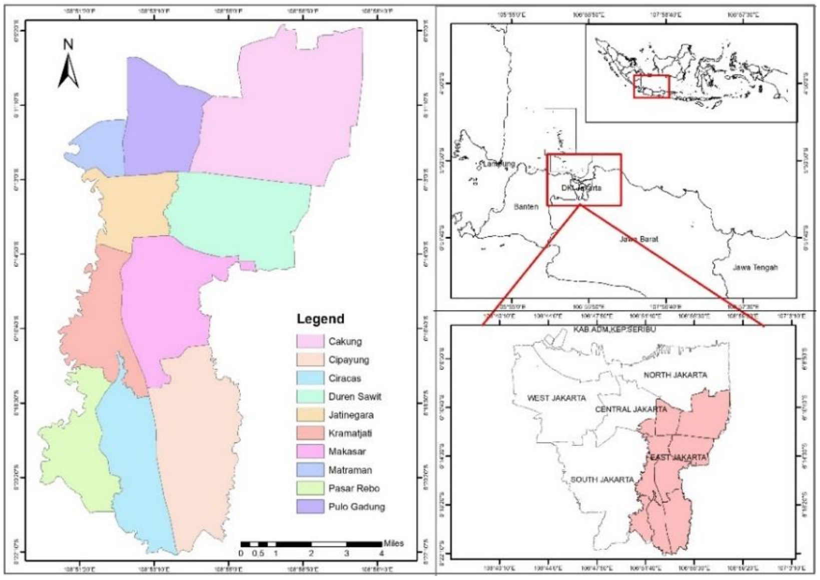


Source: Geospatial Information Agency, 2023

Figure 1. The Map of East Jakarta

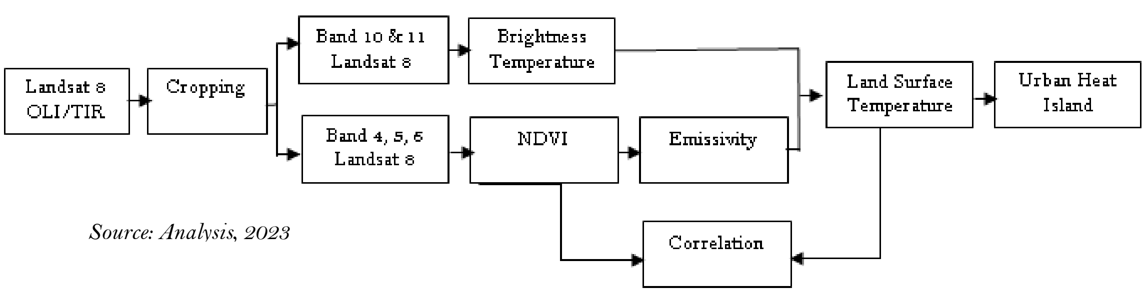
In recent years, East Jakarta has experienced steady population growth, driven by factors such as urbanization, migration, and natural population increase. The district has a relatively high population density with many densely populated neighborhoods and urban areas, it has resulted in the development of high-rise buildings and industrial estates. Many new residential areas have also been developed to accommodate the growing population, which has led to an increase in the demand for infrastructure and public service. It also makes East Jakarta known as the city with the largest number of workers among other regions, namely 28.7% of the total number of workers in Jakarta. This is because the city of East Jakarta has several large industrial areas, such as Pulogadung Industrial Estate in Cakung.

2.2. Data Collection

This study used Landsat 8 Thermal Infrared Sensor (TIRS) remote sensing imagery of the L1TP data type recorded for July 2020 and 2022 obtained from the United States Geological Survey (USGS) website to analyze UHI distribution and vegetation density. As for urban green space data, it was obtained from the Spatial Planning Agency, which was reprocessed using ArcGIS 10.4.

2.3. Data Analysis

A correction step which included radiometric calibration, that needed to obtain UHI distribution data. Based on metadata, this Landsat 8 OLI/TIRS imagery is equipped with geometric correction based on GCP (Ground Control Point) data that used the analysis flow in Figure 2.



Source: Analysis, 2023

Figure 2. Analysis Flow

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Radiometric calibration is a process of transforming image pixel values to obtain radian or reflectance spectral values, and to obtain UHI distribution data, the calibration is performed by transforming radian values so that the DN values of the images contain information about temperature. As for the steps:

1. The Digital Number (DN) of Landsat 8 band 10 satellite imagery is converted to a radian spectral value according to the Eq. 1:

$$L\lambda = (ML) * (DN) + AL - Oi \ldots\ldots\ldots (Eq.1)$$

   ML and AL: emission factor value from metadata; DN = pixel value; and Oi = constant value for band 10, namely 0.00108

2. Emissivity is the capacity of city materials that affect thermal conditions to determine the reflection and absorption of solar energy. Evaluation of values using the Normalized Difference Vegetation Index (NDVI) and Proportion Vegetation (PV) (Eq. 2) methods,

$$PV = \left(\frac{NDVI - NDVImin}{NDVImax - NDVI\ min}\right) \ldots\ldots\ldots (Eq.2)$$

   Land emissivity values vary according to the heterogeneity of vegetation, soil, humidity, roughness, and viewpoint with energy (Eq. 3).

$$\varepsilon = 0{,}004 * PV + 0{,}98 \ldots\ldots\ldots\ldots (Eq.3)$$

3. The radiance value is considered unable to represent the temperature value, so that value needs to be converted into a brightness temperature value (BT) (Eq. 4) obtained from actual temperature values recorded by remote sensing from the following equation:

$$BT = K2/\ln(K1L\lambda + 1) - 273{,}15 \ldots\ldots\ldots (Eq.4)$$

4. NDVI (Eq. 5) is a parameter for measuring the greenness of vegetation obtained from processing the brightness values of several channels of satellite sensor data, so to determine the density of vegetation in an area it is necessary to carry out a comparison process between the brightness levels of the red-light channel and the near-infrared light, channel. infrared), which is calculated based on the equation:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \ldots\ldots\ldots\ldots (Eq.5)$$

   Then NDVI will provide illustrations of vegetation in raster pixels and provide the land composition to obtain emissivity values, where NDVI values close to 1 indicate land with dense vegetation and values close to -1 indicate land with less dense vegetation or water.

5. And then, the LST (Eq. 6) can be calculated using the equation:

$$LST = BT/\left(1 + \left(\lambda * \frac{BT}{c^2}\right)\right) * \ln(\varepsilon) \quad \ldots\ldots\ldots (Eq.6)$$

   BT = brightness temperature
   λ = wavelength,
   c = the speed of light ($2.998 \times 10 - 8$ Ms $- 1$),
   ε = planck constant ($1{,}38 \times 10 - 23$JK $- 1$)

6. After that, finding out the UHI (Eq. 7) distribution on the surface can be done using remote sensing to visualize surface temperature that affects air temperature, so to get a UHI value you can use the following

equation, which is calculated using a threshold calculation where if it is positive then it is considered there is UHI and if it is negative (lower than 0) it means there is no UHI.

$$\mathrm{UHI} = \mathrm{Ts} - (\mu + 0{,}5\alpha) \quad \text{……..}(Eq.7)$$

UHI = Urban Heat Island;
Ts = Land Surface Temperature.

3. Result and Discussion

3.1. Urban Heat Island Phenomenon

Urban Heat Island is a regional climate phenomenon, which is also considered a representation of the climate miniature on land, where factors such as soil albedo and moisture availability play a significant role in the feedback effect (Taylor & Kim, 2012). Although LST data from satellites have a direct impact on the air temperature in the canopy layer through energy exchange, it is possible to detect Surface UHI (SUHI) and use it for UHI research (Shikwambana et al., 2021). The study of Putra et al. (2021) showed that the direction of UHI distribution starts from the city centre which is the centre of urban community activity and then spreads.

In 2008 the UHI area still covered 36.5% of the area of Jakarta or 23,846 ha, whereas in 2013 it increased drastically and covered most of the area, namely 84.7% of the area or 55,340.4 ha, and in 2018 the UHI area had almost covers the entire Jakarta area, reaching 93.7% of the total area or 61,820.9 ha, where the East Jakarta area has the highest UHI with the expansion of the UHI>34 ^{O}C. Meanwhile, based on research Saputra et al. (2021) found that the calculation of land surface temperature (LST) in Jakarta produces different values every month. The maximum LST value in December was 34.4^{O}C and the minimum value looks the same every month between 13 – 14^{O}C, where the dry season (July & September) looks hotter than the rainy season (May & December). The high LST value occurred in July, which shows that almost all areas in DKI Jakarta are yellow to red, even though July is not the hottest month in 2020, but September, because in September the temperature reached 35.7^{O}C.

Most of the LST results show the same pattern in each area which has higher temperatures each month. However, the temperatures displayed dynamically depend on each month, such as in the northeast of DKI Jakarta in May, September, and December showing the lowest temperatures, but in July showing a larger area of high temperatures. This is showed that land use in each region is different with different population growth, so the study case with a smaller scope is needed to design efficient urban planning in accordance with changes in the surrounding microclimate.

Therefore, measuring urban heat island that occurs in an area, in this study is the East Jakarta, can be done using land surface temperature analysis. Based on the results in Figure 3 and Table 1, the highest land surface temperature value at the peak of the dry season in July is 31.72^{o}C and the lowest temperature is 14.56^{o}C. The distribution of UHI in Figure 3 showed that Cakung District was detected as the area that has the widest UHI, with a comparison of the non-UHI area of 16.28% of its area, UHI 1 covered 53.86% of its area, UHI 2 covered 29.63% of its area, and UHI 3 covered 0.32% of its area. Meanwhile, Cipayung District was detected as the area with the lowest UHI, compared with the non-UHI area of 99.95% and UHI 1 covering 0.05% of its area. It follows the statement of (Thi Van & Xuan Bao, 2010), which states that surface temperature will increase higher in industrial areas, in this case is in Cakung where there are industrial areas, compared to other urban vegetative areas, because the geometry of urban areas also regulates surface temperature by absorbing incoming solar radiation (Chatterjee & Majumdar, 2022).

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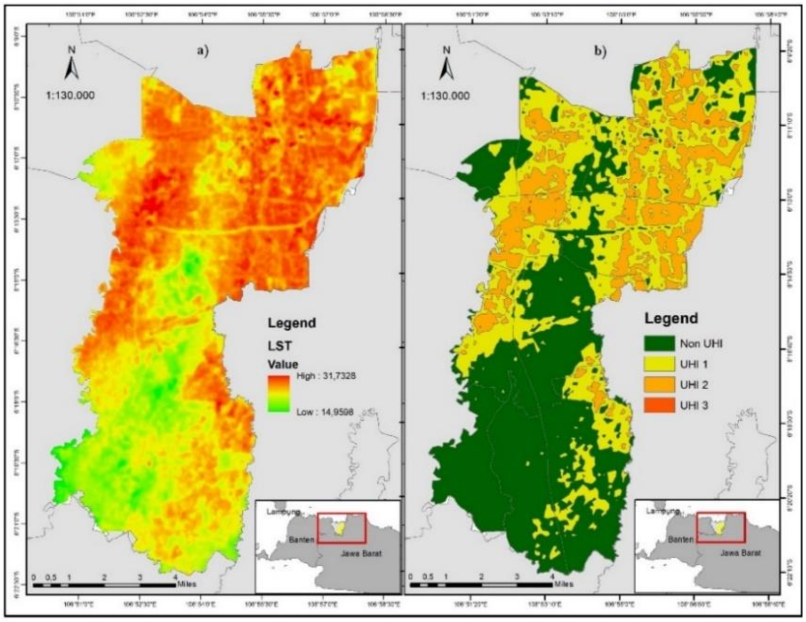


Source: Analysis, 2023

Figure 3. a) LST Value 2022, b) UHI Distribution 2022

Table 1. Urban Heat Island Distribution

District	UHI Area (ha)			
	Non-UHI	UHI 1	UHI 2	UHI 3
Cakung	657.25	2174.30	1196.17	9.31
Cipayung	1786.55	866.27	91.16	
Ciracas	1585.21	86.59	-	-
Duren Sawit	327.99	1098.69	755.25	-
Jatinegara	64.15	439.96	522.73	3.27
Kramatjati	618.66	505.93	189.90	-
Makasar	1539.54	523.29	80.56	-
Pasar Rebo	1267.08	0.64	-	-
Pulogadung	250.20	855.44	421.99	-
Matraman	375.50	116.42	-	-
Total	**8472.14**	**6667.53**	**325774**	**12,58**

Source: Analysis, 2023

The biggest contributor to air pollution emissions are now the industrial and transportation sectors (Shahid et al., 2015). In their study, Zhu et al. (2017) concluded traffic has a big impact on the UHI phenomenon, which caused by the engine exhaust's sensible heat and moisture movement as well as the tires' frictional heat dissipation, which all cause heat to be transferred to the road surface (Chapman & Thornes, 2005). In addition to vehicle and combustion emissions, the surface energy balance in cities is also significantly impacted by emissions from power plants and industrial areas (Phelan et al., 2015). Thus, knowing how regional lockdowns affected UHI can be crucial to understanding how significantly each polluting industry contributes to the dispersion of UHI. Currently, the pandemic has managed to lessen, allowing for the lifting of restrictions and the return to normal outdoor activities that could significantly boost anthropogenic emissions. Thus, mitigation that can be applied over the long term is needed to preserve the balance of the urban environment to prevent the UHI distribution area from increasing and maintain the temperature of the city environment.

3.2. Urban Green Space in East Jakarta

UHI presents a major detrimental threat to human health and the environment in urban areas, so a better understanding of UHI mitigation strategies is needed to enhance sustainable urban development (Yao et al., 2020). The most crucial ecological infrastructure in urban systems is urban green spaces because it provides an extensive resource for heat reduction, especially the cooling effect that is more efficient in summer (Cao et al., 2010; Peng et al., 2018). Based on data from the Department of Spatial Planning in 2022, East Jakarta has an area of 18,447.91 ha, with a built-up area of 17,243.02 ha or 94.43% of its area and urban green space of 1,026.98 ha or 5.57% of its area.

Law No. 26 of 2007 states that urban green spaces are classified into four types: urban forests, green belts, city parks, and cemeteries. Meanwhile, based on the Minister of Home Affairs No. 14 of 1998, urban green spaces are classified into urban forest areas, city parks, sports fields, cemeteries, yards, and productive green areas. Therefore, this study's urban green space types are divided into five types: urban forests, green belts, city parks, public cemetery parks, and others (including fields, gardens, yards, etc.). The data in Table 2. shows that the area with the most significant percentage of urban space is Cipayung, which is 5.60% of its area or 159.29 ha, and the lowest is Matraman, which is 1.09% of its area or 159.29 ha. 5.33 ha. Overall, the available green space is only 5.57% of the total area of East Jakarta.

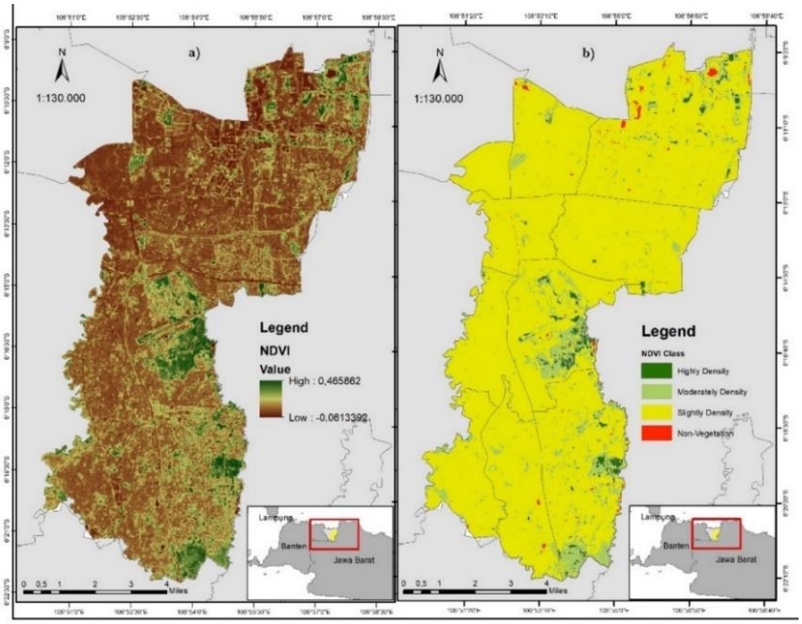
Table 2. Urban Green Space in East Jakarta 2022

No	District	Urban Green Space Area (ha)				
		Urban Forest	Green Belt	City Park	Cemetery	Others
1	Cakung	22.77	18.41	28.10	-	13.17
2	Cipayung	55.74	5.16	50.14	-	48.25
3	Ciracas	34.76	4.44	17.77	-	19.61
4	Duren Sawit	3.72	78.83	19.27	18.18	0.76
5	Jatinegara	4.75	21.72	8.74	-	-
6	Kramatjati	19.82	11.30	6.18	-	3.67
7	Makasar	39.92	9.08	8.64	-	0.21
8	Pasar Rebo	1.98	11.00	6.15	-	0.33
9	Pulo Gadung	1.19	15.17	11.01	-	-
10	Matraman	-	4.59	0.73	-	0.01
11	Undetected	4.24	1.23	243.92	133.54	18.78
Total Area		**188.89**	**180.94**	**400.65**	**151.72**	**104.79**

Source: Analysis, 2023

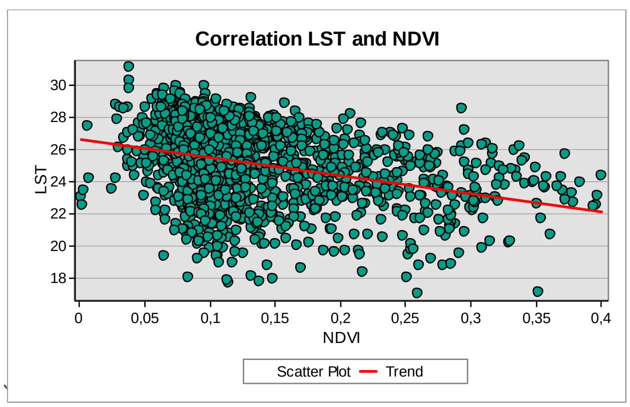
East Jakarta has an urban forest covering 188.89 ha or 1.02% of its area, green belts covering 180.94 ha or 0.98% of its area, parks covering 400.65 ha or 2.17%, cemeteries covering 151 hectares, 72 ha or 0.82% of the total area, and other green open space covering 104.79 ha or 0.57% of the total area. Based on Table 2, Cipayung has the lowest LST and UHI value and has the most urban forest, 55.74 ha or 1.96% of its area. Meanwhile, Matraman was not detected as having an urban forest, but there was 4.24 ha of urban forest which was not known to be in any area. Meanwhile, Cakung has the highest LST and UHI value and has an urban forest of 22.77 ha or 0.54% of its area. These results show that East Jakarta still does not meet the 30% green open space standard in Law No. 26 of 2007.

A correlation analysis can be performed between surface temperature and vegetation density to determine the influence of UGS on UHI's distribution. Correlation analysis in this study was carried out by extracting 1296 points scattered throughout the study locations, resulting in the equation $y = -2.5925x + 23.685$, as shown in Figure 5. From this equation, it is known that LST and NDVI show patterns of spatial distribution that are opposite or proportional reversed, where areas with high LST values indicate the urban heat island phenomenon (Guha & Govil, 2021). These results can also be concluded that vegetation cover has a negative relationship with temperature, indicating that areas with a higher percentage of urban green space have lower thermal environmental temperatures (Guo et al., 2015; Huang & Cadenasso, 2016).



Source: Analysis, 2023

Figure 4. a) NDVI Value 2022 b) NDVI Class 2022



Source: Analysis, 2023

Figure 5. Correlation LST and NDVI

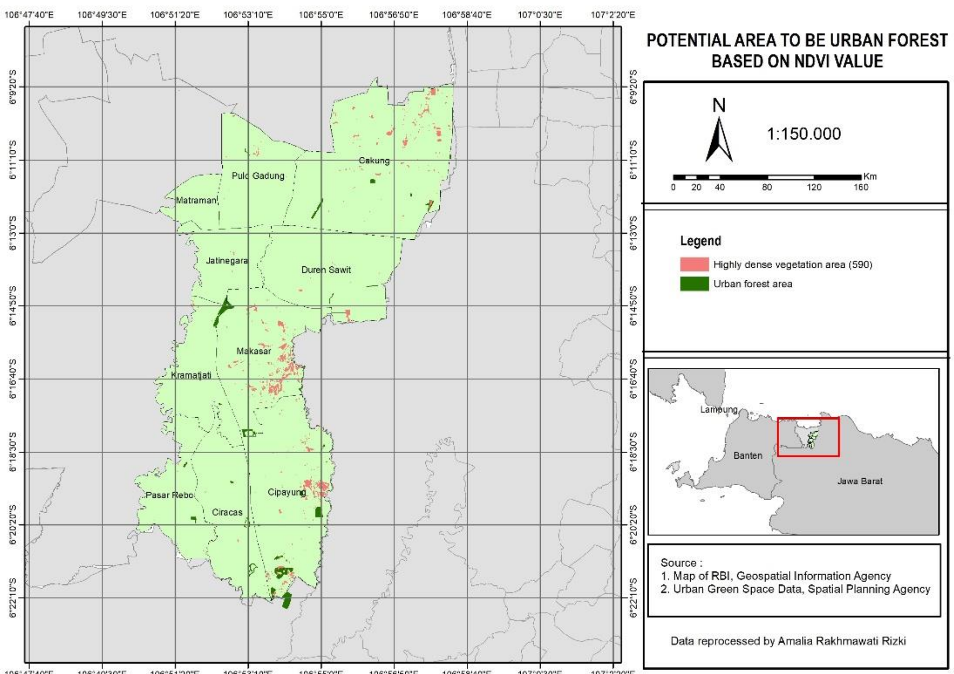
Compared to residential and public service zones, industrial and commercial zones have a relatively small proportion of UGS but produce more significant emissions (Du et al., 2016). It is also proven that denser vegetation tends to have a better cooling effect because UGS with more complex forms are proven to be more effective in UHI mitigation, such as urban forest. After all, it provides enormous resources for more heat reduction efficiency in summer (Cao et al., 2010; Li & Zhou, 2019; Peng et al., 2018). Moreover, the results of the correlation analysis show that vegetation cover has a negative relationship with temperature, where the area with a higher percentage of urban green space, especially urban forest, has a lower thermal environment temperature. The correlation is in line with the result of the availability of urban forests in East Jakarta, where Cipayung, which has the lowest LST and UHI values, has the most urban forests, namely 55.74 ha or 1.96% of its area.

According to Table 2, East Jakarta has a total area classified as an urban forest covering an area of 188.89 ha, which means only 1.02% of its area. The status of an urban forest itself has quite complex requirements that cover land area, ecological functions, and the resulting social benefits. However, as a basis for consideration, vegetation density is an essential indicator in determining the existence of an urban forest. Therefore, the potential of green areas, which can be considered for the urban forest, can be assessed from vegetation density.

Table 3. Classification of Vegetated Area

NDVI Class	Land Cover	Area (ha)	Percentage (%)
Highly Density	Tropical forest, urban forest	283.84	1.54
Moderately Density	Grassland, urban green space	1710.37	9.27
Slightly Density	Built-up area	16354.99	88.65
Non-Vegetation	Cloud cover, dry land	98.72	0.54
Total Area		**18447.91**	**100**

Source: Analysis, 2023



Source: Analysis, 2023

Figure 6. Potential Area to be Urban Forests

The results of the NDVI analysis in Figure 4. and Table 3., East Jakarta has the highest NDVI value of 0.466 and the lowest of -0.061, where the total area included in the high green class is 283.84 ha. According to (Hashim et al., 2019), areas with dense, high-density vegetation can become urban forests. Thus, based on the density of vegetation, there is still 94.95 ha of land that has the potential to become an urban forest area in East Jakarta. Furthermore, in Figure 6., there are some areas with high density that can become urban forests in Cipayung, Makasar, Cakung, Jatinegara, Pulo Gadung, and Ciracas areas, with the Makassar area having the most significant potential for urban forest area.

4. Conclusion

Several factors influence the distribution of UHI, including land use cover and anthropogenic emissions. The distribution of UHI in 2022 has apparent differences in the northern and southern parts of East Jakarta, where the northern part tends to have a high UHI, while the southern part tends to have a low UHI. One of the factors is land use cover. The areas with high LST and UHI distribution, such as Cakung, Jatinegara, and Pulo Gadung are because there are many industrial areas and less urban green spaces and because they are directly adjacent to North Jakarta, which is a coastal area. Meanwhile, areas with low LST and UHI distribution, such as in Cipayung, Ciracas, and Pasar Rebo, are dominated by residential areas, and still, many urban green spaces exist. This showed that surface temperature is correlated with vegetation cover, which increasing the vegetation cover can be one of UHI mitigation strategies. Therefore, overcoming the UHI phenomenon can be done by first managing existing vegetation areas to optimize their function, such as managing highly and moderately dense vegetation areas into urban forests to balance the city environment. Based on this study that has been carried out, there are several suggestions related to the development and implementation of the results of this study, including research related to stakeholder analysis in ongoing urban green space management, a comprehensive policy analysis to determine whether or not there is an overlap in the applicable policies and research to calculating ecosystem services that show the economic and social value of urban green space to show how important it is to balance the city environment.

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