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RESEARCH ARTICLE

# Study of Urban Temperature Profiles on Various Land Covers in The Greater Jakarta Region, Indonesia

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## ABSTRACT

The greater Jakarta is an intimate urban area that evolved into the largest integrated metropolis in Indonesia. It plays a significant role in social, economic, and political aspects. To be considered seriously, however, is the lack of planning capacity in increasingly complex area management. This study seeks to determine urban temperature profiles, classify land cover, and analyze surface albedo in Jakarta greater area. Firstly, the temperature profile is analyzed using nine years of diurnal temperature data. Secondly, land cover classification was analyzed using Landsat 7 ETM+ and Landsat 8 OLI/TIRS image datasets. Thirdly, surface albedo analysis was conducted using previously derived spatial data and land cover characteristics. Results of the temperature profile indicate that urban areas have a longer cooling period than suburban areas. The classification procedure yields seven classes of land cover with an accuracy rate of 80.95% (2010) and 83.33% (2018); the kappa coefficient is 0.74 (2010) and 0.77 (2018), respectively. Since 2010, urban areas have expanded, as can be deduced from the evidence. The distribution of surface albedo values from high to low includes built-up land, grass/shrubs, vegetation, water bodies, and moist soil. Additionally, surface albedo and air temperature positively correlate with land cover variations. This is demonstrated by the high R-square values between albedo and land cover (0.84 and 0.90) and air temperature and land cover (0.59 and 0.60). In other words, land cover changes can increase albedo and air temperature.

## Introduction

The future of the world's population will be urban, with more than 50 percent of the population residing in urban areas. The United Nations has reported that the world's urban population increased to 55% between 1950 and 2018, including Indonesia's urban population of 57% in 2021 [1]. Urbanization determines the spatial distribution of the world's population, significantly impacts land management, and contributes to the increase in the temperature and surface albedo of urban areas. Rapid urbanization in Jakarta has resulted in urban expansion and the emergence of suburbanization in suburban areas [2]. Population growth is exerting enormous pressure on the land, water, and energy resources essential to agricultural and rural communities in tropical areas and their biological resources [3].

Greater Jakarta is made up of various cities, including as Bogor, Depok, Tangerang, and Bekasi, that serve as economic hubs for Jakarta. The greater Jakarta now has an aggregate area of 6,799.2 km$^2$, representing 0.36 percent of the country's surface area, and is home to 12 percent of the Indonesian population. The urban area of greater Jakarta increased by 61% in 2015 [4]. Owing to the growing number of factors that emit solar heat and the additional heat from human activities, such as the emission of greenhouse gases, including carbon dioxide, carbon monoxide, and methane, this situation poses a heat risk through the rise in air temperature. The increase in air temperature is influenced by the amount of solar radiation reaching the

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planet. Solar radiation that reaches the surface experiences reflection and absorption; therefore, all land cover categories have an albedo value. Albedo refers to the reflection of radiation from the ground and nearby objects onto a sloped surface, resulting in reflectivity of the ground [5]. The albedo value is affected by the type of surface, the nature of the surface radiation, atmospheric conditions, and the physical characteristics of the soil. The albedo value influences the surface temperature of an area [6].

Land cover is the physical appearance of the Earth's surface and can be defined as the distribution of vegetation, water, sediment, and other human-made features over land. The relationships between land cover and urbanization, air temperature distribution, and urban surface albedo resulting from human and natural activities are similar. Few researchers have analyzed the relationship between air temperature, surface albedo, and changes in land cover. The relationship between changes in air temperature and land cover was examined, and it was found that urban and open areas positively correlated with temperature increases. In contrast, vegetation areas and water bodies are negatively correlated [7]. This study aimed to ascertain the temperature profile and urban surface albedo and map the profile of urban land cover in greater Jakarta to clarify the thermal profile of the city regarding temperature and albedo.

## Materials and Methods

### Study Area

This research was conducted in the Greater Jakarta region, considering that Jakarta is the epicentre of the national capital and that the adjacent areas (Bogor, Depok, Tangerang, and Bekasi) are buffer zones. Regarding climate and meteorological conditions, the five cities in greater Jakarta share nearly identical characteristics, such as proximity and tropical climates. Figure 1 shows a map of the study areas.

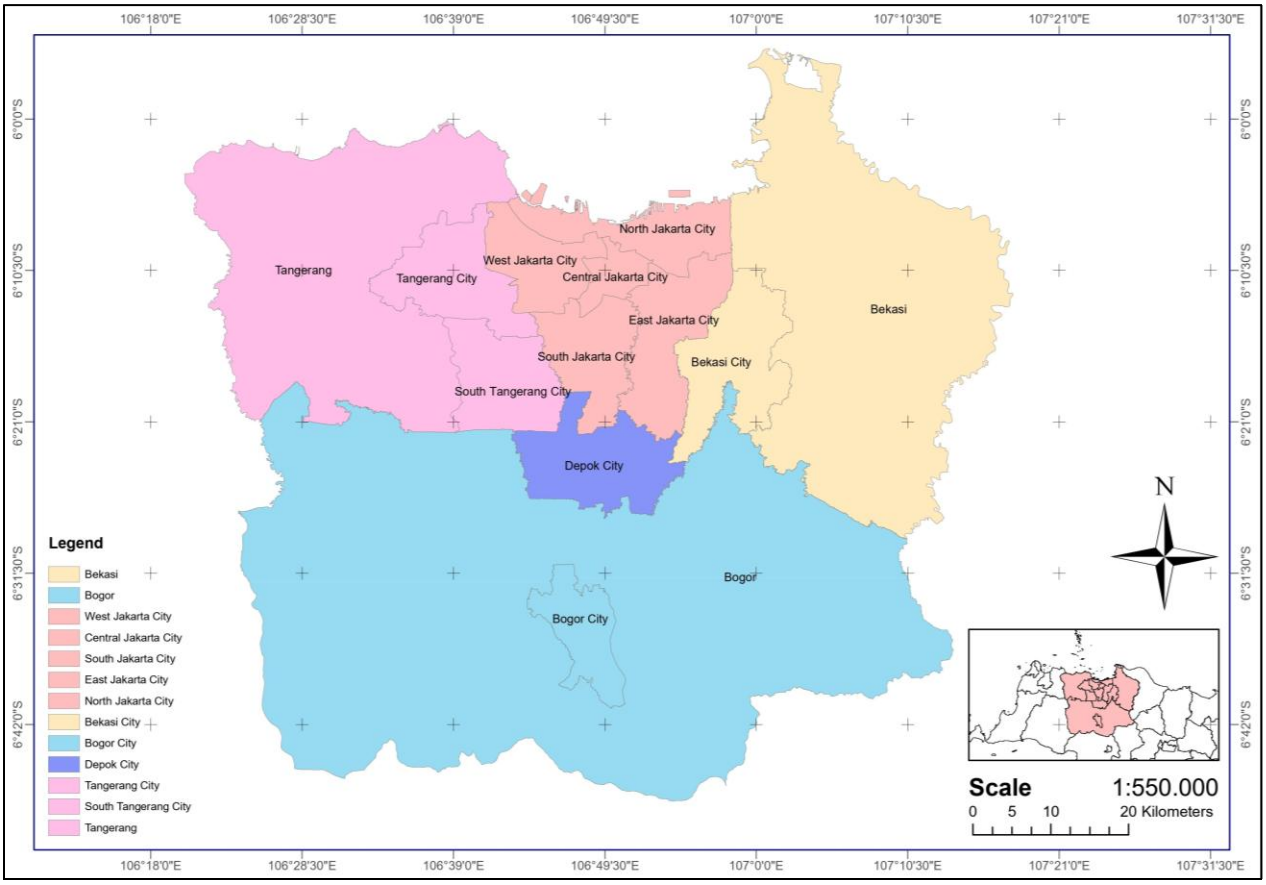



**Figure 1.** The study area encompassing the Greater Jakarta region, highlighting its geographical boundaries, key urban centers, and surrounding areas of interest relevant to the research.

## Data Sources

This research utilized diurnal and daily temperature data from the Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG) and NASA Power, Land Surface Temperature (LST) data from Climate Engine and Modis, albedo data from Google Earth Engine, and Landsat 7 ETM+ and Landsat 8 OLI/TIRS satellite imagery data from the USGS. Temperature data are used to determine the air temperature profile; LST data are used to analyze the pattern of spatial distribution of ground surface temperatures; Landsat 7 ETM+ and Landsat 8 OLI/TIRS imagery data are used to calculate surface albedo and analyze land cover classification; and greater Jakarta administrative data from the Information Agency Geospatial are used to describe the distribution of land use in the study area.

## Preprocessing Satellite Data

Landsat 7 and Landsat 8 satellite data were acquired and geometrically corrected using Google Earth Engine (GEE). The top reflectance of the atmosphere (ToA) was then corrected using a radiometric correction [8], as shown in Equation 1.

$$\rho\lambda' = M_\rho Q_{cal} + A_\rho \tag{1}$$

where ρλ' is ToA reflectance, Mρ is reflectance_mult_band_x, Mρ is reflectance_add_band_x, and Qcal is the digital number (DN) value.

The digital number value for the angle of the sun's position was corrected using the ToA reflectance, as shown in Equation 2 [8].

$$\rho\lambda = \rho\lambda'/(cos(\theta_{SZ})) = \rho\lambda'/(sin(\theta_{SE})) \tag{2}$$

where ρλ is ToA reflectance, $\theta_{SE}$ is the angle of the sun's elevation value, and $\theta_{SZ}$ is the zenith angle of the sun, $\theta_{SZ} = 90° - \theta_{SE}$.

## Urban Temperature Profile

Diurnal variations in the temperature profile were determined via data analysis by analyzing air temperature parameters. The diurnal temperature variation was examined by plotting the hourly average data against time. Furthermore, annual air temperature trends from 2010 to 2018 were investigated. To elucidate the diurnal profile of each region, five representative locations from each city with a comparable climate classification were selected: the National Monument in Jakarta, Istana Bogor in Bogor, Depok Baru Station in Depok, Ramayana Cikupa in Tangerang, and Pondok Gede Market in Bekasi. Climate classification is crucial for understanding spatial climate variations in a region, which can subsequently be applied to planning decisions in specific economic sectors, such as the suitability of land for crop cultivation [9].

## Land Cover Classification

The land cover classification procedure employed the Google Earth Engine's guided classification technique. To continue the guided classification process on remote sensing imagery, there are three steps: (1) identifying representative areas for each land cover type, (2) classifying each pixel into a land cover class, and (3) digitizing the results as a thematic map. To determine the accuracy of the land cover, guided classification was used to accumulate more than 20 points for each land cover category. Classification accuracy was measured using the aggregate accuracy level [10]. The error matrices are listed in Table 1.

**Table 1.** Error matrix.

| Interpretation of land use results | Land use | | | | | | | Total ($N_{+i}$) |
|---|---|---|---|---|---|---|---|---|
| | $P_{1+}$ | $P_{2+}$ | $P_{3+}$ | $P_{4+}$ | $P_{5+}$ | $P_{6+}$ | $P_{7+}$ | |
| $P_{+1}$ | $P_{11}$ | | | | | | | $N_{+1}$ |
| $P_{+2}$ | | $P_{22}$ | | | | | | $N_{+2}$ |
| $P_{+3}$ | | | $P_{33}$ | | | | | $N_{+3}$ |
| $P_{+4}$ | | | | $P_{44}$ | | | | $N_{+4}$ |
| $P_{+5}$ | | | | | $P_{55}$ | | | $N_{+5}$ |
| $P_{+6}$ | | | | | | $P_{66}$ | | $N_{+6}$ |
| $P_{+7}$ | | | | | | | $P_{77}$ | $N_{+7}$ |
| Total ($N_{i+}$) | $N_{1+}$ | $N_{2+}$ | $N_{3+}$ | $N_{4+}$ | $N_{5+}$ | $N_{6+}$ | $N_{7+}$ | $N$ |

where $P_{+i}$ is the type of land use resulting from the interpretation, and $P_{i+}$ is the type of land use validation result. Both parameter was calculated with sample cross multiplication (Equation 3).

$$x_{ii} = \sum_{i=1}^{r}(P_{i+} * P_{i+}) \tag{3}$$

$$k = \left(\frac{(\sum_{i=1}^{r} P_{ii} * N) - \sum_{i=1}^{r}(P_{i+} * P_{i+})}{N^2 - \sum_{i=1}^{r}(P_{i+} * P_{i+})}\right) \quad (4)$$

Equation 4 presents the formula used to calculate the kappa value, where $P_{+i}$ is the number of points resulting from the interpretation of the $i^{th}$ type of land use, $P_{i+}$ is the number of validation result points on the $i^{th}$ type of land use, $P_{ii}$ is the number of types of land use $i^{th}$ result of the interpretation that corresponds to the land use of the validation results, $x_{ii}$ is the sample cross product, i is a row or column, r is the number of land use types, N is the number of validation land use points, and k is the kappa value.

### Surface Albedo

The surface albedo was calculated from Landsat 7 and Landsat 8 satellite images using TOA reflectance bands 1, 3, 4, 5, and 7. Equation 5 is a modified formula for calculating albedo using Landsat 8 from the Landsat 7 version [11].

$$\alpha = \frac{0{,}356\rho_1 + 0{,}130\rho_3 + 0{,}373\rho_4 + 0{,}085\rho_5 + 0{,}072\rho_7 - 0{,}0018}{0{,}356 + 0{,}130 + 0{,}373 + 0{,}085 + 0{,}072} \quad (5)$$

where $\rho$ is the reflectance ToA of each band used.

### Correlation Analysis

The relationship between air temperature, surface albedo, and changes in land cover was analyzed using simple linear regression, as shown in Equation 6.

$$Y = \alpha + \beta X + \varepsilon \quad (6)$$

where Y is the dependent variable, namely air temperature, X is the independent variable, namely albedo, $\varepsilon$ is an error, and $\alpha$ is the regression parameter.

## Results

### Urban Temperature Profile

Based on the chart in Figure 2, the temperature decreases progressively from midnight to immediately before sunrise (00:00–05:00 local time). During the day, the mercury reached its highest point and then began to drop around 15:00. Bogor (Istana Bogor) has the lowest diurnal temperature (23.4 °C) because it is less influenced by the sea breeze from the Java Sea, whereas Tangerang (Cikupa) is more influenced by the sea breeze, resulting in greater heat loss. At night, urban areas chill much more slowly and have more intense heat than suburban areas throughout 2010–2018. Figure 3 shows the maximum temperature in greater Jakarta tends to increase in a relatively uniform manner. Jakarta, Tangerang, and Bekasi have higher temperatures than Bogor and Depok. The average maximum temperature in Jakarta (32.74 °C), and the average minimum temperature in Bogor (28.6 °C).

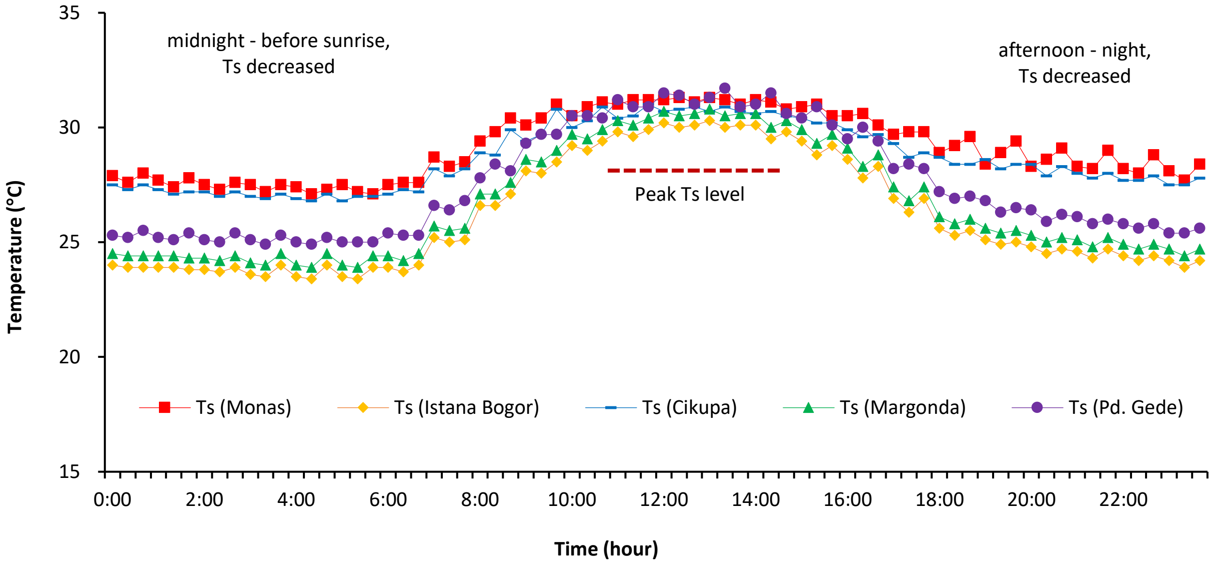



**Figure 2.** Surface temperature (Ts) diurnal in the greater Jakarta area in 2018 (Data source: Processed by Modis Terra-Aqua).

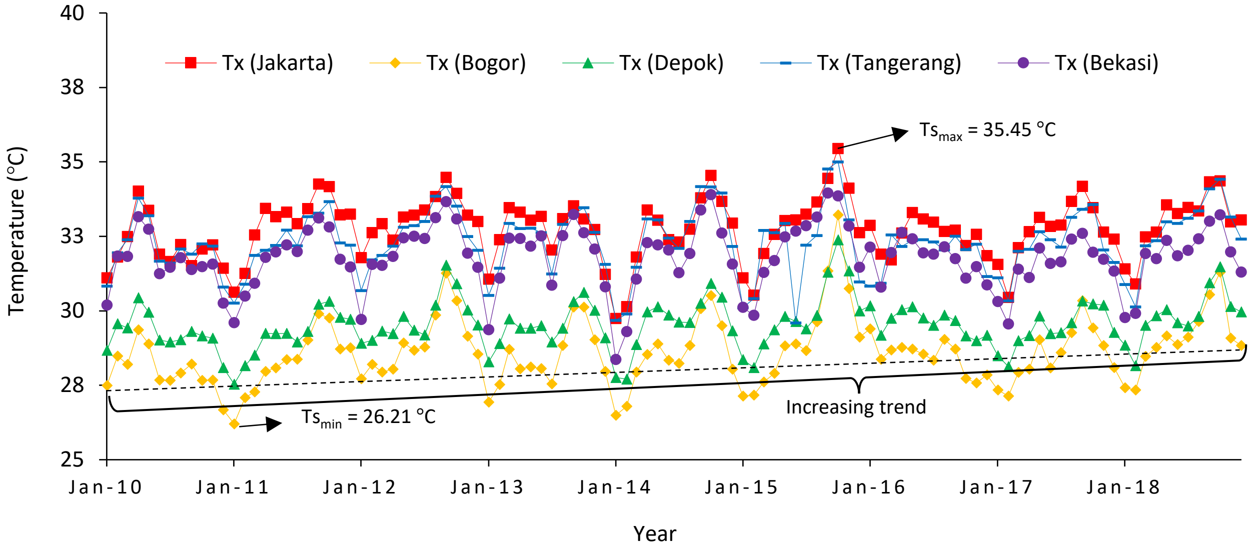



**Figure 3.** Maximum surface temperature trend in the greater Jakarta 2010–2018 (Source: Processed by Modis Terra-Aqua).

**Greater Jakarta Land Cover Distribution**

The spatial distribution of LSTs revealed that 2018 had a greater value and distribution than 2010 (Figure 4). High LST values were prevalent in most urban centers and extended into the suburbs of greater Jakarta. The average LST in urban areas was 31.25 °C in 2018 and 28.75 °C in 2010. Land cover maps were identified based on multispectral data and guided classification. Table 2 and Figure 5 classify the land cover categories as vegetation, water bodies, built-up land, ponds, grass and bush, open ground, and rice fields. The evaluation of land-use classification accuracy revealed 80.95% (2010) and 83.33% (2018). Both maps have Kappa coefficients of 0.74 and 0.77, respectively. In the classification/land cover mapping procedure, the accuracy value is closer to 1 if the kappa coefficient value is close to 1. According to Figure 6, the classification results showed that the area of paddy fields, vegetation, aquatic bodies, grasses, and shrubs decreased while the built-up area increased significantly. Urban areas and built-up land increased by 47% (734.5 km$^2$), paddy fields decreased by 34% (521.9 km$^2$), and vegetation land, aquatic bodies, grasses, and shrubs decreased by 16 percent (249.9 km$^2$).

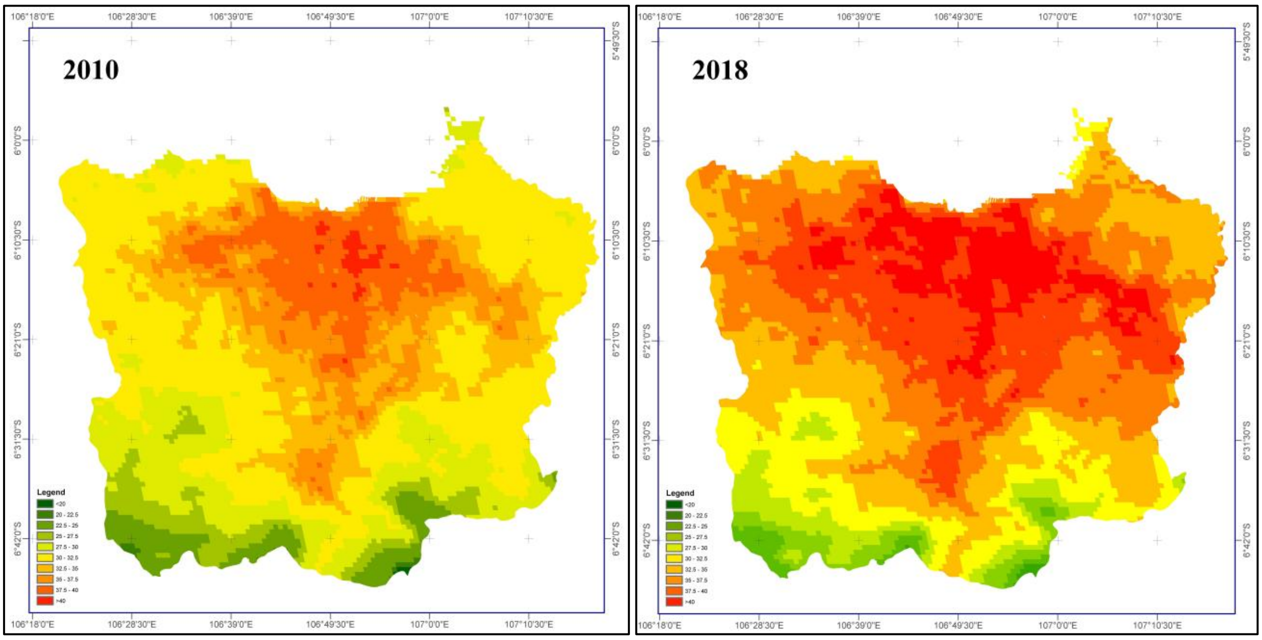



**Figure 4.** Map of the greater Jakarta land surface temperature in 2010 and 2018.

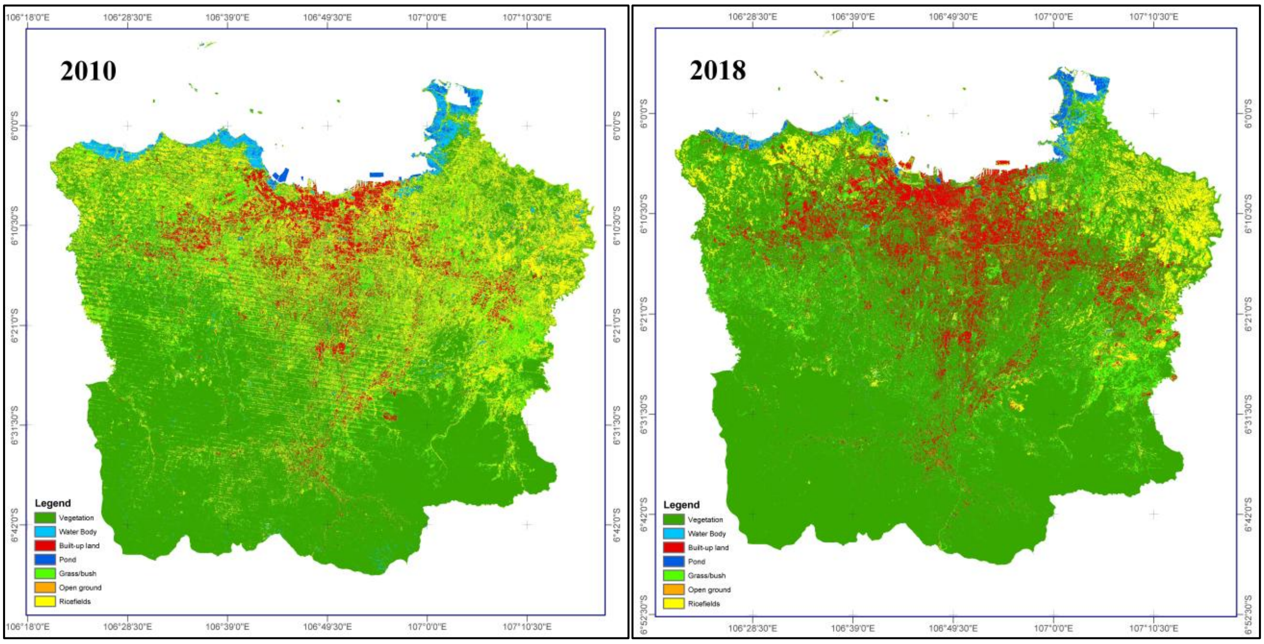



**Figure 5.** Distribution of greater Jakarta land cover in 2010 and 2018.

**Table 2.** Changes in land use in Greater Jakarta.

| No. | Land use | Area in 2010 | | Area in 2018 | | Change | |
|---|---|---|---|---|---|---|---|
| | | km$^2$ | % | km$^2$ | % | km$^2$ | % |
| 1 | Vegetation | 4,026.4 | 59.3 | 3,944.3 | 58.0 | –82.1 | –5 |
| 2 | Waterbody | 132.5 | 2.0 | 43.7 | 0.6 | –88.8 | –6 |
| 3 | Built-up land | 421.3 | 6.2 | 1,155.8 | 17.0 | 734.5 | 47 |
| 4 | Pond | 42.0 | 0.6 | 80.5 | 1.2 | 38.4 | 3 |
| 5 | Grass/bush | 773.4 | 11.4 | 694.4 | 10.2 | –79.0 | –5 |
| 6 | Open ground | 0.5 | 0.01 | 5.2 | 0.1 | 4.7 | 0 |
| 7 | Ricefield | 1397.2 | 20.6 | 875.3 | 12.9 | –521.9 | –34 |
| Total | | 6,793.4 | 100 | 6,799.2 | 100 | | |

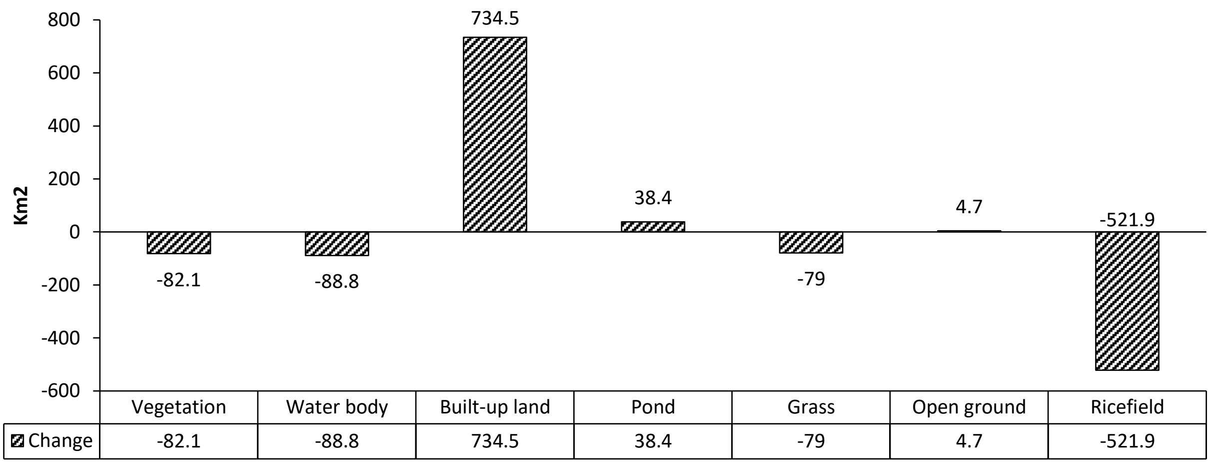



**Figure 6.** Trends in land use change across the Greater Jakarta region from 2008 to 2018, showcasing shifts in urban expansion, agricultural areas, and other land cover categories over the decade.

## Surface Albedo

According to Figure 7, the albedo values for various surface categories are as follows: deciduous trees (0.13–0.20), grass (0.20–0.28), urban areas (0.28–0.55), paved roads (0.04–0.10), and water (0.10–0.13) [6,12]. The distribution of the land cover albedo in 2010 and 2018 followed a similar logarithmic pattern. Figure 7 shows that in 2018, the surface albedo was greater than that in 2010. In both 2010 and 2018, urban areas exhibited greater variation in albedo values. The wide range of albedo values results from the diversity of surface characteristics across a spectrum of settlement classes.

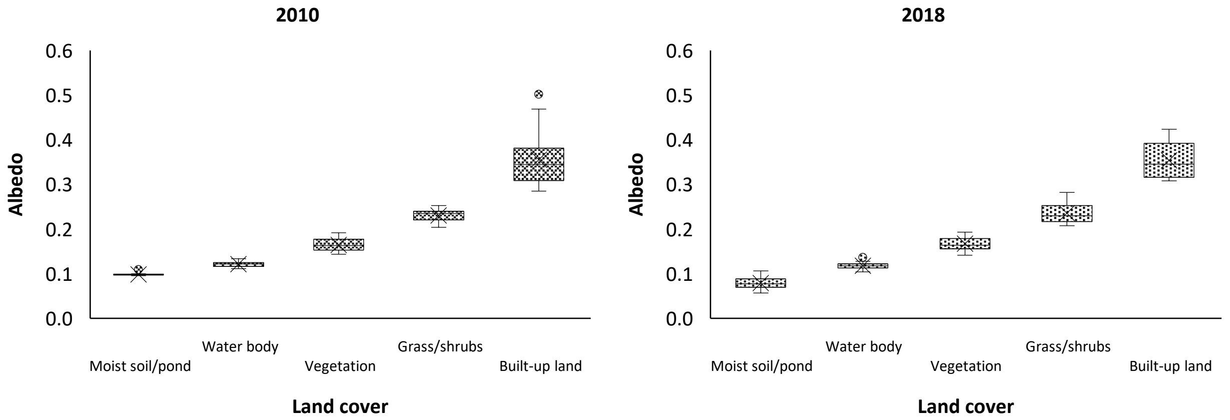
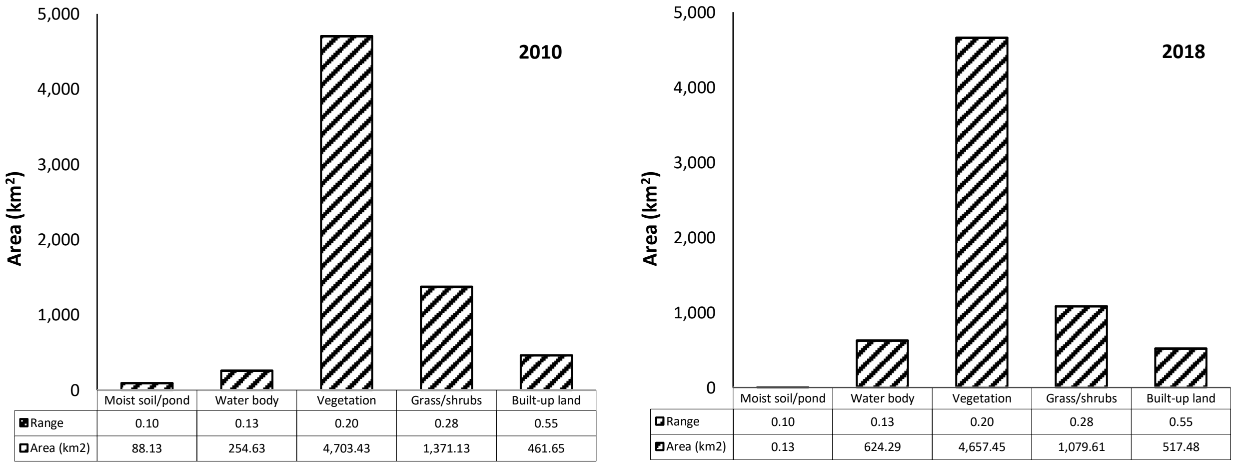



**Figure 7.** The boxplot presents the distribution of land cover albedo values across the Greater Jakarta region, highlighting variations among different land cover types and providing insights into their reflective properties.

According to data from Figure 8, the categories of vegetation (4,703.43 km$^2$) had the largest distribution area of albedo in 2010, followed by grass/shrubs (1,371.13 km$^2$), built-up land (461.65 km$^2$), water body (254,63 km$^2$), and moist soil pond (88.13 km$^2$). In 2018, the land cover consisted of vegetation covering an area of 4,657.45 km$^2$, grass and shrubs covering an area of 1,079.61 km$^2$, water bodies covering an area of 624.29 km$^2$, built-up land covering an area of 517.48 km$^2$, and moist soil ponds covering an area of 0.13 km$^2$. Between 2010 and 2018, there were changes in the distribution of the various areas. The areas of grass and shrubs (291.52 km$^2$), moist soil ponds (88 km$^2$), and vegetation (45.98 km$^2$) have decreased in size, while the area of water bodies has expanded by 369.66 km$^2$, whereas the area of built-up land has increased by 55.83 km$^2$.




| 2010 | Moist soil/pond | Water body | Vegetation | Grass/shrubs | Built-up land |
|---|---|---|---|---|---|
| Range | 0.10 | 0.13 | 0.20 | 0.28 | 0.55 |
| Area (km2) | 88.13 | 254.63 | 4,703.43 | 1,371.13 | 461.65 |

| 2018 | Moist soil/pond | Water body | Vegetation | Grass/shrubs | Built-up land |
|---|---|---|---|---|---|
| Range | 0.10 | 0.13 | 0.20 | 0.28 | 0.55 |
| Area (km2) | 0.13 | 624.29 | 4,657.45 | 1,079.61 | 517.48 |

**Figure 8.** The figure shows the albedo distribution across various land use types in the Greater Jakarta region, illustrating the range and variability of surface reflectivity associated with each land use category.

### Correlation of Albedo and Temperature with Land Cover

Figures 9 and 10 depict the relationship between the surface albedo, temperature, and land cover. The relationship between albedo and land cover is linear, with the coefficient of determination ($R^2$) between albedo and land cover in 2010 (0.84) lower than in 2018 (0.90). Furthermore, the relationship between land cover and the air temperature was linear, with a coefficient of determination ($R^2$) in 2010 (0.59) lower than in 2018 (0.63).

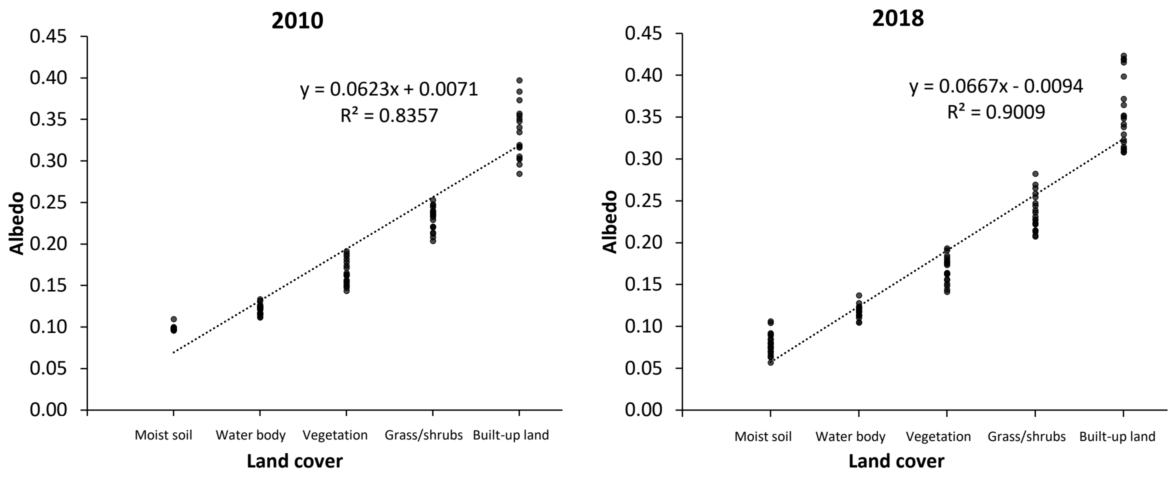



**Figure 9.** Correlation of surface albedo with greater Jakarta land cover.

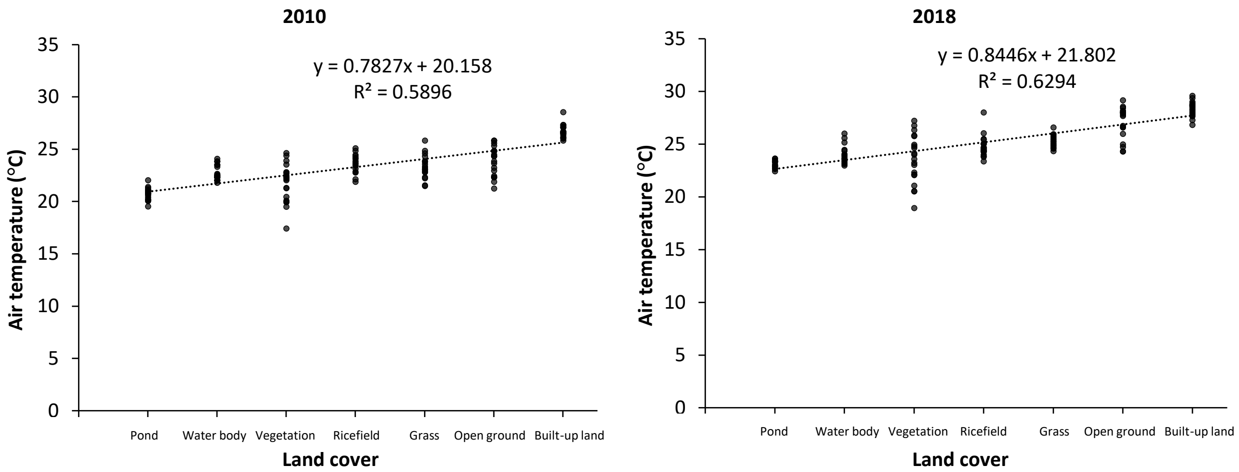



**Figure 10.** Correlation of air temperature with greater Jakarta land cover.

## Discussion

### Urban Temperature Profile

Climate monitoring is, in many ways, the most crucial aspect of evaluating a region's climatic conditions. Climate data are used for model development and evaluation, as inputs to numerous assessment components, to detect historical trends and fluctuations, and to compare prospective future conditions [13]. According to meteorological data, data analysis began at midnight, when most atmospheric processes and wind velocities were reduced. The temperature decreases from midnight to the morning before sunrise, reaching its highest point at noon at around 12 o'clock, then dropping around 15:00. Throughout 2010 through 2018, urban areas had more intense heat and chill extensively more slowly at night than suburban areas. As illustrated in Figure 3, the maximum temperature in greater Jakarta - Jabodetabek tends to rise extremely regularly. Temperature contributes significantly to the simulation of the effects of climate change on the environment and ecology because it is a key factor in the energy exchange process. The hourly availability of solar radiation influences the differences in temperature between regions [14].

### Greater Jakarta Land Cover Distribution

High LST values were found in most urban areas and extended into the suburbs of greater Jakarta. Urban areas have the highest LST, followed by barren land, vegetated areas, and water [15]. Multiple studies have found that urban areas have elevated LST values [16]. Natural factors, including geographic features, land use, and socioeconomic factors, influence land use changes. Precipitation, soil type, slope, population density, the distance to the urban capital have five components that influence the land use cover change (LUCC) of Ciliwung, while precipitation, population density, and distance to the city center are the three variables that affect the Cisadane watershed [17]. Land use changes in greater Jakarta are primarily driven by land conversion to intensive urban use. Changes in the landscape as a result of shifts in agricultural practices toward industrialization, urbanization, and commercial agriculture have become major causes of environmental degradation [18]. In greater Jakarta, numerous bountiful agricultural lands and other vegetation areas have been converted into built-up areas (settlements, industries, commercial services, etc.) [19]. Diverse parties must prioritize their efforts to overcome these challenges. However, to support these efforts, a new approach that can provide a comprehensive portrait of landscape configuration is required, such as landscape ecological analysis [20]. The analysis emphasizes the discussion of the landscape's structure, function, and dynamics [21].

According to Figure 6, the classification results demonstrate that the area of paddy fields, vegetation, aquatic bodies, grasses, and shrubs reduced while the built-up area escalated drastically. The development of arid greatly impacts the surrounding environment, and paddy lands are transformed into built-up areas. A city's expanding physical construction is positively correlated with its economic growth. Moreover, they have detrimental effects on ecosystems. The conversion of green open spaces into urbanized regions is a form of environmental deterioration [22]. In contrast to natural disruptions, human activity can hasten landscape deterioration and provide unique variants [23]. These changes indicate that the landscape is generally not permanent and can vary in terms of quality, configuration, size, shape, and function, among other characteristics [21].

Jakarta's built-up areas are expanding rapidly, followed by Bogor, Depok, Tangerang, and Bekasi, which are "satellite cities" constructed in suburban areas that surround the main city as centers of built spaces with complete infrastructure and facilities [24]. Urban expansion primarily occurred along the major thoroughfares. Land cover changes alter the surface's physical properties, such as albedo, emissivity, and surface texture, thereby altering the surface's heat absorption. According to this description, one of the ecological functions of the landscape is the transfer of energy, materials, and species among their constituent elements [1]. Understanding landscape dynamics significantly influences landscape management and planning. Approximately 80 mg of carbon could be stored per hectare if vegetation-like *pekarangan* systems and other smallholder tree-based systems were to grow more on currently damaged and unused lands, such as the Imperata grasslands. However, the actual amount varies depending on the type of species present and the methods used for managing vegetation. There is the possibility of encouraging management practices that increase carbon stocks at the system level. Nevertheless, it is crucial to establish incentive mechanisms that guarantee smallholders reap the advantages of adopting management approaches that promote increased carbon stocks [25].

**Surface Albedo**

Through reflection, scattering, and absorption, the atmosphere modifies the solar radiation that reaches Earth's surface [26]. Therefore, the sensor used to calculate albedo is a sensor that detects short wavelengths. Albedo indicates the darkness of an object. If the albedo value of the object is zero, it absorbs all incident short-wave radiation, whereas if it is one, it reflects all incident short-wave radiation. The greater the amount of radiation reflected into the atmosphere, the greater the albedo and the lower the amount of radiation absorbed by the Earth's surface. The response of the surface to low-to-high radiation absorption depends on the properties of the surface. Non-vegetated surfaces reflect more radiation into the atmosphere, resulting in greater albedo values and decreased radiation absorption. When the urban atmosphere is polluted with air pollutants from various activities (transportation and industry), the back reflections emitted by long-wave radiation from various types of urban land cover are trapped by the atmosphere, allowing these pollutants to continue to cause a rise in temperature [27].

The color, texture, and wettability of an object predominantly influence albedo. Consequently, surface heterogeneity results in a greater diversity of albedo values. Jakarta's settlements consist of roads, buildings, vegetation, industrial properties, and transportation infrastructure [28]. Because the range of albedo values is relatively limited, land with vegetation cover, such as moist soil, water bodies, and vegetation, has a lower albedo than built-up land. Owing to the high reflectance of incident radiation, the albedo of developed land is the highest.

The moist soil/ponds, water bodies, vegetation, grass/shrubs, and built-up land determine the albedo distribution from the lowest to the highest value. The considerable variation in albedo distribution throughout the greater Jakarta region was influenced by substantial changes in the surface conditions from

2010 to 2018. Variations in planted vegetation significantly impact surface properties and albedo values. The long-wave reflections of low-height plants, such as paddy rice, vegetable commodities, and notably tubers, differ from those of tall plants, such as fruit, shade, and other tall trees. In addition to plant height, leaf type, and spacing also influence albedo variations [29]. The surface temperature characteristics of various land cover types vary. The variation in albedo among land cover types affects the quantity of absorbed or reflected solar radiation [30,31]. Changes in albedo can have a local impact on surface temperature and surface energy balance [32,33]. Surface temperature and albedo are greater on arid, sparsely vegetated terrains.

If vegetation such as *pekarangan* systems and other smallholder tree-based systems were to expand in currently degraded and underutilized lands, such as Imperata grasslands, the C sequestration potential would be approximately 80 mg C $ha^{-1}$, with considerable variation depending on species composition and management practices. Opportunities exist to induce management, which leads to higher C stocks at the system level. However, incentive mechanisms ensure that smallholders benefit from selecting management practices favoring higher C stocks [25].

#### Correlation of Albedo and Temperature with Land Cover

The relationship between albedo and land cover is linear, meaning that a low albedo indicates that the land cover has a low reflectance level, and vice versa. Therefore, it is assumed that the regression model satisfies the assumption that albedo and land cover are related. Furthermore, the relationship between land cover and air temperature was linear, indicating that the more open the land cover, the higher the air temperature, and vice versa. The simple linear regression model for the relationship between albedo and land cover indicated that albedo and land cover are related.

## Conclusions

Urban areas cool more slowly than their suburban counterparts do. Greater Jakarta experiences an annual temperature increase, with average maximum temperatures of 32.74°C (Jakarta) and minimum temperatures of 28.6°C (Bogor). This study demonstrates that changes in greater Jakarta's land cover are highly visible, beginning in the center of Jakarta and then spreading throughout the region. The classification procedure yielded seven classes of land cover with an accuracy rate of 80.95% (2010) and 83.33% (2018), with kappa coefficient of 0.74 (2010) and 0.77 (2018), respectively. Since 2010, urban areas have grown by 55.4% (234.94 $km^2$), as can be deduced from the data. According to the study's results, built-up areas had the highest surface albedo values, whereas areas with saturated soil and water had the lowest. Additionally, surface albedo and air temperature positively correlate with land cover change via surface energy partitioning. This is demonstrated by the high R-square values between albedo and land cover (0.84 and 0.90) and air temperature and land cover (0.59 and 0.60). These results support the evidence that land cover changes can increase albedo values and air temperatures.

## Author Contributions

**RF**: Conceptualization, Methodology, Software Analytics, Data Processing, Writing - Review & Editing; **HSA**: Review, Supervision; and **P**: Review, Supervision.

## Conflicts of interest

There are no conflicts to declare.

## References


1. Department of Economic and Social Affairs. *World Urbanization Prospects 2018: Highlights*; United Nations: New York, USA, 2019; ISBN 978-92-1-148318-5.
2. Pravitasari, A.E.; Rustiadi, E.; Mulya, S.P.; Fuadina, L.N. Developing regional sustainability index as a new approach for evaluating sustainability performance in Indonesia. *Environmental and Ecology Research* **2018**, *6*, 157–168, doi:10.13189/eer.2018.060303.
3. Arifin, H.S.; Nakagoshi, N. Landscape ecology and urban biodiversity in tropical Indonesian cities. *Landscape Ecol Eng* **2011**, *7*, 33–43, doi:10.1007/s11355-010-0145-9.

4. Robbany, I.F.; Gharghi, A.; Traub, K. Land use change detection and urban sprawl monitoring in metropolitan area of Jakarta (Jabodetabek) from 2001 to 2015. *KEG* **2019**, *4*, 257–268, doi:10.18502/keg.v4i3.5862.
5. Widén, J.; Munkhammar, J. *Solar Radiation Theory*; Uppsala University: Uppsala, Sweden, 2019; ISBN 978-91-506-2760-2.
6. Dobos, E. Albedo. In *Encyclopedia of Soil Science*, 2nd ed.; Lal, R., Eds.; CRC Press: Boca Raton, FL, USA, 2005; ISBN 978-0-8493-3830-4.
7. Sencaki, D.; Sukotjo, B.; Wahyu, U. Analisa relasi perubahan tutupan lahan dan suhu permukaan tanah di Kota Surabaya menggunakan citra satelit multispektral tahun 1994–2012. *Jurnal Teknik Pomits* **2013**, *2*, 1–6.
8. Yanuar, R.C.; Hanintyo, R.; Muzaki, A.A. Penentuan jenis citra satelit dalam interpretasi luasan ekosistem lamun menggunakan pengolahan algoritma cahaya tampak. *Geomatika* **2017**, *23*, 75–86, doi:10.24895/JIG.2017.23-2.704.
9. Perdinan; Adi, R.F.; Sugiarto, Y.; Arifah, A.; Arini, E.Y.; Atmaja, T. Climate regionalization for main production areas of Indonesia: Case study of West Java. *IOP Conf. Ser.: Earth Environ. Sci.* **2017**, *54*, 1–8, doi:10.1088/1755-1315/54/1/012031.
10. Hua, A.K.; Ping, O.W. The influence of land-use/land-cover changes on land surface temperature: A case study of Kuala Lumpur Metropolitan City. *European Journal of Remote Sensing* **2018**, *51*, 1049–1069, doi:10.1080/22797254.2018.1542976.
11. Liang, S.; Shuey, C.J.; Russ, A.L.; Fang, H.; Chen, M.; Walthall, C.L.; Daughtry, C.S.T.; Hunt, R. Narrowband to broadband conversions of land surface albedo: II. Validation. *Remote Sensing of Environment* **2003**, *84*, 25–41, doi:10.1016/S0034-4257(02)00068-8.
12. Ahrens, C.D.; Henson, R. *Meteorology Today: An Introduction to Weather, Climate, and the Environment*, 12th ed.; Cengage: Boston, MA, USA, 2019; ISBN 978-1-337-61666-9.
13. Perdinan; Winkler, J.A. Changing human landscapes under a changing climate: Considerations for climate assessments. *Environmental Management* **2014**, *53*, 42–54, doi:10.1007/s00267-013-0125-6.
14. Gallo, K.; Hale, R.; Tarpley, D.; Yu, Y. Evaluation of the relationship between air and land surface temperature under clear- and cloudy-sky conditions. *Journal of Applied Meteorology and Climatology* **2011**, *50*, 767–775, doi:10.1175/2010JAMC2460.1.
15. Nurwanda, A.; Honjo, T. Analysis of land use change and expansion of surface urban heat island in Bogor City by remote sensing. *IJGI* **2018**, *7*, 1–15, doi:10.3390/ijgi7050165.
16. Stewart, I.D.; Oke, T.R. Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society* **2012**, *93*, 1879–1900, doi:10.1175/BAMS-D-11-00019.1.
17. Arifasihati, Y.; Kaswanto. Analysis of land use and cover changes in Ciliwung and Cisadane watershed in three decades. *Procedia Environmental Sciences* **2016**, *33*, 465–469, doi:10.1016/j.proenv.2016.03.098.
18. Kurnia, A.; Rustiadi, E.; Fauzi, A.; Pravitasari, A.; Saizen, I.; Ženka, J. Understanding industrial land Development on Rural-Urban Land Transformation of Jakarta Megacity's Outer Suburb. *Land* **2022***, 11,* 1–20, doi:10.3390/land11050670.
19. Rustiadi, E.; Pribadi, D.O.; Pravitasari, A.E.; Indraprahasta, G.S.; Iman, L.S. Jabodetabek Megacity: From city development toward urban complex management system. In *Urban Development Challenges, Risks and Resilience in Asian Mega Cities*; Singh, R.B., Eds.; Springer Japan: Tokyo, Japan, 2015; pp. 421–445, ISBN 978-4-431-55042-6.
20. Prastiyo, Y.B.; Kaswanto; Arifin, H.S. Analisis ekologi lanskap agroforestri pada riparian Sungai Ciliwung di Kota Bogor. *Jurnal Lanskap Indonesia* **2019**, *9*, 81–90.
21. Arifin, H.S.; Wulandari, C.; Pramukanto, Q.; Kaswanto, R.L. *Agroforestry Landscape Analysis: Concepts, Methods, and Landscape Scale Agroforestry Management with Case Studies of Indonesia, Philippines, Laos, Thailand, and Vietnam*; IPB Press: Bogor, Indonesia, 2009.
22. Sitorus, S.R.P.; Patria, S.I.D.; Panuju, D.R. Analisis perubahan penggunaan lahan ruang terbuka hijau di Jakarta Timur. *Jurnal Lanskap Indonesia* **2012**, *4*, 28–36.

23. Hermanto, S.S.A.; Makalew, A.D.N.; Sulistyantara, B. Hubungan antara perubahan tutupan lahan terhadap total penduduk yang dipengaruhi oleh fenomena urbanisasi di Bogor, Jawa Barat. *Jurnal Lanskap Indonesia* **2018**, *10*, 7–11, doi:10.29244/jli.v10i1.17397.

24. Siswanto, S.; Nuryanto, D.; Ferdiansyah, M.; Prastiwi, A.; Dewi, O.; Gamal, A.; Dimyati, M. Spatio-temporal characteristics of urban heat island of Jakarta Metropolitan. *Remote Sensing Applications: Society and Environment* **2023**, *32*, 1–15, doi:10.1016/J.RSASE.2023.101062.

25. Arifin, H.S.; Kaswanto, R.L.; Nakagoshi, N. Low carbon society through pekarangan, traditional agroforestry practices in Java, Indonesia. In *Designing Low Carbon Societies in Landscapes*; Nakagoshi, N., Mabuhay, J.A., Eds.; Springer Japan: Tokyo, Japan 2014; pp. 129–143, ISBN 978-4-431-54818-8.

26. Dobos, E. Albedo. In *Atmosphere and Climate*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2020; ISBN 978-0-429-44098-4.

27. Rushayati, S.B.; Dahlan, E.N.; Hermawan, R. Ameliorasi iklim melalui zonasi hutan kota berdasarkan peta sebaran polutan udara. *Forum Geografi* **2010**, *24*, 73–84.

28. Badan Pusat Statistik. *Statistika Indonesia 2020*; Badan Pusat Statistik: Jakarta, Indonesia, 2020; ISBN 0126-2912.

29. Artikanur, S.D.; June, T. Surface temperature and heat fluxes: Comparison between natural forest and oil palm plantation in Jambi Province using surface energy balance algorithm for land (SEBAL). *J.Agromet* **2019**, *33*, 62–70, doi:10.29244/j.agromet.33.2.62-70.

30. Pal, S.; Ziaul, S. Detection of land use and land cover change and land surface temperature in english bazar urban centre. *The Egyptian Journal of Remote Sensing and Space Science* **2017**, *20*, 125–145, doi:10.1016/j.ejrs.2016.11.003.

31. Tran, D.X.; Pla, F.; Latorre-Carmona, P.; Myint, S.W.; Caetano, M.; Kieu, H.V. Characterizing the relationship between land use land cover change and land surface temperature. *ISPRS Journal of Photogrammetry and Remote Sensing* **2017**, *124*, 119–132, doi:10.1016/j.isprsjprs.2017.01.001.

32. Burakowski, E.; Tawfik, A.; Ouimette, A.; Lepine, L.; Novick, K.; Ollinger, S.; Zarzycki, C.; Bonan, G. The role of surface roughness, albedo, and bowen ratio on ecosystem energy balance in the eastern United States. *Agricultural and Forest Meteorology* **2018**, *249*, 367–376, doi:10.1016/j.agrformet.2017.11.030.

33. Trlica, A.; Hutyra, L.R.; Schaaf, C.L.; Erb, A.; Wang, J.A. Albedo, Land cover, and daytime surface temperature variation across an urbanized landscape. *Earth's Future* **2017**, *5*, 1084–1101, doi:10.1002/2017EF000569.