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Analysis of Dense Residential Areas Using Normalized Difference Built-Up Index and Its Relation to Land Surface Temperature

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Abstract

In 2022, the population increased compared to the previous year. Rapid urban development has led to various challenges in providing urban infrastructure, public amenities, and a suitable residential environment. Land use changes from residential areas to commercial purposes such as trade, hotels, offices, and services have significantly impacted land availability. This shift also influences land surface temperature (LST), as it is affected by vegetation density, building density, and population levels in the area. This study aims to analyze dense residential areas using the Normalized Difference Built-up Index (NDBI) and Land Surface Temperature (LST) in Balikpapan City, covering an area of 510.79 hectares in East Kalimantan in 2022. In 2019, the dense residential area in Balikpapan consisted of approximately 295.81 ha of non-settlement area, 133.74 ha of non-compact settlement, and 81.24 ha of dense settlement. By 2022, the non-settlement area was approximately 291.64 ha, with 141.33 ha of non-compact settlement and 77.82 ha of dense settlement. In 2019, LST in Balikpapan ranged between 16°C and 31°C, while in 2022, it ranged between 19°C and 30°C. Correlation analysis between NDBI values and LST in 2019 showed a correlation coefficient (r) of 0.79, and in 2022, an r value of 0.71. Based on this range of 0.70 to 0.89, the correlation between NDBI and LST in Balikpapan is considered strong and significant.

Keywords: Dense Settlement; Built Normalized Difference Index; Land Surface Temperature; Landsat-8 OLI/TIRS.

1. Introduction

Rapid urban development poses challenges in the provision of urban infrastructure, amenities, and residential environments. More importantly, this growth is not aligned with the availability of employment opportunities. As a result, low-income populations tend to settle in areas that correspond to their financial capacity [1–4]. According to the Balikpapan City Spatial and Regional Plan (RTRW) 2012–2032, Section 50, Paragraph (1), the area allocated for housing, as stated in Article 47, covers approximately 10,902 hectares. This area is designated for high-density, medium-density, and low-density residential use [5]. The projected population of Balikpapan City by sub-district in 2022 is as follows: South Balikpapan – approximately 148,650; Balikpapan City – approximately 83,000; East

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Balikpapan – approximately 95,064; North Balikpapan – approximately 175,440; Central Balikpapan – approximately 107,155; and West Balikpapan – approximately 94,302. This reflects an increase in population compared to the previous year [6, 7].

The development of a region can be observed through its physical transformation. Physical development is typically marked by land use changes—from agricultural to non-agricultural uses—beginning at the periphery and extending toward the urban center. One such change involves the conversion of residential areas into commercial zones, including trade, hotels, offices, and services, which significantly impacts land availability. These changes also influence Land Surface Temperature (LST), as it is affected by vegetation density, building density, and population distribution in the area [8].

According to the Instruction of the Minister of Home Affairs No. 14 of 1988, the recommended ratio between green open space and built-up areas for a city or regency is 3:2 [9]. However, in practice, not all cities or districts are able to achieve this ratio. Consequently, the continued expansion of built-up areas—both buildings and other infrastructure—has contributed to temperature increases of up to 56°C [10].

In many Indonesian cities, rising temperatures are common and are largely a result of urban development that overlooks the necessity of green open space. To mitigate these impacts, various approaches are needed to estimate and manage urban land dynamics. This can be achieved by mapping building density and classifying building density levels, which in turn helps identify areas where land has been converted for urban development.

This study aims to analyze dense residential areas in Balikpapan City, East Kalimantan, using the Normalized Difference Built-up Index (NDBI) and relate it to Land Surface Temperature (LST) in 2022. The methodology involves the analysis of satellite and thermal sensor data from Landsat-8 OLI/TIRS imagery to assess the effects of dense residential development on surface temperature. The authors applied the NDBI algorithm to identify densely built-up areas and used LST data to determine land surface temperatures [11, 12]. NDBI was introduced by Zha et al. (2003) as a method for automating the mapping of built-up land [13]. This research is therefore expected to provide deeper insights into the relationship between dense residential land use and variations in land surface temperature in Balikpapan City.

2. Research Methodology

2.1. Research Location

The location of this research is in Balikpapan City, East Kalimantan Province [6]. This study analyzes slum areas using the Normalized Difference Built-Up Index (NDBI) algorithm and examines its impact on Land Surface Temperature (LST) in Balikpapan City in 2022 (Figure 1).

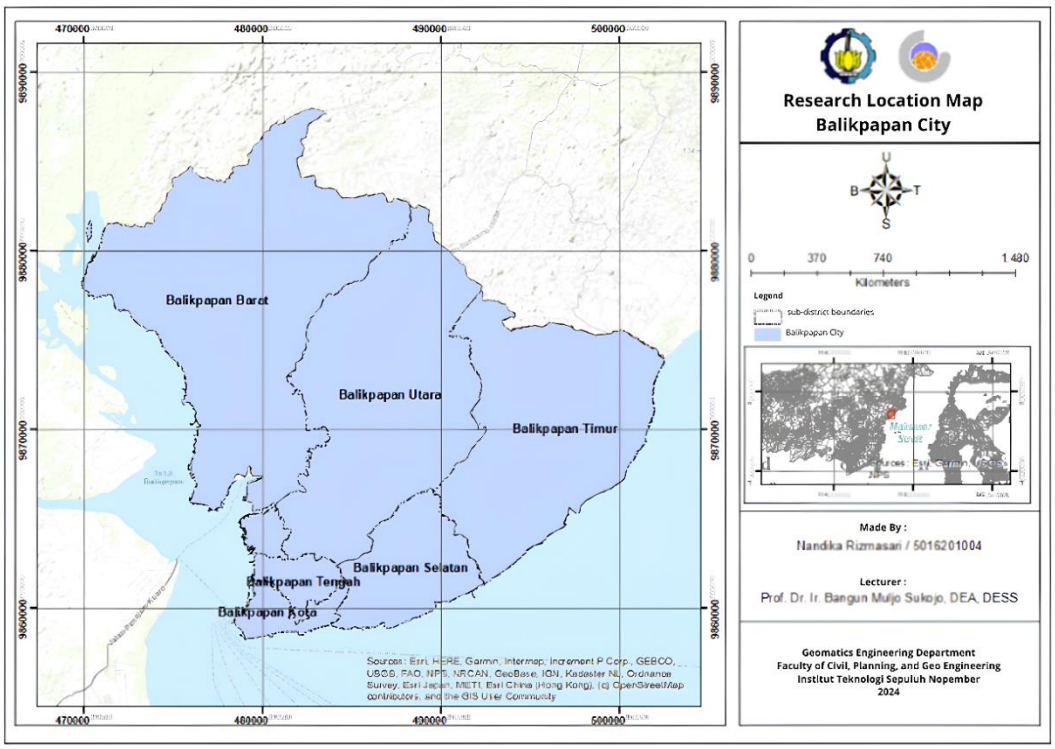


Figure 1. Research Location

The methods employed in this research include the Normalized Difference Built-Up Index (NDBI) [13] and Land Surface Temperature (LST) [14, 15]. The study area is located in East Kalimantan Province, specifically in Balikpapan City. Geographically, Balikpapan is situated between 116.5º and 117.0º East Longitude, and between 1.0º and 1.5º South Latitude. The sub-districts included in the study have the following geographical boundaries:

- North bordering Kutai Kartanegara Regency;
- West bordered by North Penajam Paser Regency;
- South bordered by the Makassar Strait;
- East bordered by the Makassar Strait.

2.2. Equipment and Data

The data required for this study are as follows:

- **Landsat 8 OLI/TIRS Level 1 and 2 satellite imagery**, acquired between January 1, 2019, and December 31, 2019, and between January 1, 2022, and December 31, 2022, obtained from the USGS [16]. These images are used to analyze residential areas and land surface temperature.
- **Shapefile (shp) data of Balikpapan City's sub-district boundaries** at a scale of 1:25,000, obtained from the Ina-Geoportal website [17].
- **Validation data** collected directly from the settlement areas.
- **Temperature distribution data** from BPS and BMKG, used to validate the average temperature of Balikpapan City [6].

The equipment used for data processing in this study includes hardware such as an *Asus TUF Gaming A15* laptop, and software such as *ArcGIS 10.8.2* [18], *Google Earth Engine* [16, 19, 20], and *Microsoft Office 365*.

2.3. Data Processing Phase

The flowchart of the research methodology that was used to achieve the study's aims is shown in Figure 2.

Figure 2. Data Processing Flowchart

1. Landsat-8 OLI/TIRS

Landsat 8 OLI/TIRS Level 1 and 2 satellite images, acquired between January 1, 2019, and December 31, 2019, and between January 1, 2022, and December 31, 2022, were obtained from the USGS [16].

2. Cropping

The cropping process is conducted to focus the analysis on the specific study area.

3. NDBI Extraction

NDBI is used to identify built-up areas. In this study, the NDBI is calculated using Band 5 (near-infrared) and Band 6 (shortwave infrared) [13].

4. NDBI Classification

Based on the NDBI index, building density levels can be determined, indicating the extent of dense residential development in an area. NDBI classification divides residential areas into three categories: non-settlement, non-dense, and dense [20, 21].

5. LST Processing

Land Surface Temperature (LST) processing was performed using Band 10 from Landsat-8 OLI/TIRS Level 1. The digital number (DN) values from the image were converted into spectral radiance using the formula provided in [14].

$$L\lambda = ((LMAX\lambda - LMIN\lambda)/(QCALMAX - QCALMIN)))^* (QCAL - QCALMIN) + LMIN\lambda \quad (1)$$

where; Lλ = Spectral radiance, QCAL = Digital number (DN), LMAXλ = Maximum value of spectral radiance at thermal band, LMINλ = Minimum value of spectral radiance at thermal, QCALMAX = Minimum quantized pixel value, QCALMIN = Maximum quantized pixel value.

After getting the radiation results, it is converted into a temperature value with the formula [14, 15]:

$$T = K2/In ((K1/ L\lambda + 1) \quad (2)$$

where; T = Temperature obtained from satellite sensor (Kelvin), K1 = Calibration constant 1 for Landsat OLI (774.853 K), K2 = Calibration constant 2 for Landsat OLI (1321.0789 K), Lλ = Spectral radiance from the 10th band.

From the temperature value obtained, it is still in the form of Kelvin units, so it is converted to Celsius using the formula:

$$Temp - °C = Temp - K - 272.15 = T - 272.15 \quad (3)$$

1. Accuracy Test

   This process was conducted by validating the data using geotagged points collected in the field and performing a correlation test using the Pearson Correlation method [14].

2. Result Analysis

   The analysis was carried out using the results from NDBI and LST processing to examine the relationship between dense residential areas and land surface temperature in Balikpapan City.

3. Results and Discussion

3.1. Normalized Difference Built-Up Index (NDBI)

In this study, the Normalized Difference Built-Up Index (NDBI) was used to analyze dense residential areas in Balikpapan City, utilizing Landsat-8 Level 2 imagery processed through Google Earth Engine (GEE). The analysis is based on data from 2019 to 2022. The results are illustrated in Figure 3, showing the dense residential areas in 2019, and Figure 4, depicting those in 2022.

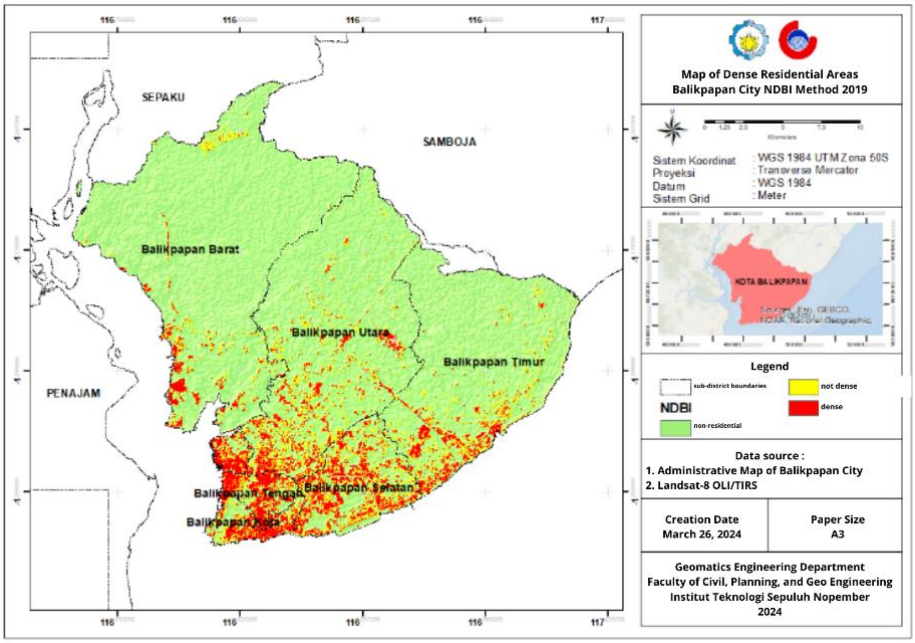


Figure 3. NDBI 2019

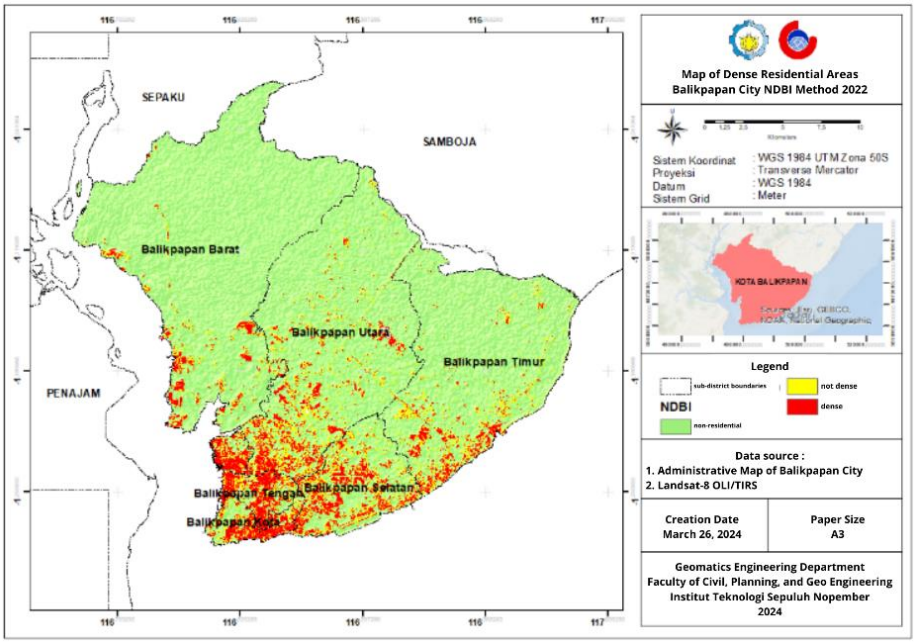


Figure 4. NDBI 2022

NDBI values range from -1 to 1. Values less than 0 indicate non-built-up areas, classified as non-settlement zones. These areas may include vegetation, water bodies, or roads. Values within the range of 0 to 1 represent varying levels of building density, where higher values indicate greater building concentration and denser development. In the classification results, non-settlement areas are visualized in green, non-dense areas in yellow, and dense residential areas in red.

Based on the NDBI results for 2019, as shown in Figure 5 and Table 1, non-residential areas are predominantly located in West Balikpapan. This is consistent with the fact that the western part of Balikpapan City is still largely covered by forest. In contrast, the northern, southern, central (city), and eastern parts of Balikpapan show a high density of built-up areas. While East and West Balikpapan display a wide range of density values, these regions still maintain a significant presence of vegetation and non-residential land. Central, South, and City Balikpapan are the most densely populated sub-districts and exhibit very high building density.

The classification of dense residential areas using NDBI in 2019 resulted in a value range from -0.648 to 0.165, as illustrated in Figure 5, the NDBI 2019 histogram.

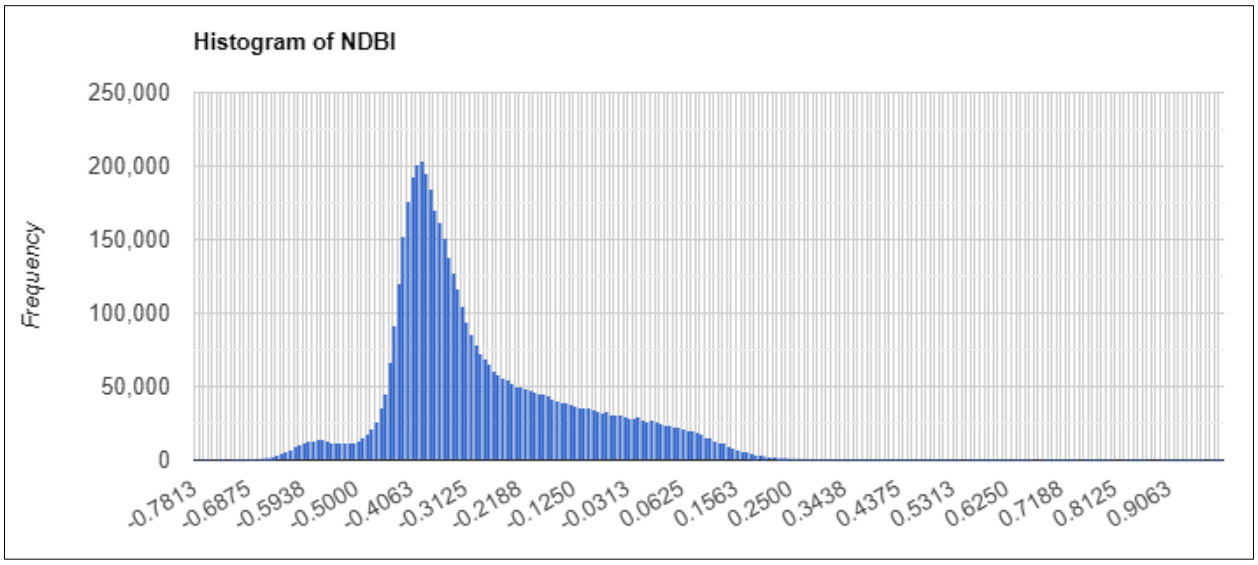


Figure 5. Histogram NDBI 2019

Areas classified into the non-settlement class with an NDBI index range of -0.65 – 0 can be vacant land, vegetation, roads or water bodies. Areas classified into the non-dense class with an NDBI index range of 0 – 0.1 indicate that the area has a low building density. While slum areas have an NDBI index range of 0.1 – 0.16 indicating the area has a high building density. From the classification results, the area is obtained as follows

Table 1. Area of dense settlement area in 2019

Class	Area (ha)
Non-Settlement	295,81
Non-Desen	133,74
Dense	81,24
Total	**510,79**

Based on the analysis, densely populated settlement areas in 2022 are classified into three categories, with an NDBI value range of -0.67 to 0.23 (see Figure 6 and Table 2). Areas falling within the non-settlement class, with NDBI values between -0.67 and 0, may include vacant land, vegetation, roads, or water bodies. Areas within the non-dense class, with NDBI values ranging from 0 to 0.1, indicate low building density. Meanwhile, slum or densely built-up areas are characterized by NDBI values between 0.1 and 0.22, reflecting high building density. The extent of the dense residential areas is as follows:

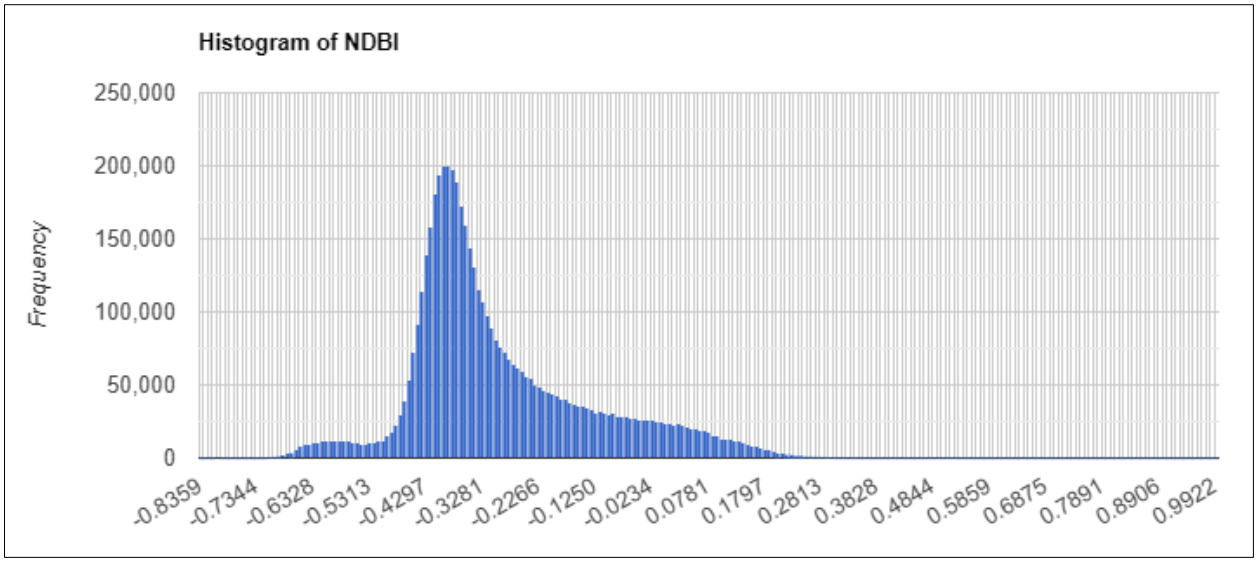


Figure 6. Histogram NDBI 2022

Table 2. Area of dense settlement area in 2022

Class	Area (ha)
Non-Settlement	291,64
Non-Desen	141,33
Dense	77,82
Total	510,79

3.2. Land Surface Temperature (LST)

The results of the surface temperature analysis of Balikpapan City using the Land Surface Temperature (LST) method utilizing Landsat-8 images in 2019 and 2022 at levels 1 and 2 using Google Earth Engine (GEE) can be seen in Figures 7 and 8.

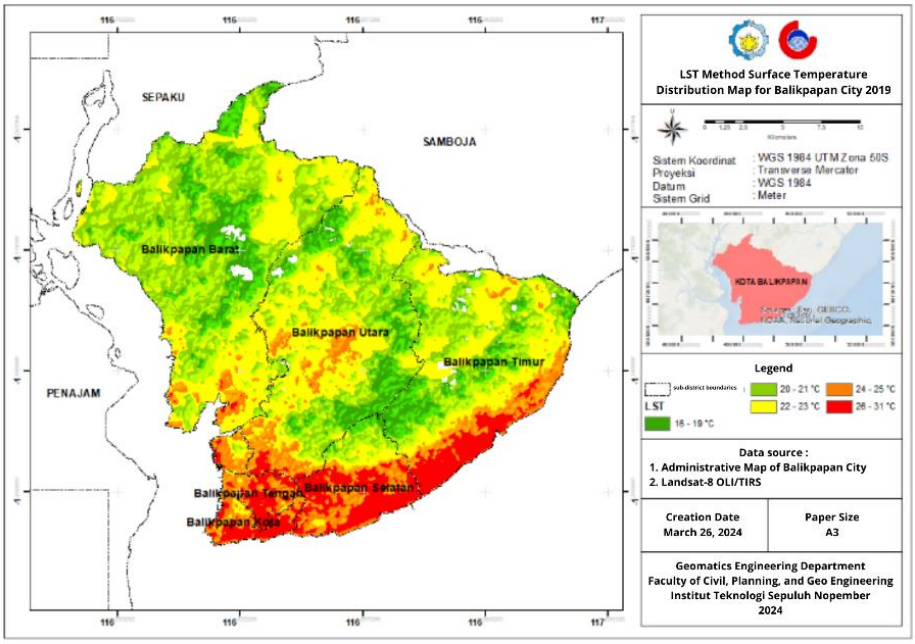


Figure 7. LST 2019

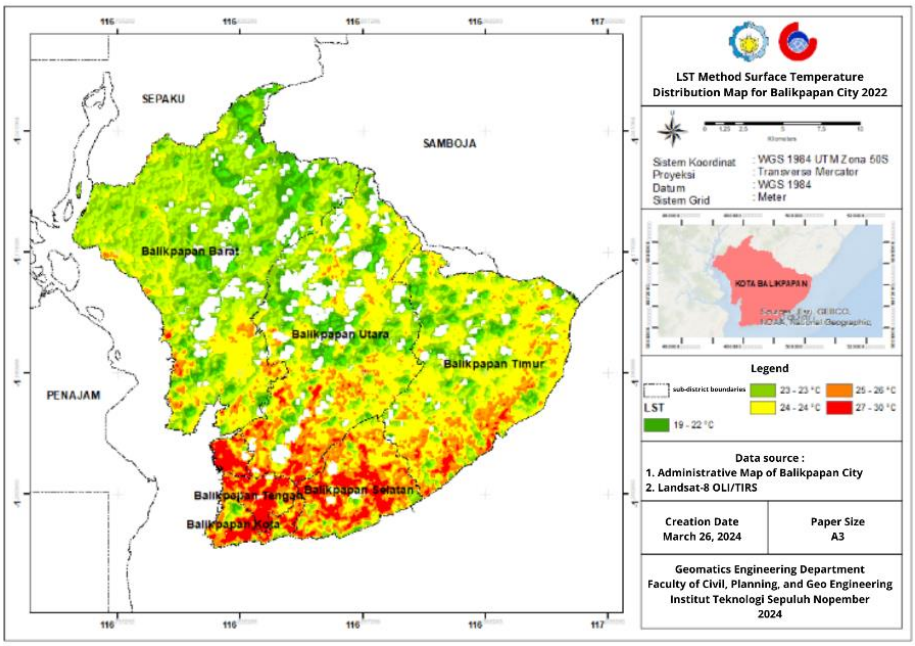


Figure 8. LST 2022

In this study, the Land Surface Temperature (LST) method is used to analyze the surface temperature of Balikpapan City. Based on the LST processing results, the city exhibits a temperature range between 16°C and 31°C, which is categorized into five temperature classes. Visually, Balikpapan is still largely dominated by temperatures in the 16–23°C range. However, Central, South, and East Balikpapan show higher temperature ranges, predominantly between 24–31°C. These areas are known to have high building density. Additionally, land fires occurring from August to September in the South and East Balikpapan regions, along with disrupted air circulation, have contributed to elevated surface temperatures.

In contrast, West and North Balikpapan are mainly characterized by lower temperatures, ranging from 16–23°C, due to the prevalence of green spaces and vegetation cover. In the 2022 LST analysis, surface temperatures in Balikpapan ranged from 19°C to 30°C. The southern region of Balikpapan—including the Central and South sub-districts—was primarily dominated by temperatures in the 25–30°C range. Meanwhile, the northern areas—covering the West and North sub-districts—experienced lower temperatures, mostly in the 19–23°C range. In East Balikpapan, the temperature was predominantly around 24°C.

The findings indicate that land surface temperatures in Balikpapan vary significantly depending on land cover type and observation period. Areas dominated by vegetation generally exhibit lower temperatures compared to areas with high building density, such as residential and industrial zones. Furthermore, coastal areas also influence surface temperatures, as marine environments tend to have higher heat absorption and storage capacity due to their thermal characteristics.

3.3. Validation Test

Figure 9 shows a map of validation result points in dense residential areas of Balikpapan City

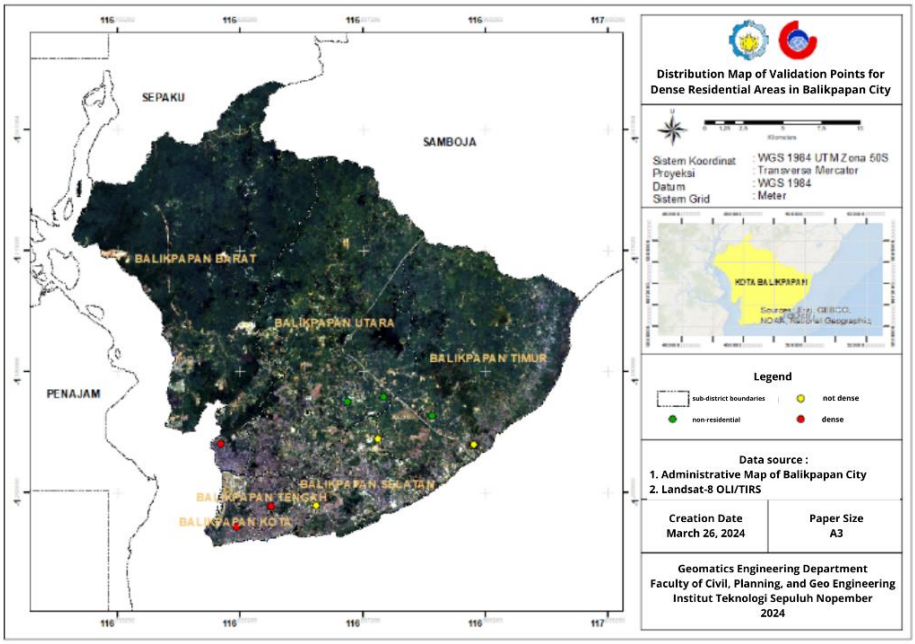


Figure 9. Validation Point Distribution

Validation points were randomly selected and categorized into three classes: non-settlement, non-dense, and dense. These points were collected through geotagging using the GPSMap application on a smartphone. A total of 43 validation points were recorded across six sub-districts, consisting of 17 points in the non-settlement class, 12 in the non-dense class, and 14 in the dense class. The non-settlement class is represented by green dots, the non-dense (uncrowded) class by yellow, and the dense (crowded) class by red. The results indicate that dense settlements are highly concentrated in Central Balikpapan, an area characterized by minimal vegetation and limited green space. Data collection in West Balikpapan was limited due to difficult or inaccessible road conditions.

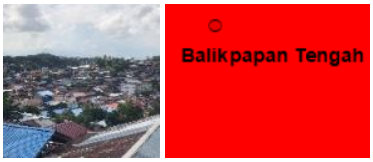
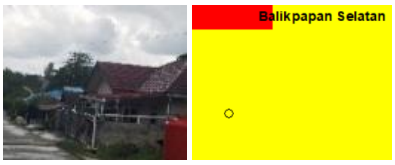
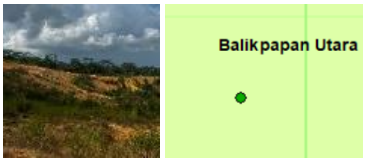
Table 3 presents the distribution of validation points across Balikpapan City:

Table 3. Validation Point Distribution

X	Y	Class
116,908084	-1,261357	Dense
116,904829	-1,239559	
116,823834	-1,271103	
116,82099	-1,26958	
116,843858	-1,257107	
116,842866	-1,25722	
116,839491	-1,268082	
116,972606	-1,216332	
116,973622	-1,216815	
116,820694	-1,272082	
116,84827	-1,23231	
116,84262	-1,24263	
116,83963	-1,24447	
116,83926	-1,24257	
116,870077	-1,258823	Non-Dense
116,905899	-1,220355	
116,865074	-1,264906	
116,81605	-1,220517	
116,814632	-1,223197	
116,91439	-1,195928	
116,889374	-1,196423	
116,876931	-1,204432	
116,961729	-1,22363	
116,959643	-1,225995	
116,86601	-1,4531	
116,8668	-1,24822	
116,87729	-1,25828	Non-Settlement
116,87671	-1,25475	
116,906414	-1,235122	
116,900644	-1,247006	
116,869523	-1,259332	
116,821061	-1,269614	
116,869645	-1,259184	
116,81525	-1,221711	
116,888303	-1,198649	
116,909406	-1,195797	
116,92301	-1,197013	
116,937524	-1,206734	
116,87614	-1,25696	
116,923768	-1,213142	
116,8866	-1,20026	
116,838484	-1,19883	
116,85616	-1,24107	

Validation points are only taken from a sample of 3 classification classes, which are matched with the results of NDBI processing. Can be seen in Table 4 as follows:

Table 4. NDBI Validation

X	Y	Class
116,843858	-1,257107	Dense 
116,905899	-1,220355	Non-Dense 
116,909406	-1,195797	Non-Settlement 

3.4. Analysis of Surface Temperature Relationship between LST Method and Dense Residential Area using NDBI Method

The parameter value test in the calculation process utilizes the results of surface temperature analysis using the Land Surface Temperature (LST) method, along with building density values obtained from the Normalized Difference Built-Up Index (NDBI) processing. The Pearson correlation test is applied to assess the relationship between surface temperature and built-up land. This relationship is illustrated in Figure 10, which shows the scatter plot of the LST and NDBI correlation test for the years 2019 and 2022.

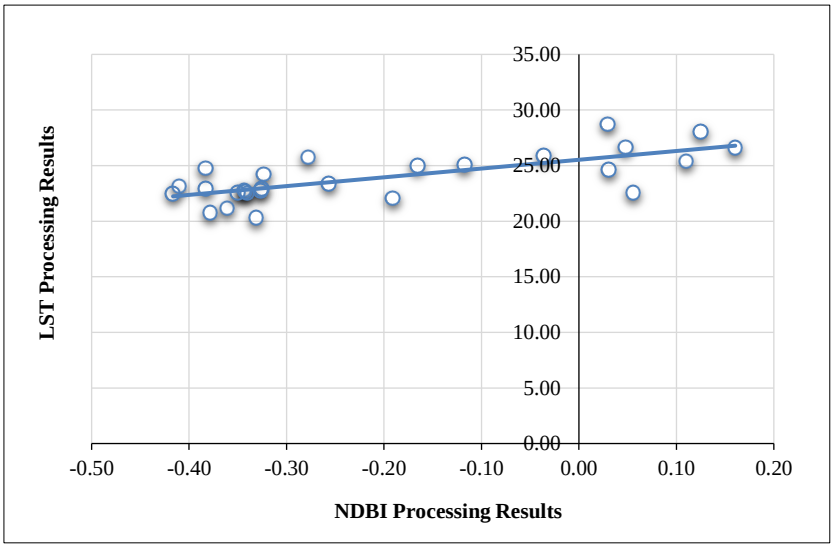


Figure 10. Scatter Plot of LST and NDBI Correlation Test in 2019 and 2022

The relationship between surface temperature and NDBI was determined by statistical analysis of the Pearson product moment correlation test. The results obtained from the correlation test show a positive relationship between land surface temperature and NDBI values. The correlation value between land surface temperature and NDBI value in 2019 is 0.79.

While in 2022 it shows a correlation value of 0.71. The correlation direction graph goes to a positive direction value, it can be interpreted that the building density value is directly proportional to the land surface temperature value, where the higher the land surface temperature value, the higher the building density value.

4. Conclusions

Based on the research results, the following conclusions were obtained:

- The processing method using Normalized Built-Up Index (NDBI) to analyze the dense residential areas in Balikpapan City in 2019 obtained the non-settlement area of 295.81 ha, non-dense settlements of 133.74 ha, and dense settlements of 81.24 ha. While in the NDBI processing in 2022, the area of non-settlement is 291.64 ha, non-dense settlement is 141.33 ha, and dense settlement is 77.82 ha. The total area is 510.79 ha.
- Balikpapan City in 2019 has a temperature interval between 16°C - 31°C which is divided into five temperature classes. Visually, Balikpapan City is still dominated by temperature between 16°C - 23°C. It can be seen that Balikpapan City, Central, South, and East are dominated by high temperatures in the range of 24°C - 31°C. In 2019, the high surface temperature in the city, east, south, and central parts of Balikpapan City is due to land fires and air circulation that affect the surface temperature in the Balikpapan City area. In 2022, the temperature in Balikpapan City has a range between 19°C - 30°C. Based on the LST results, it can be seen that the sub-districts of Balikpapan City, Central, South have temperatures dominated by the temperature range of 25°C - 30°C. The high temperature interval in those areas can be caused by the presence of dense built-up land or settlement density and lack of green open land.
- Land Surface Temperature (LST) in Balikpapan City varies significantly depending on the type of land cover and time of observation. It can be seen that areas with land cover dominated by vegetation tend to have lower temperature than areas with high building density such as residential areas or areas with industrial activities. In addition, areas located in coastal areas can also affect the temperature level where the characteristics of marine waters have very high temperatures and are able to absorb and store heat in high enough amounts.

Suggestions that can be given from this research include:

- It is necessary to determine the parameters of each processing method in order to have more accurate results.
- When choosing a study area, it is better to first study the area so that there are no difficulties when selecting cloud-free images and maximizing processing.
- It is necessary to conduct further studies of the research results using different method correlations.

5. Declarations

5.1. Author Contributions

Conceptualization, B.M.S. and N.R.; methodology, F.B.; software, N.H.; validation, B.M.S., N.R., and A.W.H.; formal analysis, E.B.S.; investigation, I.A.; resources, F.B.; data curation, N.R.; writing—original draft preparation, H.A; writing—review and editing, H.A.; visualization, N.R.; supervision, A.W.H.; project administration, N.H.; funding acquisition, B.M.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding and Acknowledgments

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5.4. Institutional Review Board Statement

Not applicable.

5.5. Informed Consent Statement

Not applicable.

5.6. Declaration of Competing Interest

The authors declare that there are no conflicts of interest concerning the publication of this manuscript. Furthermore, all ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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