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Assessing the Relationship Between Land Surface Temperature and Vegetation Index During Revegetation Activities: A Remote Sensing Study on Berau Regency, East Kalimantan (2015-2021)

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Abstract

Coal mining, particularly open-pit mining methods, induces severe environmental degradation, including deforestation, loss of flora and fauna, and soil erosion. Consequently, extensive revegetation efforts are necessary to restore and rehabilitate the damaged vegetation. This study uses remote sensing techniques to investigate the correlation between land surface temperature (LST) and vegetation density over six years of revegetation activities. Temporal Landsat 8 imagery from 2015 to 2021 was used for data analysis. Image processing involved transforming the Normalized Difference Vegetation Index (NDVI) and extracting LST data. Statistical correlation analysis using Pearson correlation was employed to analyze the data. Results indicate a notable decline in land surface temperature at the project site from 2015 to 2021, attributed to the gradual reduction of open spaces from coal mining activities, which were gradually replaced by vegetation cover. Concurrently, NDVI values at the site significantly increased over the same period, indicating the successful transition from barren land to vegetated land. Moreover, a substantial correlation between LST and NDVI values was observed, as denoted by Pearson coefficient exceeding 0.7, with a strong negative correlation. This underscores the significant relationship between vegetation cover and land surface temperature dynamics. These findings emphasize the effectiveness of revegetation efforts in mitigating the adverse impacts of coal mining on the environment. They highlight the crucial role of remote sensing in monitoring and assessing the progress of rehabilitation activities, guiding future revegetation strategies for sustainable land management and ecosystem restoration.

Keywords: Revegetation, Coal mining, Remote sensing, Land surface temperature (LST), NDVI

1. Introduction

Coal mining in Indonesia, particularly through open-pit mining methods, involves land clearing, topsoil removal, overburden removal, temporary stockpiles, crushing, washing, hauling, and shipping/barging[1][2]. These methods carry the potential risk of environmental damage because of their extractive activities [3][4]. Environmental damage includes decreased soil productivity, alterations in soil physical and chemical properties, disruptions to soil mechanical stability, habitat disturbances for flora and fauna, as well as perturbation of the microclimate and health of the surrounding community near the mine site [5][6].

The extensive environmental impact necessitates the prompt restoration of ex-mining land following relevant regulations. Permit-holding companies play an important role in restoring former mining areas' function to their original function, aligning with Law No. 4 of 2009 [7] and technical implementation based on Government Regulation No. 78 of 2010 [8] and the Ministry of Energy and Mineral Resources Regulation No. 18 of 2008 [9]. However, it is also necessary to monitor the success of reclamation on ex-mining land following Ministry of Environment Regulation No. 04 of 2011 [10]. A key criterion for reclamation success involves assessing the revegetation activities regarding environmental indicators relevant to open-pit coal mining. An effective approach for monitoring revegetation success in reclaimed areas involves integrating environmental factors, particularly microclimate dynamics within the region. Changes in land cover also contribute to variations in the microclimate within an area [5][11][12].

Nusantara Berau Coal (NBC), one of the coal mining companies in Berau, East Kalimantan, has carried out revegetation activities in the reclamation area. Related research on revegetation activities at the NBC is limited to land processing to reduce soil acid levels, selecting local and non-local plant species with economic value, and calculating the percentage of plant life [13]. This prompted us to conduct further research on the effectiveness of reclamation activities, particularly focusing on the changes in land surface temperature during the revegetation process. In this study, we employed remote sensing technology and statistical analysis to determine the correlation.

As evidenced by prior research, the utilization of remote sensing technology for assessing reclamation efficacy has been extensively undertaken, as demonstrated at the Vale Indonesia company and Aroma Cipta Anugrahtama company mining sites through the analysis of the normalized difference vegetation index (NDVI) values [14][15]. The NDVI value serves as a valuable metric for assessing the degree of success and monitoring the progress of revegetation efforts across open pit reclamation sites from year to year [16]. However, remote sensing studies in post-coal mining reclamation areas have limited evidence of the relationship between the NDVI and Land Surface Temperature (LST). Urban areas typically research the relationship between NDVI and LST to determine the heat island effects [17][18]. Therefore, monitoring reclamation success, particularly linking changes in NDVI to LST in revegetation areas, needs further examination. Thus, this study aims to assess the effectiveness of reclamation efforts at the NBC Company by employing remote sensing techniques to analyze the NDVI and changes in LST within the area.

2. Materials and Methods

2.1. Study location

This research was conducted on the post-coal mining land of the NBC company Berau Regency, East Kalimantan (Figure 1). The post-coal mining land area was approximately 5 ha. There are two observation locations, Block A coordinate points at N 2°18'00.3" and E 117°20'49.8" and Block B at points N 2°17'46.4" and E 117°20'16.1". Block A has flat topography, and Block B has undulating topography. Three primary plants were planted at the research location: *Shorea balangeran*, *Vitex pubescens*, and *Melaleuca cajuputi*, with the predominant species being approximately 5 years old. In each block, there were four planting patterns (plots), namely 3 plots using similar planting patterns (*Shorea balangeran, Vitex pubescens*, and *Melaleuca cajuputi*) and one plot using mixed planting patterns. Therefore, the total number of plots constructed was eight.

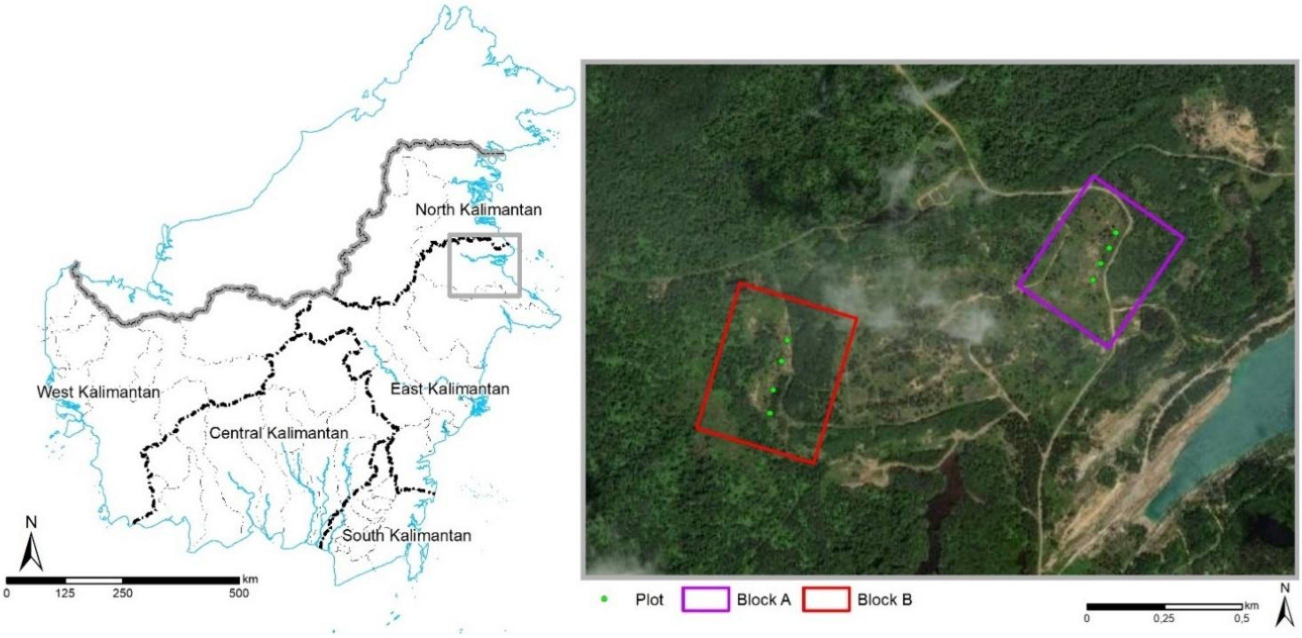

Figure 1. The research site is situated in the Berau Nusantara Coal Revegetation Area, Berau Regency, East Kalimantan.

2.2. Data Processing

2.2.1. Data collection

The data used in this study were Landsat 8 images recorded over the last six years (2015, 2016, 2017, 2018, 2019, and 2021) (Table 1). Landsat 8 images have a spatial resolution of 30 meters for the bands relevant to vegetation analysis, thus producing high-quality and accurate data [19]. The 2020 Landsat 8 imagery at the study area had cloud cover above 20%, making it difficult to analyze. Although some images have high cloud cover, the study area has very little cloud cover. Landsat 8 records cycles every 16 days, thus providing consistent and up-to-date data[20]. This is important for monitoring vegetation changes over time, such as in NDVI analysis. NDVI analysis was used to obtain data on the changes in land cover resulting from the revegetation process. The NDVI values indicate the year-to-year transformation of land cover in the revegetation area, whereas the LST values from image processing provided information on the changes in surface temperature in that area.

Table 1. The information of cloud cover in the study area data from the Landsat 8

No	Year	Date acquired	Cloud cover (%)
1.	2015	28 August 2015	17.22
2.	2016	15 September 2016	6.72
3.	2017	02 September 2017	56.23
4.	2018	17 June 2018	68.58
5.	2019	03 May 2019	45.46
6.	2021	06 April 2021	67.61

2.2.2. Image Processing

Image pre-processing was performed by applying radiometric correction and image masking. Radiometric correction, according to the USGS[20], includes conversion to top-of-atmosphere (TOA) radiance and TOA reflectance. Furthermore, an Area of Interest (AOI) at the research location was applied to obtain a more specific area for this study, and image masking reduced cloud cover outside the AOI because high cloud cover could interfere with the analysis. Vector data were used as mask files.

NDVI transformation was performed by comparing the reflectance values of the near-infrared (NIR) and red (R) wavelengths[19]. The formula for NDVI is as follows:

$$\text{NDVI} = \frac{(NIR - R)}{(NIR + R)} \quad (1)$$

The NDVI values ranged from -1 to 1. A value of -1 signifies the absence of vegetation, whereas a value of 1 represents dense vegetation. An NDVI value below 0.3 indicates sparse or low vegetation conditions, whereas a value above 0.6 denotes fairly dense to highly dense vegetation [19–21].

NDVI was also utilized to perform emissivity correction for band 10 (thermal band) of Landsat imagery [22]. Conversion to surface temperature follows this equation [17]:

$$T = \frac{K_2}{\ln\left(\frac{K1}{L\lambda} + 1\right)} \quad (2)$$

where T is the top of the atmospheric brightness temperature (K), Lλ is the TOA spectral radiance (Watts/(m^2 * srad * μm)), and K1 and K2 are band-specific thermal conversion constants from the metadata.

2.2.3. Correlation Analysis

Pearson correlation analysis was used to determine the relationship between NDVI and LST using the SPSS software. Pearson's correlation analysis is a statistical method used to measure the strength and direction of the linear relationship between two continuous variables. This approach has been widely applied to analyze the relationship between NDVI and climatic factors [21][22]. The result, known as the Pearson correlation coefficient (r), ranges from -1 to +1, where +1 indicates a perfect positive linear relationship, -1 indicates a perfect negative linear relationship, and 0 indicates no linear relationship.

3. Results

3.1. Result of Land Surface Temperature and Normalized Difference Vegetation Index

Figure 2 shows the changes in LST at the revegetation site from 2015 to 2021. Open areas exhibited higher temperatures than vegetated areas. From 2015 to 2017, open areas from coal mining exhibited significantly high temperatures, as indicated by the red gradation in Figure 2. However, the temperature gradually decreased in 2018, 2019, and 2021, with the map colors transitioning towards green gradations.

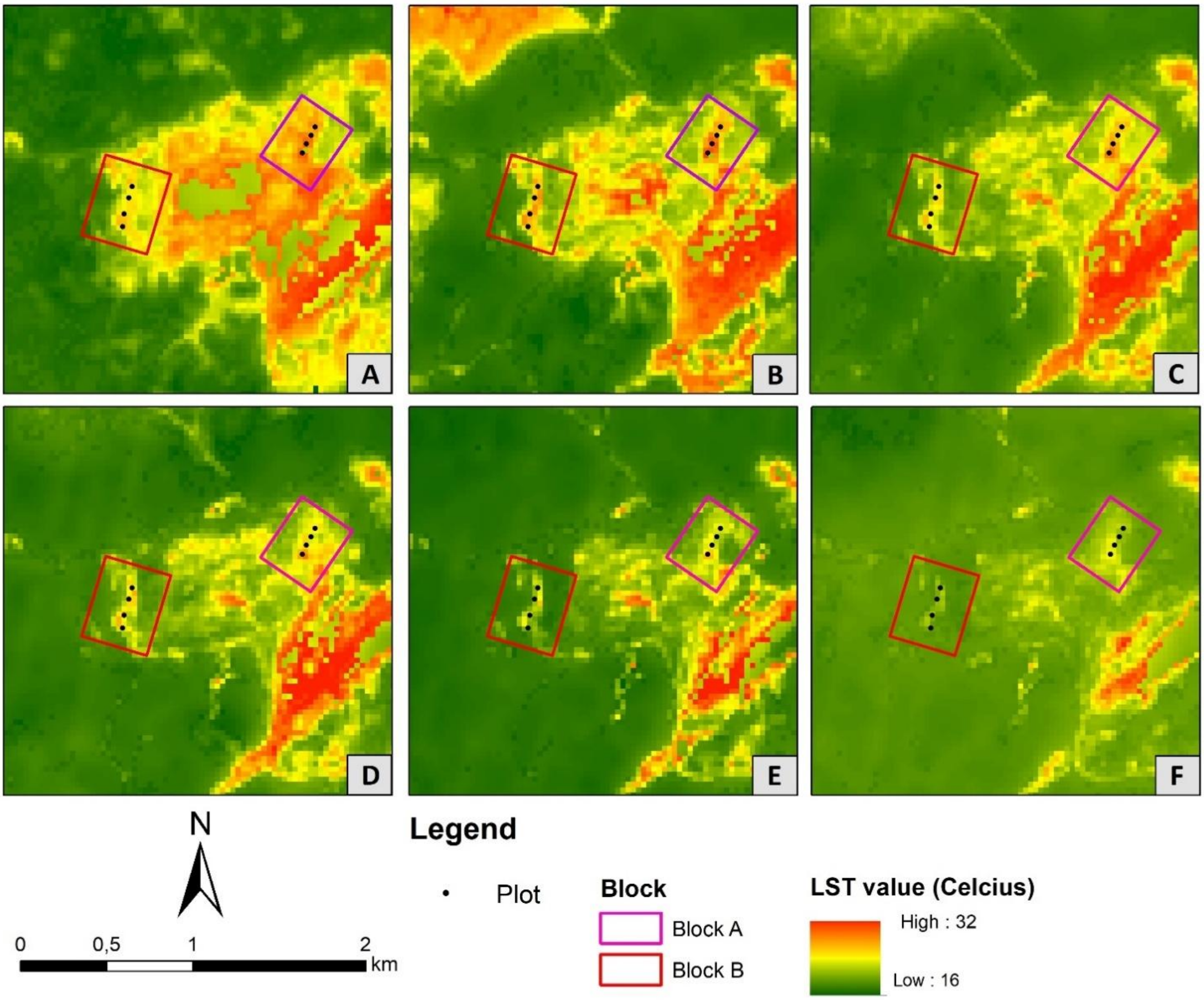

Figure 2. The results of the analysis of LST at the research location showed changes in LST values from year to year., (A) 2015; (B) 2016; (C) 2017; (D) 2018; (E) 2019; (F) 2021.

LST calculations were carried out on each measurement plot consisting of *V. pubescens*, *M. cajuputi, S. balangeran*, and mixed plant types for 2015, 2016, 2017, 2018, 2019, and 2021 (Table 2). 29°C for land vegetated with *V. pubescens* and *M. cajuputi*, 28°C for land vegetated with *S. balangeran*, and 27°C for land with mixed plant types. By 2021, temperatures have decreased for all plant types to around 20.4°C–21.9°C, marking a reduction of approximately 7.4°C.

Table 2. LST recapitulation based on Landsat 8 Image

Plot	Temperature (°C)					
	2015	2016	2017	2018	2019	2021
A_*Vitex pubescens*	29.1	26.9	26.7	25.2	27.0	21.9
A_*Melaleuca cajuputi*	29.0	26.0	26.0	24.3	26.2	21.4
A_*Shorea balangeran*	28.0	25.0	25.0	23.2	25.3	20.6
A_Mixed	27.9	24.9	25.1	23.6	25.3	20.4
B_ *Vitex pubescens*	26.8	24.8	23.9	23.2	24.0	19.5
B_ *Melaleuca cajuputi*	26.3	25.1	25.0	25.0	25.3	20.9
B_ *Shorea balangeran*	26.1	24.6	24.4	24.2	24.5	20.1
B_Mixed	26.2	24.3	24.0	23.8	25.5	20.2

In 2015, Block B plots showed lower LST than Block A, at approximately 26 °C. By 2021, the temperature in block B decreased to between 19,5 °C and 20,9°C, marking a reduction of approximately 6,18 °C. In other words, the temperature decline in the plots of block A was greater than that in the plots of block B. The decrease in temperature in the plots of blocks A and B indicates that the open areas resulting from coal mining activities are gradually covered by vegetation. The trend of decreasing temperatures from 2015 to 2021 is shown in Figure 3.

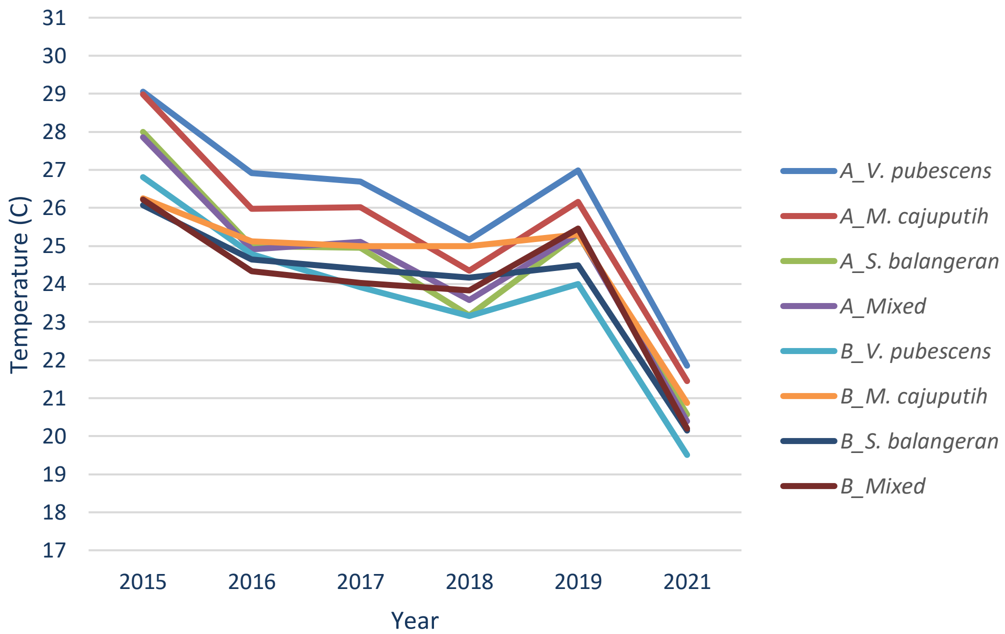

Figure 3. LST graph on each plot from 2015 to 2021. showed penurunan temperature dari tahun ke tahun di semua lokasi pengamatan

NDVI is used to assess land cover conditions, differentiate between vegetation and non-vegetation objects, and indicate the level of greenness and vegetation density [23][24][25]. NDVI values range from -1 to 1: water bodies have values <0, objects from 0 to 0.1 represent bare or built-up land, and values approaching 1 indicate dense vegetation. Figure 4 provides a visual comparison of NDVI values from 2015 to 2021, clearly showing the transformation from open areas (yellow) to areas gradually covered by vegetation (blue).

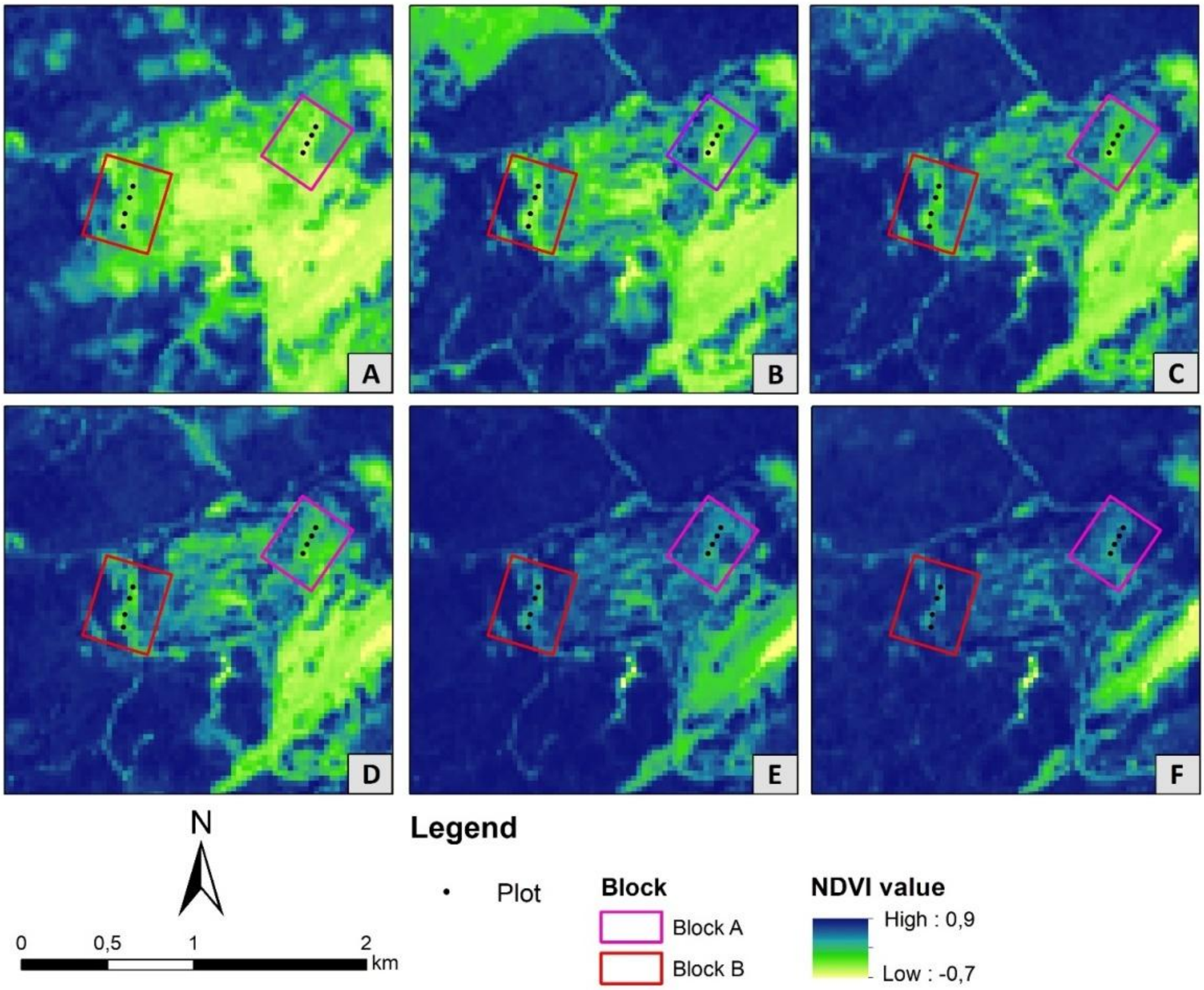

Figure 4. NDVI maps at research locations: (A) 2015; (B) 2016; (C) 2017; (D) 2018; (E) 2019; (F) 2021.

The NDVI values were calculated for each plot (**Table 3**). In 2015, the NDVI value in block A plots ranged from 0.16 to 0.21, indicating vegetation with low or sparse density, and increased to 0.45 from 0.61 in 2021. In block B's plots, NDVI values ranged from 0.23 to 0.26 in 2015 and increased to 0.44 to 0.66 in 2021. The increase in NDVI values was due to changes in land cover, transitioning from open to vegetated areas. The trend of increasing NDVI values at the active locations is illustrated in **Figure 5**.

Table 3. Recapitulation of NDVI values based on the Landsat 8 Image

Plot	2015	2016	2017	2018	2019	2021
A_*Vitex pubescens*	0.17	0.16	0.22	0.27	0.30	0.45
A_ *Melaleuca cajuputi*	0.16	0.21	0.26	0.33	0.39	0.49
A_ *Shore balangeran*	0.21	0.28	0.35	0.44	0.51	0.61
A_Mixed	0.21	0.28	0.33	0.39	0.48	0.61
B_ *Vitex pubescens*	0.23	0.22	0.33	0.39	0.55	0.66
B_ *Melaleuca cajuputi*	0.26	0.21	0.26	0.25	0.38	0.44
B_ *Shorea balangeran*	0.25	0.25	0.30	0.31	0.47	0.55
B_Mixed	0.26	0.27	0.32	0.32	0.35	0.53

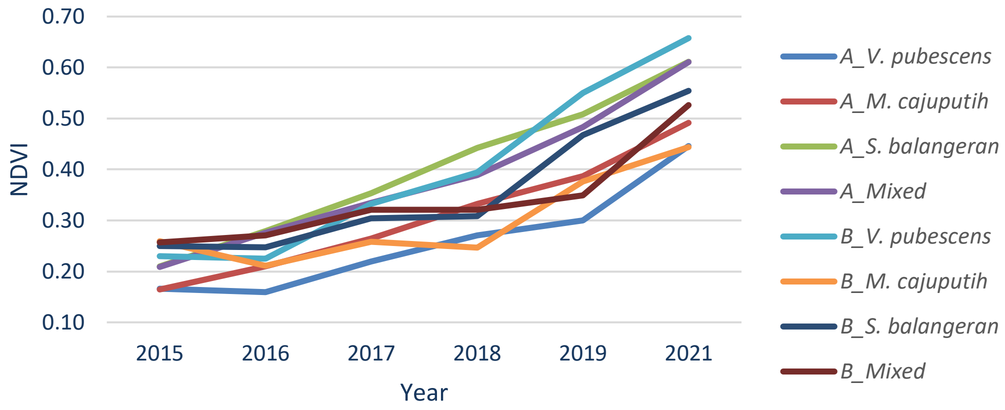

Figure 5. NDVI analysis results in graphic on each plot from 2015 to 2021

3.2 Correlation of Normalized Difference Vegetation Index and Land Surface Temperature

The data presented in Table 4 illustrate the Pearson correlation coefficients between NDVI and LST for 2015 to 2021, excluding 2020. In 2015, the Pearson coefficient was -0.979, indicating a very strong negative correlation between the NDVI and LST. As NDVI increased, LST decreased significantly and vice versa. In 2016, the coefficient was -0.805, demonstrating a strong negative correlation, albeit not as pronounced as in 2015, yet still signifying a significant inverse relationship between NDVI and LST. In 2017, the correlation coefficient was -0.745, indicating that the negative correlation, while still strong, was weaker than that in 2015 and 2016, but the inverse relationship persisted with slightly less intensity. In 2018, the coefficient was -0.925, reflecting a strong negative correlation almost as robust as in 2015, underscoring a significant inverse relationship. Similarly, in 2019, the coefficient was -0.821, indicating a strong negative correlation akin to 2016, suggesting that the LST tended to decrease as vegetation increased (higher NDVI). Lastly, in 2021, the coefficient was -0.782, showing a strong negative correlation, although slightly weaker than in 2019 and 2016, the inverse relationship between NDVI and LST remained robust.

Table 4. Pearson correlation between NDVI and LST

No	Year	Pearson coefficients (r)
1.	2015	-0.979
2.	2016	-0.805
3.	2017	-0.745
4.	2018	-0.925
5.	2019	-0.821
6.	2021	-0.782

4. Discussion

Remote sensing technology is frequently used to monitor reclamation activities in mining areas, particularly for revegetation across extensive areas over prolonged periods [15]. This method is effective and efficient, especially for monitoring the success of ecosystem restoration on post-mining lands. Post-open mining activities often result in extreme land conditions with high temperatures and low humidity[26]. This trend was evident in the LST value for 2015, which decreased following revegetation activity. However, by 2019, all plots in each block had shown an increase in temperature (Figure 3 and Table 1). According to independent analyses conducted by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) [27], Earth's global surface temperatures in 2019 were the second warmest since modern recordkeeping began in 1880, with a global land and ocean surface temperature departure from an average of +0.95°C (+1.71 °F). However, as depicted in the LST graph (Figure 3), the 2021 LST decreased again.

In addition, the results obtained from this study, utilizing remote sensing technology, demonstrated the successful implementation of revegetation activities. There was a change in land cover from open areas to revegetated areas based on NDVI values (Figure 4). In 2015 and 2016, all plots in each block exhibited weak vegetation conditions, as indicated by NDVI values of <0.3. However, in 2017, the NDVI value began to increase to above 0.3. Nevertheless, several plots, including the V. *pubescens* plot in Block A, *M. cajuputi* plot in Block A, and *M. cajuputi* plot in Block B, still showed values below 0.3. This is consistent with the observational report on the plots conducted by Fajri et al. [28], indicating that *V. pubescens* in block A has a low survival rate compared to other plots, while weeds were observed in *M. cajuput*i in blocks A and B. Weeds are among the environments suspected to interfere with growth [29]. Following maintenance on the plot, plants exhibited robust growth, as evidenced by NDVI results ranging from 0.45 to 0.66 in 2021 across all plots in Block A B. An NDVI value exceeding 0.6 indicates vegetation ranging from fairly dense to highly dense [30][31].

Vegetation in the reclaimed area affects the microclimate of the area [32]. Similar to the results of our study, there was a negative correlation between NDVI and LST (Table 4). The Pearson correlation coefficients between NDVI and LST indicated a strong negative correlation across multiple years, as the data provided shows. This means that as NDVI increases, indicating a higher vegetation density, LST tends to decrease, and vice versa. These findings align with those of Chen et al.[17], who examined the heat island effect in subtropical areas and discovered a negative correlation between the NDVI and LST in Wuhan. Similarly, studies in several parts of Chhattisgarh State in India have examined the relationship between the NDVI and LST [18]. This study is unique because it focuses on mining areas in Indonesia, which have soil and tropical climate conditions that differ from those of subtropical regions.

The transition of land cover in the revegetation area, as indicated by NDVI, positively influenced LST. This was attributed to vegetation growth within the plot, representing a succession process. The succession or vegetation growth process in post-mining land undoubtedly enlarges the vegetation canopy, covers the surrounding area, and alters the microclimate, consequently reducing the temperature. Simply put, the light that illuminates the soil surface diminishes as the plant canopy obstructs it. Heightened canopy cover subsequently lowers both temperature and sunlight intensity [33]. Changes in land cover influence ecosystem function, which subsequently affects the microclimate and directly impacts restoration processes [32]. LST and NDVI can also be regarded as indices for studying the ecological environment and contribute to further validating the application of moderate spatial resolution and low-cost satellite imagery in evaluating the environmental impacts in a region[34].

5. Conclusions

The findings of this study demonstrated that remote sensing is an effective method for monitoring and assessing the progress of revegetation in post-mining reclamation areas. Consequently, remote sensing is an appropriate tool for overseeing the process of post-mining land restoration. This was evidenced by the changes in LST and NDVI values observed annually from 2015 to 2021 using Landsat 8 imagery. The LST at the research site declined from 2015 to 2021, attributable to the revegetation efforts conducted by the company, where areas previously open due to coal mining activities gradually became vegetated, altering the land cover reflected in the NDVI variations. The data revealed a consistently strong negative correlation between NDVI and LST over the examined years. The increase in vegetation, as indicated by NDVI, was significantly associated with a decrease in LST. This suggests that establishing vegetation in post-mining land reclamation areas or the transition of land cover from open to vegetated areas contributes to reducing the local temperature (microclimate).

Author Contributions

RMN: Conceptualization, Methodology, Software, Investigation, Writing-original draft, Writing - Review and Editing, and **UKS**: Conceptualization, Formal Analysis, Writing-original draft, Writing - Review and Editing.

Conflicts of interest

We declare no conflicts of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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