GeoPlanning
Journal of Geomatics and Planning
Vol. 10, No. 1, 2023

e-ISSN: 2355-6544

Received: 07 January 2023;
Accepted: 30 October 2023;
Published: 31 October 2023.

Keywords:
LST, Area Forest Change, Spatial Pattern

*Corresponding author(s)
email: rickykemarau@ukm.edu.my

Original Research Open access

Impact Deforestation on Land Surface Temperature: A Case Study Highland Kundasang, Sabah

Ricky Anak Kemarau[1]*, Oliver Valentine Eboy[2], Zaini Sakawi[1], Stanley Anak Suab[3], and Nik Norliati Fitri Md Nor[4]

1. *Institute Of Climate Change, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.*
2. *Faculty Of Social Science and Humanities, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Sarawak.*
3. *Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0810, Japan*
4. *Geography Section, School of Distance Education, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia*

DOI: 10.14710/geoplanning.10.1.45-54

Abstract

In recent decades, extensive deforestation in tropical regions has dynamically reshaped forests and land cover. Driven by demands for intensified agriculture, rural settlement expansion, and urban growth, this transformation underscores the need for vigilant monitoring of vegetation and forest cover to comprehend global and local environmental shifts. This study focuses on the intricate interplay between deforestation and its impact on land surface temperature (LST) within Sabah's Kundasang highland. Analyzing years 1990, 2009, and 2021, the study employs Landsat 5 and Landsat 8 satellite data spanning three decades to decipher forest cover dynamics. Utilizing remote sensing techniques, it unveils the evolving relationship between deforestation, forest cover, and LST fluctuations, validated using Moderate Resolution Imaging Spectroradiometer (MODIS) insights from 1990 to 2021. Motivated by the scarcity of research on tropical deforestation's LST impact, the study's core aim is to establish a robust link between forest loss extent and ensuing thermal changes. The findings highlight a tangible influence of reduced vegetation on rising surface temperatures, necessitating a precise understanding of deforested areas and their thermal responses. Revealing a striking scenario, around 76% of Kundasang highland's forest cover transformed into agriculture and urban zones over 27 years. The study further uncovers a clear inverse relationship between LST and forest area in square kilometres, as well as the Normalized Difference Vegetation Index (NDVI). These findings provide valuable guidance for forest management, identifying vulnerable areas, while also empowering local governance to shape sustainable land management strategies.

1. Introduction

Land surface temperature (LST) is profoundly influenced by changes in land cover and land use (Choudhury, & Das, 2019),, with urban-forest interfaces acting as key junctions for micro- and regional climate sustenance (Deng et al., 2018). This interplay reshapes energy balance, precipitation, and evapotranspiration dynamics (Katul et al., 2012; Culf et al., 1996). Deforestation notably expedites climate warming by diminishing surface albedo and increasing greenhouse gas emissions (O'Brien,1996; Kemarau & Eboy, 2020a), while concurrently being a major driver of global biodiversity loss (Cusack et al., 2016). Current projections from the United Nations International Tropical Timber Organization (ITTO) anticipate a rise in annual deforestation to 12.9 million hectares, alongside 850 million hectares of existing degradation (Wan Mohd Jaafar et al., 2020;

DOI: 10.14710/geoplanning.10.1.45-54

Ngwira & Watanabe, 2019). The ramifications of deforestation extend to local temperature increases and the disruption of forest-associated microclimates (Wan Mohd Jaafar et al., 2020). As highlighted by Kemarau & Eboy (2021), vegetation significantly modulates LST by selectively absorbing and reflecting solar radiation, alongside regulating heat exchange.

Satellite-derived LST has been pivotal in studies exploring the relationship between Normalized Difference Vegetation Index (NDVI) and urban land-use impacts on environmental quality using Landsat 8 (Adeyeri, et al. 2017; Malik et al., 2019), as well as investigating deforestation's effects on surface temperature. Additionally, research like Sabajo et al. (2017) has identified economic crop expansion in Indonesia as a driver of elevated temperatures. Conversely, urban regions exhibit cooling trends attributed to green spaces (Kemarau & Eboy, 2021), and pasture areas typically exhibit higher LST compared to forested zones (Connors et al., 2013; Kong et al., 2014). The Normalized Difference Vegetation Index (NDVI), a remote sensing metric indicative of vegetation cover and photosynthetic activity, plays a crucial role in numerous studies investigating LST relationships (Culf et al., 1996; Malik et al., 2019; Shahfahad, et al., 2020). NDVI serves as a surrogate for biomass concentration (Huete et al., 1999; Cabrera-Bosquet et al., 2011; Johnson et al., 2018). Notably, Peng et al. (2014) demonstrated afforestation-induced decreases in daytime LST and slight increases in nighttime LST in China, while Bala et al. (2007) documented how South American forest-to-grassland conversions impacted local and regional climates in Central Africa.

Despite this wealth of research, there remains a dearth of studies scrutinizing the decade-long shifts in tropical rainforest land cover at Southeast Asian highlands, particularly within Sabah. The study site of Kundasang, Sabah, renowned for its favorable climate and tourist appeal, has witnessed transformations in land cover and usage due to economic growth. This study zeroes in on the repercussions of deforestation on the Kundasang plateau's surface temperature. Leveraging multispectral Landsat and MODIS data, the research dissects the impact of deforestation on the Kinabalu Mountains' surface temperature in Sabah from 1991 to 2018.

2. Data and Methods

Situated in the Ranau district of Sabah, Malaysia, Kundasang is a town nestled within the picturesque Kundasang valley (see Figure 1). Positioned approximately 6 km away from Kinabalu National Park and 12 km from Ranau Town, it holds the distinction of being the nearest urban center to Mount Kinabalu, affording it a sweeping panoramic vista of the iconic mountain. The town's population is primarily composed of the indigenous Dusun community, complemented by a smaller Chinese demographic. Notably, Kundasang occupies an elevation of 1,900 meters (6,200 feet), securing its status as Malaysia's loftiest settlement.

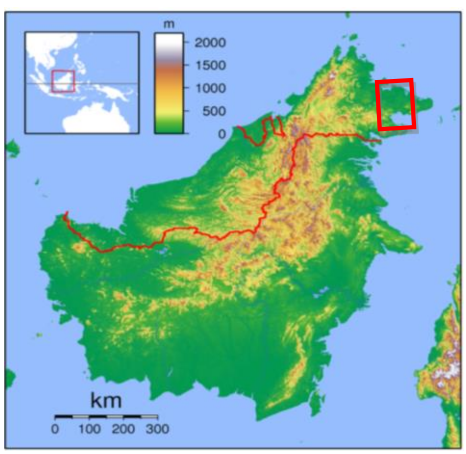

Figure 1. Location of Study.

The initial phase involves preprocessing procedures, encompassing geometric correction, atmospheric correction, and radiometric correction. Subsequently, the thermal band's surface temperature is extracted for the designated datasets corresponding to 1991, 2004, 2014, and 2018. Following this, NDVI analysis is conducted on each of the selected datasets to generate distinct land cover maps for the specified years, utilizing the methodology outlined in the study by Kemarau & Eboy (2020b). The ultimate goal is to establish a correlation between forested areas and land surface temperature (LST). The inversion of surface temperature for Landsat 5 and Landsat 8 follows the guidelines detailed in the work of Kemarau & Eboy (2020b). The pivotal step taken to accomplish the study's object can be seen in Figure 2.

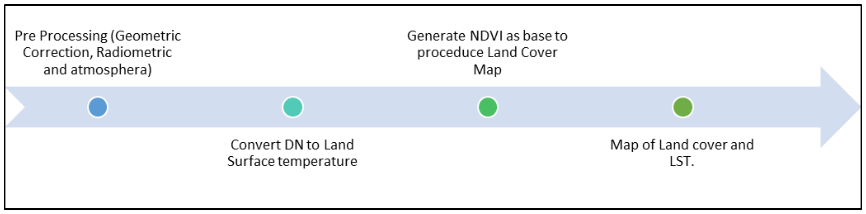

Figure 2. The pivotal step taken to accomplish the study's objective.

The extraction of land surface temperature from thermal data harnessed from Landsat 5 Thematic Mapper (TM) band six and Landsat 8 Operational Land Imager Thermal Infra-red Scanner (OLI TIRS) employs a well-established algorithm as detailed in the work of Kemarau & Eboy (2020b). Notably, the optical and thermal wavelength data are notably susceptible to meteorological conditions, particularly cloud cover. Clouds act as barriers, impeding the penetration of these wavelengths. Consequently, the availability of land surface temperature data is contingent upon cloud-free images, specifically in 1988, 2000, 2011, and 2019. Cloud coverage results in a complete loss of land surface temperature information. Landsat data utilized in this study can be seen in Table 1.

Table 1. A comprehensive overview of the Landsat data utilized in this study, elucidating the specifics of the data sources applied.

Satellite	Thermal Band	Spatial resolution	Data Acquisition
Landsat 5	Band 6	30 meters	25 July 1991
Landsat 5	Band 6	30 meters	30 August 2004
Landsat 8	Band 6	30 meters	30 September 2014
Landsat 8	Band 10	30 meters	15 July 2018

3. Result and Discussion

In this research, a classification process was conducted to categorize the study area into four distinct land cover (LC) groups: built-up areas, human settlements, agricultural zones, and forests. To achieve this classification, the Normalized Difference Vegetation Index (NDVI) was employed for the years 1991, 2004, 2014, and 2018, as visualized in Figure 3. The accuracy of these classifications was evaluated, and the outcomes of this assessment are presented in Table 2.

Table 2. Result Accuracy Assessment

Indices	Land Cover	1988	2007	2014	2020
User Accuracy (%)	Built-up	90	97	95	97
	Agriculture	99	94	92	96
	Forest	91	95	99	99
Producer Accuracy (%)	Built-up	98	96	98	99
	Agriculture	94	100	99	97
	Forest	91	92	98	97
Overall Accuracy (%)		99	98	99	98
Kappa Coefficient (%)		98	98	98	98

The table demonstrates that user and producer accuracy marks were generated to a greater extent than about 90% demonstrating precision for all segments. The kappa measurement for the four-year category was 98, 98, 98, and 98, correspondingly. Kemarau & Eboy (2021) stated the kappa coefficients larger than 0.75 points to that classification and reference work data are consistent.

The process depicted in Figure 3 involves altering the land use patterns for each of these specific years: 1991, 2004, 2014, and 2018. The nuanced breakdown is elaborated upon in Figure 4, where the focus is placed on each year within this selected timeframe. Across these years, the forested area emerges as the most extensive, encompassing 136 km² in 1991, 124.57 km² in 2004, 110.61 km² in 2014, and 99 km² in 2018.

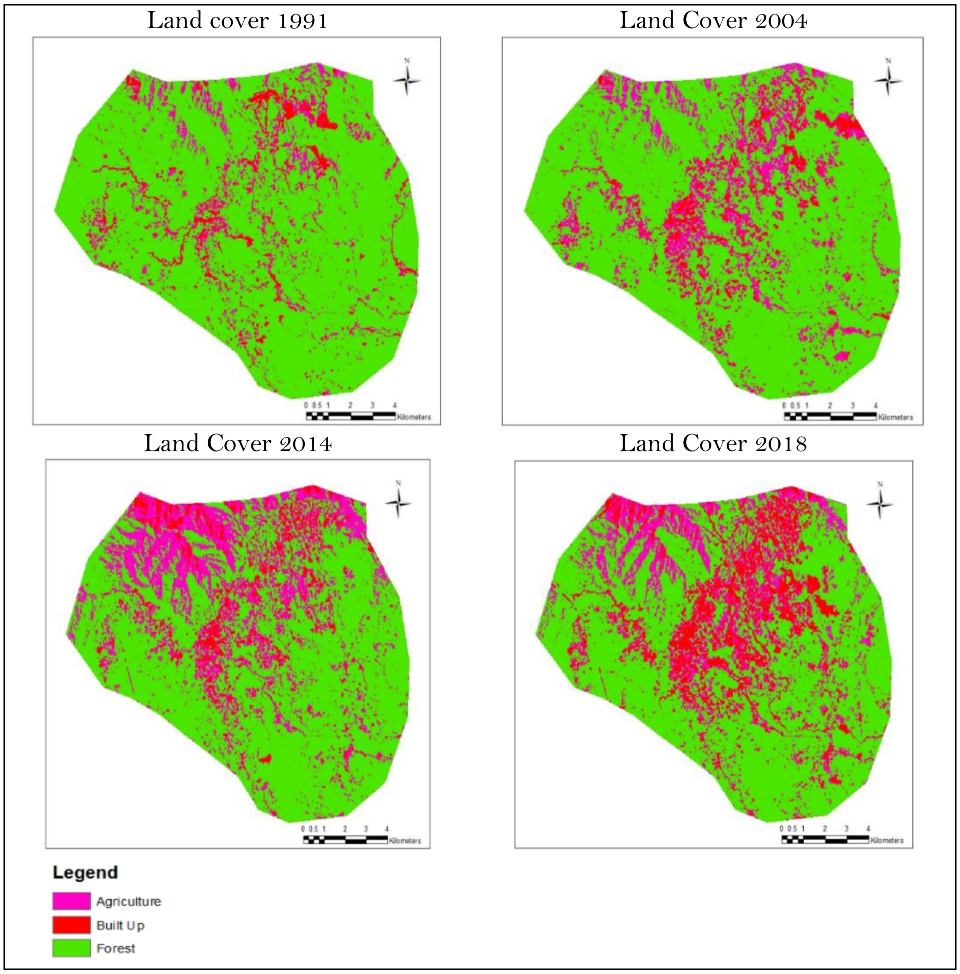

Figure 3. The changing landscape of land cover in Kundasang, Sabah, spanning the years 1991, 2004, 2014, and 2018.

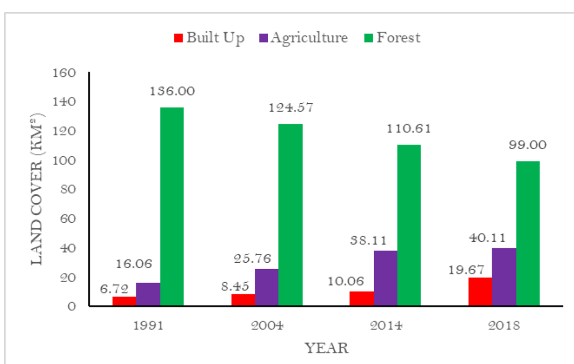

Figure 4. The land cover areas spanning the years 1991, 2004, 2014, and 2018.

Interestingly, while the forest area remains the predominant land cover for each of the years under consideration, a consistent trend of diminishing forest area is observed across the selected years. This reduction in forested areas is met with a corresponding increase in both agricultural land use and built-up areas.

DOI: 10.14710/geoplanning.10.1.45-54

Consequently, over this period, the forested expanse gradually contracts, while the areas dedicated to agricultural activities and human settlements exhibit a progressive expansion.

Moving to Figure 5 presents the dynamic shifts in land use within the study area across those four specific years: 1991, 2004, 2014, and 2018. Upon referencing Figure 5, it's evident that the most significant reduction in forest area occurred between 2004 and 2014, with a decrease of 13.96 km². Comparatively, the decrease between 2014 and 2018 and between 1991 and 2004 was 11.61 km² and 11.44 km², respectively.

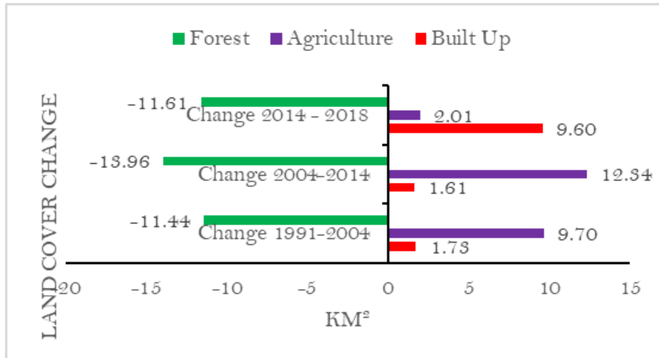

Figure 5. The elucidates alterations in land cover area across three distinct time spans: 1991-2004, 2004-2014, and 2014-2018.

Interestingly, the evolution of forested regions, coupled with changes in agricultural land use and urban expansion, witnessed notable shifts. Specifically, between 2004 and 2014, the area designated for agriculture increased by 12.34 km², while between 1991 and 2004, the agricultural sector expanded by 9.70 km². Furthermore, the areas undergoing urban development saw significant growth, peaking at 9.60 km² in 2014 and 2018.

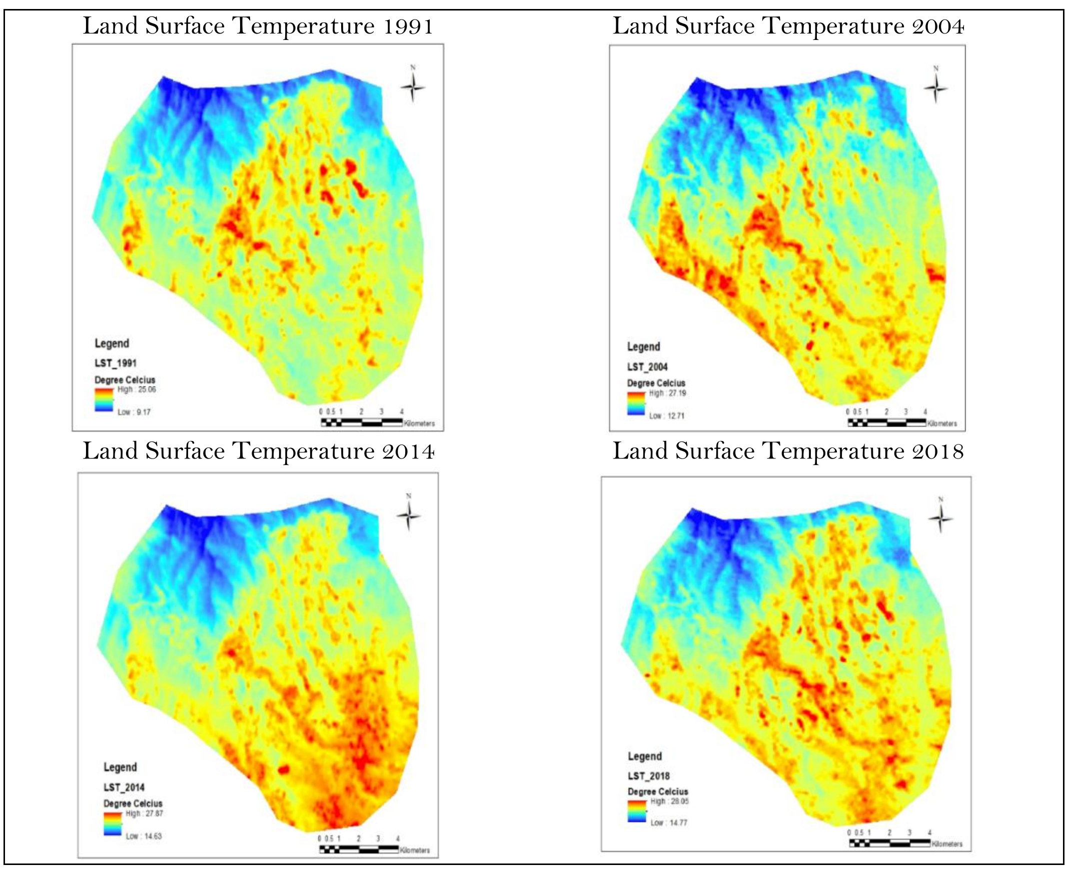

Figure 6. The spatial distribution of surface temperatures within the study area for the years 1991, 2004, 2014, and 2018.

This observation points to a distinctive pattern where the most recent transformation, between 2018 and 2014, primarily involved the conversion of forested zones into built-up urban spaces. Conversely, when contrasting the years 1991 to 2014, the transformation predominantly entailed a shift from forest areas to agricultural use.

As referenced in Figure 5, the narrative of land use changes unfolds as forests give way to agricultural expanses and burgeoning urban developments. These shifts reverberate in the manipulation of land surface temperatures, a phenomenon vividly depicted in Figure 6. The emergence of hot spot regions extends from urban locales into more rural territories. Remarkably, this study unveils the elevated land surface temperature values within agricultural areas, which contrast with the relatively lower values in forested areas (Zhou & Wang, 2012). This aligns with earlier findings posited by Kong et al. (2014) and Connors et al. (2013).

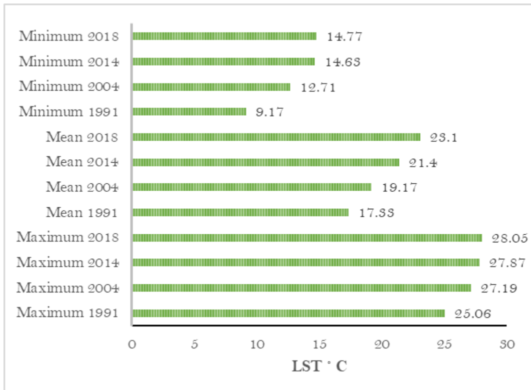

Figure 7. The maximum, minimum, and mean land surface temperature measurements across the years 1991, 2004, 2014, and 2018.

Turning to Figure 8, an illustration is offered that delineates the alterations in mean land surface temperature values for each of the selected years. This investigation uncovers noteworthy temperature shifts, with the most significant change occurring between the years 2004 and 2014, marked by a substantial increase of 2.23°C. The second most notable temperature alteration transpired from 1991 to 2004, manifesting as a rise of 1.84°C. Lastly, between the years 2014 and 2018, the land surface temperature exhibited an increase of 1.7°C, as elaborated upon in Figure 8.

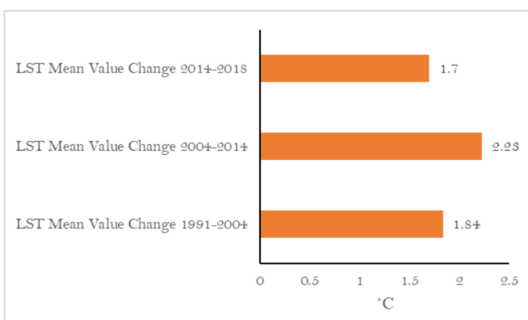

Figure 8. The alterations in mean land surface temperature values within the study area, focusing on the shifts between the selected years.

Moving to Figure 9, a comprehensive insight is offered into the correlation between changes in land area and corresponding variations in land surface temperature. The value of the correlation coefficient, which stands at 0.991 R^2, encapsulates the strength and direction of this relationship. Figure 9, on the other hand, ventures into the realm of relationship exploration. Specifically, it delves into the interplay between alterations in land area and the corresponding fluctuations in land surface temperature. The correlation coefficient value, a robust 0.991 R^2, serves as an indicator of the degree of correlation between these variables. This coefficient value holds crucial insights into the extent to which changes in the land area are aligned with shifts in land surface temperature. A value close to 1 indicates a strong positive correlation, implying that as one variable changes, the other predictably follows suit. Conversely, values close to -1 would indicate an inverse relationship, while values close to 0 would suggest a lack of significant correlation. The high value in this context, 0.991, points to a strong and nearly linear positive relationship between changes in land area and land surface temperature shifts.

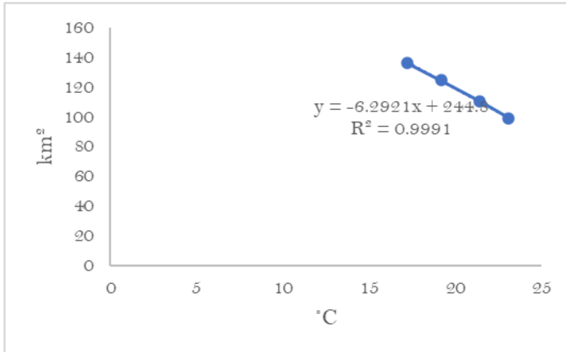

Figure 9. The Association Between Area Change and Mean Land Surface Temperature:

In Figure 9, a comprehensive depiction emerges, highlighting the intricate interplay between alterations in land area (measured in km²) and shifts in mean land surface temperature (measured in °C).

Delving into this relationship, a noteworthy observation surfaces: the compelling and nearly perfect negative correlation between forest area (measured in km²) and land surface temperature (measured in °C). This finding underscores a significant pattern – as the forest area decreases, the mean land surface temperature within the study area experiences an increase. This intriguing relationship suggests a strong regulatory influence that forested areas exert on local temperature dynamics. Each reduction of forest cover by 18 km² correlates with a temperature uptick of 2 °C. This pattern underscores the vital role of forests in maintaining cooler local temperatures.

The study ventures further into the potential ramifications of forest cover changes on land surface temperature. This quantification is achieved by computing the mean land surface temperature difference (ΔLST) between forested areas and adjacent non-forest regions (excluding water bodies). This calculation takes the form of the equation:

$$\Delta LST = LST\ Forest\ Areas - LST\ Non\text{-}Forest$$

Here, LST forest area and LST non-forest correspond to the average land surface temperatures for the selected years, spanning from 1994 to 2018. These values remain consistent for both forested and non-forested areas, respectively. The ΔLST values unravel the distinct roles forests and non-forests play in regulating local temperatures, a function of their differing biophysical properties. This assessment provides a preview of the potential influence of forest cover changes on temperatures before any such changes take place. The approach employs existing vegetation conditions to project hypothetical alterations and their corresponding impacts on temperature dynamics.

Table 3. LST values in each type of use and temperature value differences between forest and non-forest areas.

Year	Forest (°C)	Agriculture (°C)	Built-up (°C)	ΔLST Forest – Agriculture	ΔLST Forest – Built-up
1991	11.12	13.12	25.06	2	13.94
2004	13.89	14.12	27.09	0.23	13.2
2014	15.87	16.89	27.87	1.02	12.0
2018	15.98	17.11	28.05	1.13	12.07

Table 3 offers a comprehensive overview of temperature values corresponding to different land use types within the Kunadasang area. The study's findings consistently reveal lower temperature values within forested regions in comparison to both agricultural and built-up areas across each selected year. To illustrate, in 1991, the temperature within forest areas measured 11.12°C, while adjacent agricultural regions recorded 13.12 °C and built-up areas surged to 25.06 °C. Similarly, in 2004, the forested temperature stood at 13.89 °C, the lowest among the land use types, juxtaposed with 14.12 °C in agricultural zones and 27.09 °C in built-up regions. This pattern persisted in 2014 and 2018, as forested areas maintained the lowest temperature values in contrast to agricultural and built-up areas.

The transformation of land use from forested to non-forested areas triggers discernible shifts in temperature values. In 1991, the study notes that deforestation, leading to the conversion of forest areas to agricultural land, incurs an increase in temperature, with a change of approximately 13.94 °C. Similarly, the transformation to built-up areas yields an even more significant temperature rise of 25.06 °C. This pattern persisted in 2004 when deforestation in agricultural areas brought a temperature increase of 0.22 °C, and the transition to built-up areas led to a 13.2 °C surge. This trend continued in 2018, with deforestation to agricultural zones contributing to a temperature rise of 1.13 °C, and conversion to built-up regions causing a 12.07 °C increase.

The findings underscore the direct relationship between deforestation activities and temperature elevation. Logging and clearance activities, often preceding agricultural endeavours, lead to a direct temperature rise. However, as vegetation grows and thrives, temperature moderation occurs due to the moderating effect of plant cover. Nevertheless, temperatures in these areas remain higher than in natural forested regions.

Our evaluation showcases robust evidence regarding the substantial influence of forest cover changes on surface temperature. These findings resonate with studies by Peng et al. (2014), Fall et al. (2010), Li et al. (2016), Alkama & Cescatti (2016), and Yuan et al. (2017), which allude to temperature alterations linked to biophysical transformations resulting from forest changes. These alterations encompass shifts in surface albedo, evapotranspiration, and roughness, ultimately culminating in temperature shifts (Otieno & Anyah, 2012; Kemarau, 2021; Li et al., 2016). This deforestation-driven transformation amplifies the albedo effect, diminishes evapotranspiration, and reduces surface roughness, collectively elevating the ambient temperature (Seymour & Busch, 2016; Li et al., 2016).

4. Conclusion

This study employed Landsat 5 and Landsat 8 data to scrutinize the repercussions of deforestation on surface temperature in the Kundasang area of Sabah over 27 years. The study's findings underscore that the forested regions within this area experienced a considerable decline in forest coverage by 76% between 1991 and 2018. This reduction in forest cover correlates with a noteworthy temperature increase of 5.77 ˚C over the same time frame. The investigation also revealed a robust negative correlation between forest area and surface temperature, emphasizing the pivotal role forests play in temperature regulation. Building upon these findings, future research endeavors should delve into the intricacies that contribute to forest degradation, identify factors that mitigate deforestation, and devise strategies to curb the pace of deforestation, all to advance sustainable forest management practices.

The outcomes of this study hold particular significance in comprehending the broader climate responses of plant ecosystems. Furthermore, the insights gained from understanding the repercussions of forest alterations on local climates and various land use patterns are invaluable. These findings serve as a crucial reference for assessing the influence of climate change on vegetation coverage. To further enhance the scope of this research, future assessments should encompass a comprehensive exploration of multiple contributing factors. This will provide a more holistic understanding of the dynamics influencing the changes observed in this study. The insights garnered from such investigations could potentially aid policymakers, land managers, and conservationists in crafting effective strategies to combat the adverse impacts of deforestation and climate change while preserving the delicate balance of local ecosystems.

5. Acknowledgments

Thanks to NASA because of the "Free Data" policy to MODIS and Landsat satellite data.

6. References

Adeyeri, O. E., Akinsanola, A. A., & Ishola, K. A. (2017). Investigating surface urban heat island characteristics over Abuja, Nigeria: Relationship between land surface temperature and multiple vegetation indices. Remote Sensing Applications: Society and Environment, 7, 57–68. [Crossref]

Alkama, R., & Cescatti, A. (2016). Biophysical climate impacts of recent changes in global forest cover. *Science*, *351*(6273), 600–604. [Crossref]

Bala, G., Caldeira, K., Wickett, M., Phillips, T. J., Lobell, D. B., Delire, C., & Mirin, A. (2007). Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences*, *104*(16), 6550–6555. [Crossref]

Cabrera-Bosquet, L., Molero, G., Stellacci, A., Bort, J., Nogués, S., & Araus, J. (2011). NDVI as a potential tool for predicting biomass, plant nitrogen content and growth in wheat genotypes subjected to different water and nitrogen conditions. Cereal Research Communications, 39(1), 147–159. [Crossref]

Chen, H., Liu, L., Zhang, Z., Liu, Y., Tian, H., Kang, Z., Wang, T., & Zhang, X. (2022). Spatio-temporal correlation between human activity intensity and land surface temperature on the north slope of Tianshan Mountains. Journal of Geographical Sciences, *32*(10), 1935–1955.

Choudhury, D., Das, K., & Das, A. (2019). Assessment of land use land cover changes and its impact on variations of land surface temperature in Asansol-Durgapur Development Region. The Egyptian Journal of Remote Sensing and Space Science, *22*(2), 203–218. [Crossref]

Connors, J. P., Galletti, C. S., & Chow, W. T. L. (2013). Landscape configuration and urban heat island effects: assessing the relationship between landscape characteristics and land surface temperature in Phoenix, Arizona. *Landscape Ecology*, *28*(2), 271–283. [Crossref]

Culf, A. D., Esteves, J. L., Marques Filho, O., & Rocha, H. R. da. (1996). Radiation, temperature and humidity over forest and pasture in Amazonia. In *John Wiley and Sons*. John Wiley and Sons.

Cusack, D. F., Karpman, J., Ashdown, D., Cao, Q., Ciochina, M., Halterman, S., Lydon, S., & Neupane, A. (2016). Global change effects on humid tropical forests: Evidence for biogeochemical and biodiversity shifts at an ecosystem scale. *Reviews of Geophysics*, *54*(3), 523–610. [Crossref]

Deng, Y., Wang, S., Bai, X., Tian, Y., Wu, L., Xiao, J., Chen, F., & Qian, Q. (2018). Relationship among land surface temperature and LUCC, NDVI in typical karst area. *Scientific Reports*, *8*(1), 641. [Crossref]

Fall, S., Niyogi, D., Gluhovsky, A., Pielke, R. A., Kalnay, E., & Rochon, G. (2010). Impacts of land use land cover on temperature trends over the continental United States: assessment using the North American Regional Reanalysis. *International Journal of Climatology*, *30*(13), 1980–1993. [Crossref]

Huete, A., Didan, K., Leeuwen, W. Van, Jacobson, A., Solanos, R., & Laing, T. (1999). MODIS vegetation index (MOD13). In *cen.uni-hamburg.deA Huete, C Justice, W Van LeeuwenAlgorithm theoretical basis document*.

Johnson, H. E., Gustine, D. D., Golden, T. S., Adams, L. G., Parrett, L. S., Lenart, E. A., & Barboza, P. S. (2018). NDVI exhibits mixed success in predicting spatiotemporal variation in caribou summer forage quality and quantity. Ecosphere, 9(10), e02461.

Katul, G. G., Oren, R., Manzoni, S., Higgins, C., & Parlange, M. B. (2012). Evapotranspiration: a process driving mass transport and energy exchange in the soil-plant-atmosphere-climate system. Reviews of Geophysics, 50(3).

Kemarau, R. A. (2021). Spatial Temporal of Urban Green Space in Tropical City Of Kuching, Sarawak, Malaysia. *Journal of Applied Science & Process Engineering*, *8*(1), 660–670. [Crossref]

Kemarau, R. A., & Eboy, O. V. (2020a). Analyses Water Bodies Effect in Mitigation of Urban Heat Effect: Case Study Small Size Cities Kuching, Sarawak. *IOP Conference Series: Earth and Environmental Science*, *540*(1), 012010. [Crossref]

Kemarau, R. A., & Eboy, O. V. (2020b). Urbanization and It Impacts to Land Surface Temperature on Small Medium Size City for Year 1991, 2011, and 2018: Case Study Kota Kinabalu. *Journal of Borneo Social Transformation Studies*, *6*(1), 58–76. [Crossref]

Kemarau, R. A., & Eboy, O. V. (2021). Land Cover Change Detection in Kuching, Malaysia Using Satellite Imagery. *Borneo Journal of Sciences & Technology*, *3*(1), 61–65. [Crossref]

Kong, F., Yin, H., James, P., Hutyra, L. R., & He, H. S. (2014). Effects of spatial pattern of greenspace on urban cooling in a large metropolitan area of eastern China. *Landscape and Urban Planning*, *128*, 35–47. [Crossref]

Li, Y., Zhao, M., Mildrexler, D. J., Motesharrei, S., Mu, Q., Kalnay, E., Zhao, F., Li, S., & Wang, K. (2016). Potential and Actual impacts of deforestation and afforestation on land surface temperature. *Journal of Geophysical Research: Atmospheres*, *121*(24), 14372–14386. [Crossref]

DOI: 10.14710/geoplanning.10.1.45-54

Majumdar, D. Das, & Biswas, A. (2016). Quantifying land surface temperature change from LISA clusters: An alternative approach to identifying urban land use transformation. Landscape and Urban Planning, 153, 51–65.

Malik, M. S., Shukla, J. P., & Mishra, S. (2019). Relationship of LST, NDBI and NDVI using landsat-8 data in Kandaihimmat watershed, Hoshangabad, India. *Indian Journal of Geo Marine Sciences*, *48*(1), 25–31.

Ngwira, S., & Watanabe, T. (2019). An Analysis of the Causes of Deforestation in Malawi: A Case of Mwazisi. *Land*, *8*(3), 48. [Crossref]

O'Brien, K. L. (1996). Tropical deforestation and climate change. Progress in Physical Geography, 20(3), 311–335.

Otieno, V. O., & Anyah, R. O. (2012). Effects of Land Use Changes on Climate in the Greater Horn of Africa. Climate Research, 52, 77–95.

Peng, S.-S., Piao, S., Zeng, Z., Ciais, P., Zhou, L., Li, L. Z. X., Myneni, R. B., Yin, Y., & Zeng, H. (2014). Afforestation in China cools local land surface temperature. *Proceedings of the National Academy of Sciences*, *111*(8), 2915–2919. [Crossref]

Sabajo, C. R., le Maire, G., June, T., Meijide, A., Roupsard, O., & Knohl, A. (2017). Expansion of oil palm and other cash crops causes an increase of the land surface temperature in the Jambi province in Indonesia. *Biogeosciences*, *14*(20), 4619–4635. [Crossref]

Seymour, F., & Busch, J. (2016). Why forests? Why now?: The science, economics, and politics of tropical forests and climate change. Brookings Institution Press.

Shahfahad, B. K., Tayyab, M., Ahmed, I. A., Baig, M. R. I., Khan, M. F., & Rahman, A. (2020). Longitudinal study of land surface temperature (LST) using mono-and split-window algorithms and its relationship with NDVI and NDBI over selected metro cities of India. Arabian Journal of Geosciences, 13, 1–19.

Wan Mohd Jaafar, W. S., Abdul Maulud, K. N., Muhmad Kamarulzaman, A. M., Raihan, A., Md Sah, S., Ahmad, A., Saad, S. N. M., Mohd Azmi, A. T., Jusoh Syukri, N. K. A., & Razzaq Khan, W. (2020). The influence of deforestation on land surface temperature—A case study of Perak and Kedah, Malaysia. Forests, 11(6), 670.

Yuan, X., Wang, W., Cui, J., Meng, F., Kurban, A., & De Maeyer, P. (2017). Vegetation changes and land surface feedbacks drive shifts in local temperatures over Central Asia. *Scientific Reports*, *7*(1), 3287. [Crossref]

Zhou, X., & Wang, Y.-C. (2011). Dynamics of land surface temperature in response to land-use/cover change. Geographical Research, 49(1), 23–36.