p-ISSN 2089 – 0133 e-ISSN 2477-6416
URL : https://jurnal.uns.ac.id/ijap/article/view/79048

DOI : https://doi.org/10.13057/ijap.v14i1.79048

ANALYSIS OF LAND USE LAND COVER AND LAND SURFACE TEMPERATURE IN KARST AREA: A CASE STUDY WONOGIRI REGENCY

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Received 22-09-2023, Revised 23-01-2024, Accepted 20-03-2024,
Available Online 01-04-2024, Published Regularly April 2024

ABSTRACT

Urban development and global climate change are driving an increase in Land Surface Temperature (LST). Wonogiri Regency is an area within the development reach of Surakarta City. Urban impacts can increase the percentage of built-up land, thereby increasing surface temperatures. Land surface temperature analysis is essential in Wonogiri Regency as an effort to mitigate urban heat islands. This research aims to measure and compare Land Surface Temperature (LST) in the karst area of Wonogiri Regency and determine controlling factors in the form of Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), seasons and zones based on landform. The methods used to determine LST, LULC, and NDVI are Google Earth Engine and field surveys for LULC validation. The data used is USGS Landsat 8 and landforms. The analysis technique used in this research is comparative descriptive, comparing other controlling factors. This research shows the important role of LULC, NDVI, seasonality, and landforms on LST. LULC built land type, low NDVI value, and dry season cause LST to be higher than others. Karst zones also tend to have higher LST.

Keywords: LST; LULC; NDVI; Landform

Cite this as: Noviani, R., Saputra, A. E., Wijayanti, P., & Koesuma, S. 2024. Analysis of Land Use Land Cover and Land Surface Temperature in Karst Area: A Case Study Wonogiri Regency. *IJAP: Indonesian Journal of Applied Physics, 14*(1), 89-105. doi: https://doi.org/10.13057/ijap.v14i1.79048

INTRODUCTION

World population growth is very rapid, especially in urban areas. Based on data from the World Bank, half of the world's population in 2022 will live in urban areas. Global urbanization significantly impacts climate change and challenges sustainable development, especially in urban agglomerations [1]. Rapid economic growth, especially in large cities, significantly affects urban ecosystems, changing their function and structure [2]. Uncontrolled urban growth forces urban systems to change, and the conversion of agricultural land and urban green space declines [3].

Surakarta City is one of the major cities in Central Java that is growing. [4]. The development of Surakarta City has a significant impact on the surrounding area [5]. Population growth in peripheral areas significantly contributes to the formation of built-up land [6]. Urbanization will encourage economic, cultural, and social development, and it will become a way to improve the welfare of human life in [7]. Economic and industrial development and high population levels are associated with the rapid change in land use cover (LULC) in the 21st Century due to the increase in built-up land. [8-9].

Surakarta and its surrounding areas led to the formation of metropolitan cities due to high shuttle or commuting activities from the second cities to central [10]. Wonogiri Regency is in the SUBOSUKOWONOSRATEN area, so it is affected by the development of Surakarta City. A unique phenomenon occurs in Wonogiri Regency, where the urbanization process occurs not only due to the impact of Surakarta City but also from residents who migrate more "circularly" so that development continues in the area of origin [11]. The construction of houses will result in an increase in residential areas and built-up land. The existence of the Wonogiri Regency RAPERDA for 2022-2042, which focuses on large-scale industrial development to suppress Wonogiri Regency residents who work outside the area, is encouraging the phenomenon of urbanization.

The existence of industry can increase urbanization in an area [12]. Developed land is one indication of urbanization in the Wonogiri Regency. Built-up areas are an accurate sign of the urbanization process [13]. Land cover change is highly dependent on urbanization [14]. Land urbanization is the change from agricultural to non-agricultural land cover [12]. Areas with a rapid urbanization process, such as Jakarta, Surabaya, and Medan, are the evidence of the reduction of vegetation areas into built-up areas due to the development of [15]. Identifying LULC changes becomes essential to determine long-term landscape impacts caused by natural processes and anthropogenic stresses [16]. Built-up land will result in Urban Heat Island (UHI) [2]. Land surface changes caused by urbanization can significantly alter the urban thermal environment and cause changes in the UHI effect [1]. Excess anthropogenic activity will increase UHI potential [4]. The presence of UHI will be higher in densely populated cities with a low percentage of green open space [17]. Land Surface Temperature (LST) is one of the indicators for determining UHI [18]. Loss of vegetation increases heat retention in the surface layer of land and building materials and contributes to rising air and surface temperatures in urban areas [9]. Land Surface Temperature (LST) plays an essential role in studying climate, air temperature, and urban environments locally and globally. [18].

This study aims to measure and compare Land Surface Temperature (LST) in Wonogiri Regency and determine the controlling factors in Land Use Land Cover (LULC), NDVI, season, and zone based on landform. Wonogiri Regency was the research location because it has karst landforms, so it is interesting to link LST with landforms. Remote sensing methods and mapping heat energy released by the atmosphere from the earth are methods for measuring LST using satellite image data [8]. A supporting tool to accurately calculate LST is Google Earth Engine [19]. An analysis of LST changes over time and the identification of different temperature patterns in certain areas can be done using Google Earth Engine [20]. Remote sensing is used not only to determine LST but also to determine LULC. Land cover determination is very effective using remote sensing techniques [21]. Land cover will be classified into built-up and non-built-up land using Landsat 8 imagery with unguided classification methods.

METHOD

Study Area

The research location is in Wonogiri Regency, Central Java Province. Astronomically, the area of Wonogiri Regency is between 7° 32' - 8° 15' South Latitude and 110° 41' - 111° 18' East Longitude. Administratively, Wonogiri Regency consists of 25 sub-districts divided into 43 urban villages and 251 villages. The distance between Wonogiri Regency and the nearest big city, Surakarta City, is 33 km. The position of Wonogiri Regency is very strategic because it is at the node of the SUBOSUKOWONOSRATEN route (Surakarta, Boyolali, Sukoharjo, Wonogiri, Sragen, and Klaten) and the southern crossing of Glonggong or the border of Pacitan Regency, East Java Giriwoyo-Giritontro-Pracimantoro -Duwet Gunung Kidul, Special Region of Yogyakarta. Based on landform, this study divided the Wonogiri Regency into three zones. The northern zone is a landform of volcanic and fluvial origin, the transition zone is a mixed landform consisting of several landforms, and the southern zone is a landform of karst origin. The division of zones by landform is presented in **Figure 1**.

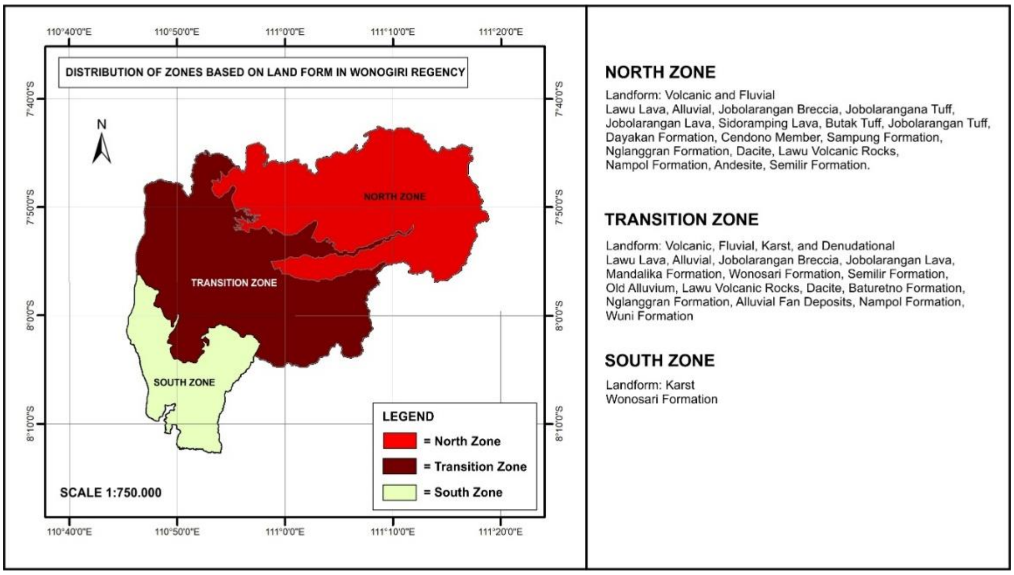

Figure 1. Distribution of Zones Based on Landform in Wonogiri Regency

Data and Data Sources

The data sources in this research are Primary and Secondary Data. Primary data is processed or obtained by the researcher, while secondary data is not directly. The details of the data, data sources, data type, format, and specifications of this study are presented in **Table 1.**

Table 1. Research Data

Data	Data Source	Data Type	Format	Specifications
Landsat 8: 2015 and 2022 recording	USGS	Secondary	tiff	Resolution 30 m
Map of Wonogiri Regency Boundaries	Badan Informasi Geospasial	Secondary	Shp	Scale 1:50.000
Land Use Land Cover Map 2015 and 2022	Data processing	Primary	Tiff	Scale 1:50.000
Landform Map	Badan Informasi Geospasial	Secondary	Shp	Scale 1:50.000
Land Surface Temperature Map 2015 and 2022	Data processing	Primary	Tiff	Scale 1:50.000
NDVI Map 2015 and 2022	Data processing	Primary	Tiff	Scale 1:50.000

Land Cover Classification

The Land Cover and Land Use classification process starts from data collection to analysis using Google Earth Engine using code (1)

https://code.earthengine.google.com/eb6bd9292df903f11a2ac8609f337d46 (1)

The dataset used is USGS Landsat 8. The bands used in the LULC classification are combinations of bands 1 to 7 with the highest accuracy compared to other band combinations in the Landsat imagery [22]. The cloud-based Google Earth Engine (GEE) platform is helpful for the analysis of large spatial areas using high-performance computing resources without downloading data and as a filter for imagery with little cloud cover 23]-[25]. GEE has provided reliable results in monitoring LULC changes related to development [25].

The Landsat imagery obtained is then classified as unguided using machine learning in this research using the SmileCart method in determining LULC. This research divides LULC into four classes: vegetation, water bodies, agricultural land, and built-up land. LULC determination also requires samples for more accurate results in processing in Google Earth Engine. Google Earth Engine view is presented in **Figure 2.**

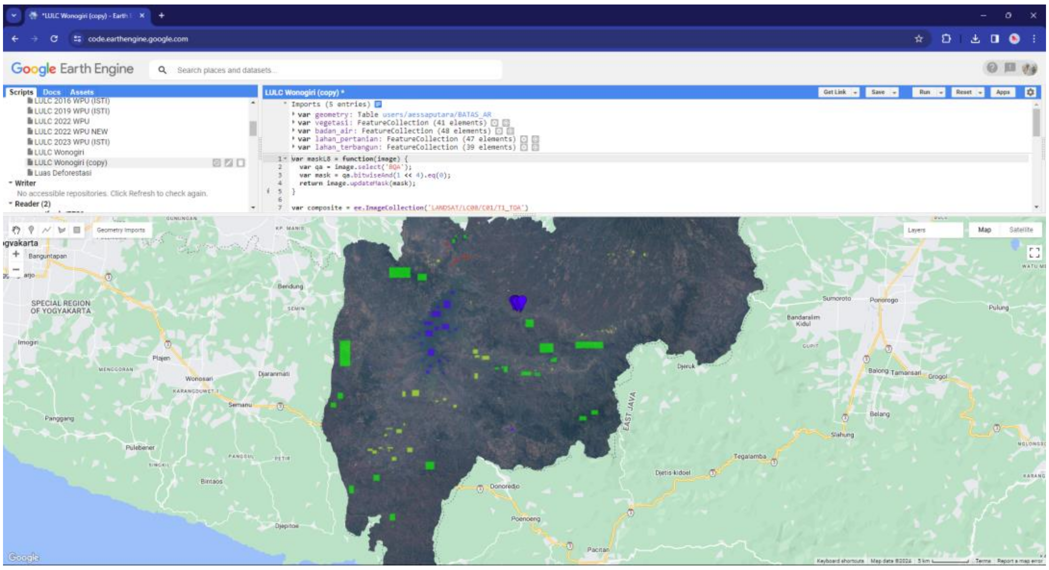

Figure 2. Google Earth Engine view

Validation of the 2015 LULC classification results through verification with Google Earth and interviews while field checks for the 2022 classification. Test the accuracy of the verification results using the confusion matrix table and Kappa coefficient to test the quality of accuracy. Confusion matrix and Kappa coefficients are standard for assessing image accuracy and have been used in numerous land classification studies [26]. A confusion matrix is an image accuracy test matching the classification of processed land use with actual land use in the field based on predetermined samples by determining the maker's accuracy level, user accuracy, and overall accuracy. Determination of accuracy test samples requires a minimum of 10n to 100n pixels where n is the number of bands combined in the land use classification [27]. In this study, the composite bands used were bands 4, 3, and 2 of the Landsat Imagery band so that the minimum pixels used as field samples were 30-300 pixels. The number of sample pixels in this study was 300, distributed evenly according to the LULC proportion by choosing a different sample location from the training area samples. Hence, the accuracy value was more acceptable. The kappa coefficient is perfect when the result approaches one and decreases further to 0 and [26]. The accuracy value of the Kappa Coefficient that is feasible and acceptable for accuracy is at least 0.80 or 80% [27]. Image accuracy tests are presented in **Table 2** and **Table 3**.

Table 2. Image Accuracy Test for LULC Year 2015

		Land Cover from Field Surveys				Total	User Accuracy (%)	Commission Error (%)
		Vegetation	Agricultural Land	Built Land	Water Body			
Land cover classified through Landsat imagery	Vegetation	199	2	0	0	201	99.00	1.00
	Agricultural Land	16	38	3	2	59	64.41	35.59
	Built Land	10	5	18	0	33	54.55	45.45
	Water Body	0	0	0	7	7	100.00	0.00
						300		
	Total	225	45	21	9	**262**		
	Maker Accuracy (%)	88.44	84.44	85.71	77.78	**Overall Accuracy (%)**	87.33	
	Omission of Mistakes (%)	11.56	15.56	14.29	22.22			

Table 3. Image Accuracy Test for LULC in 2022

		Land Cover from Field Surveys				Total	User Accuracy (%)	Commission Error (%)
		Vegetation	Agricultural Land	Built Land	Water Body			
Land cover classified through Landsat imagery	Vegetation	191	3	0	0	194	98.45	1.55
	Agricultural Land	13	50	5	0	68	73.53	26.47
	Built Land	9	1	19	0	29	65.52	34.48
	Water Body	0	0	0	9	9	100.00	0.00
						300		
	Total	213	54	24	9	**269**		
	Maker Accuracy (%)	89.67	92.59	79.17	100.00	**Overall Accuracy (%)**	89,67	
	Omission of Mistakes (%)	10.33	7.41	20.83	0.00			

Calculation of NDVI and Land Surface Temperature

Data collection and data analysis in NDVI and Land Surface Temperature (LST) determination using Google Earth Engine using code (2)

https://code.earthengine.google.com/cdbcc4d1bd188ebaa52ba6a8aa3c7ea7 (2)

Land Surface Temperature (LST) is one of the indicators used to determine UHI using remote sensing with imagery from Landsat 8 [18]. The vegetation index or NDVI is an index that describes the level of greenness of a plant. The vegetation index is a mathematical combination of the red band and the NIR (Near-Infrared Radiation) band as an indicator of the presence and condition of vegetation [4]. The dataset used in determining NDVI and LST in this study was USGS Landsat 8. The bands used in the LULC classification are a combination of bands 2-6 and Band 10. One of the uses of Google Earth Engine is to analyse LST changes over time and identify patterns [20]. The imagery data is then processed using algorithms in Google Earth Engine and generates LST and NDVI.

Driven Factor Analysis Techniques for Land Surface Temperature

The analysis technique used in determining land surface temperature control factors, which consist of seasons, LULC, NDVI, and zones based on landform, use comparative descriptive. Comparative research is descriptive research that seeks to find fundamental answers about cause and effect by analyzing the factors that cause the occurrence or emergence of a particular phenomenon [28]. Each controlling factor is then ranked so that it can be known the type of factor that produces the highest LST. Pattern analysis is also carried out to determine the distribution of each element.

RESULTS AND DISCUSSION

Land Use Land Cover (LULC) Analysis

This research's land use land cover (LULC) classification has four classes. Application of generalization to other classes with too small an area into neighbouring or similar classes. Results from LULC classification using Google Earth Engine using Landsat 8 imagery in 2015 and 2022 in vegetation, agricultural land, built-up land, and water bodies (**Fig. 3**). Google Earth Engine can provide reliable results for LULC changes [25]. Further analysis is a tabulation to calculate the rate of transformation of the area of change in LULC each year, increase, decrease and change (**Table 2 and Table 3**). The LULC classification has been measured by accuracy test results using Kappa and obtained coefficient results of 0.87 in 2015 and 0.89 in 2022, which are pretty accurate. The accuracy of image classification results has increased due to the increasing quality of images every year. The LULC pattern in Wonogiri Regency in 2015 and 2022 is presented in **Figure 1**. The most dominating LULC type in Wonogiri Regency is the vegetation of 134,593.44 ha (75% of the total area) in 2015 and 142,213.94 ha (71% of the total area).

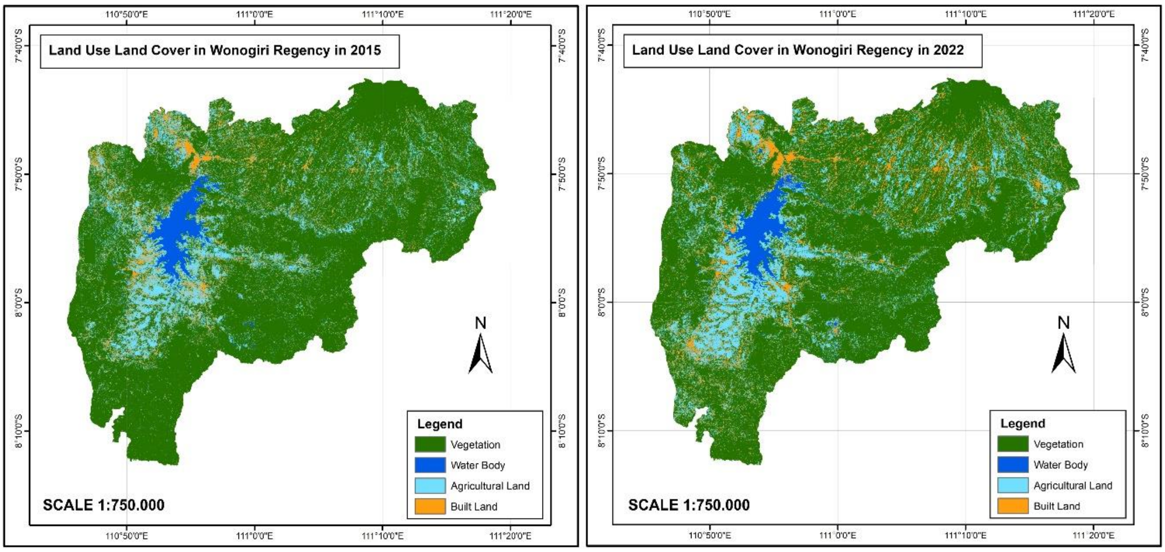

Figure 3. Land Use Land Cover in Wonogiri Regency 2015 & 2022

Based on **Figure 3**, the dominance of LULC is vegetation and agricultural land. The pattern of developed land tends to cluster due to topographic conditions in the Wonogiri Regency. The development pattern of built and agricultural land from 2015 to 2022 is expanding following existing conditions in 2015. The development of agricultural land accompanies the built land. In detail, the development of LULC Wonogiri Regency is presented in **Table 4**.

Table 4. Land Use Land Cover Change in Wonogiri Regency 2015-2022

Land Use Land Cover	Pixel		Pixel Area (M^2)	LULC Area (ha)				Area Change (ha)	Area Change (%)
	2015	2022		2015	%	2022	%		
Vegetasi	1,605,793	1,519,747	885.63	142,213.94	75	134,593.44	71	-7,620.50	5.36
Agricultural Land	324,043	379,193	885.63	28,698.24	15	33,582.49	18	4,884.25	-17.02
Built Land	142,713	182,430	885.63	12,639.10	7	16,156.56	8	3,517.46	-27.83
Water Body	78,441	69,620	885.63	6,946.97	3	6,165.76	3	-781.21	11.25
Total	2,150,990	2,150,990	[redacted]	190,498.26	100	190,498.26	100	[redacted]	[redacted]

Table 4 shows changes in LULC in Wonogiri Regency. The most significant increase in LULC area is agricultural land, with a rise of 4,884.25 ha to 33,582.49 ha in 2022 from 28,698.24 in 2015. The most significant advancement in the LULC area in percentage terms was built-up land, which increased by 21.77% from 2015 to 2022. Vegetation and water bodies have decreased in the area. Transformation occurs in a lot of vegetation into agricultural and built-up land due to population growth and development. The total area of converted vegetation is 7,620.50 ha, or a decrease of 5.66% from 2015-2022. The water body decreased by 12.67% due to the reduced volume of water in the Gajah Mungkur Reservoir in Wonogiri Regency, which reduced the area. Changes in LULC in the 21st Century lead to landscape transformation towards increased built-up land [8]. LULC changes in Wonogiri Regency are relatively the same as in other regions worldwide. The transformation of LULC in the Wonogiri Regency is presented in detail in **Table 5**.

Table 5. Land Use Land Cover Transformation in Wonogiri Regency 2015-2022

LULC Transformation	Vegetation	Agricultural Land	Built Land	Water Body
LULC Change 2015-2022	-7,620.50	4,884.25	3,517.46	-781.21
Area change to	0	4,884.25	3,517.46	0
Area converted from	7,620.50	0	0	781.21
Transformation Rate (%/year)	-0.77	2.43	3.98	-1.61
Increased Rate (%/year)	0.00	2.43	3.98	0.00
Decrease Rate (%/year)	0.77	0.00	0.00	1.61

Table 5 shows that LULC in Wonogiri Regency has experienced an increase and decrease. Agricultural land and built-up land are two types of LULC that have increased. The highest transformation rate is on built-up land, where the rate of increase is 3.98% per year, while for agricultural land, the growth rate is 2.43% per year. Vegetation and water bodies are declining every year. Water bodies have the highest rate of decline at 1.61% per year, while vegetation has decreased by 0.77% per year. The conversion of LULC from vegetation to built-up land and agricultural land in Wonogiri Regency occurred due to several causes. The development of Surakarta City is one of the causes of land conversion in Wonogiri Regency. The change in LULC from non-developed to developed indicates land urbanization [12]. A unique phenomenon occurs in Wonogiri Regency, where the urbanization process occurs not only due to the impact of Surakarta City but also from residents who migrate more "circularly" so that development continues in the area of origin [11]. The construction of houses will result in built land. The structure of houses will result in built land. The existence of the RAPERDA for Wonogiri Regency for 2022-2042, which focuses on industrial development, is the cause of the change in LULC in Wonogiri Regency. Large-scale industrial development suppresses Wonogiri Regency residents who work outside the area. The existence of industry can increase urbanization in an area [12].

Land Surface Temperature (LST) Analysis

The analysis of land surface temperature (LST) in Wonogiri Regency in this study took two seasons in 2015 and 2022, namely the dry season (April-September) and the rainy season (October-March). There are 4 LST calculation results in Wonogiri Regency (**Fig. 4**) based on the results of processing from Landsat 8 using Google Earth Engine. The maximum value of LST in Wonogiri Regency in 2015 and 2022 was in the dry season in 2015, reaching a maximum surface temperature of 41.68 °C. The lowest surface temperature occurs in 2022 in the rainy season with a minimum value of 8.09 °C. The trend of LST in Wonogiri Regency from 2015 to 2022 tends to decrease. The decrease occurred due to the 2015 Wonogiri Regency being affected by the presence of El Nino, which resulted in drought in several areas and increased surface temperatures. Deficiency also significantly affects the rate of photosynthesis, plant height, number of tillers, leaf length, and root weight. Hence, soil moisture content or moisture and dryness levels are the main parameters affecting crop production [29]. The lack of vegetation can also increase surface temperatures. Climate change is one of the causes of high LST [30]. In detail, the results of LST analysis in Wonogiri Regency are presented in **Table 6.**

Table 6. Land Surface Temperature in Wonogiri Regency 2015 & 2022

Land Surface Temperature	Max (°C)	Min (°C)	Average (°C)	Sdv
Rainy Season in 2015	33.51	14.83	26.36	1.86
Dry Season in 2015	41.68	16.68	29.17	3.14
Rainy Season in 2022	30.89	8.09	23.43	1.68
Dry Season in 2022	32.78	17.16	25.16	1.81

Table 6 shows that the highest average LST in Wonogiri Regency in 2015 and 2022 occurred in the dry season of 2015, with an average of 29.17 °C. The lowest average LST in Wonogiri Regency happened in the rainy season of 2022, which was 23.43 °C. The results of LST analysis show that the dry season tends to have higher surface temperatures than the rainy season. The intensity of solar lighting will affect LST. Seasonal changes also affect surface temperatures, where seasons with more intense solar illumination result in higher LST [21]. The rainy season tends to have higher rainfall than the dry season, so surface temperature conditions tend to be lower.

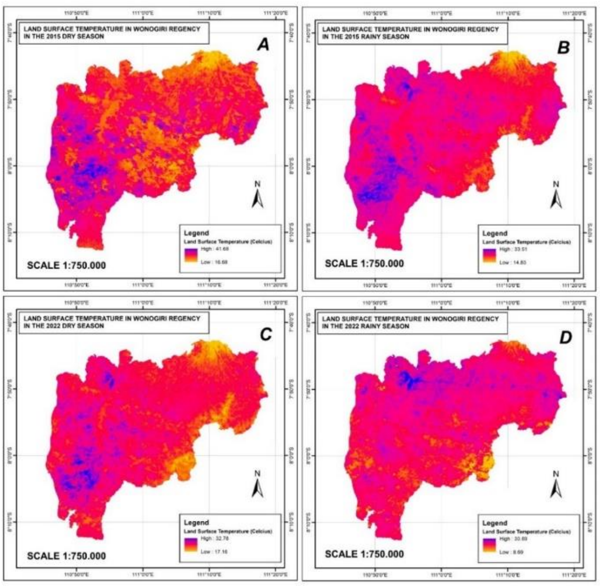

Figure 4. Land Surface Temperature Map in Wonogiri Regency 2015 & 2022

The distribution of high LST patterns in the Wonogiri Regency is in the central and southern parts. Areas with high surface temperatures in all seasons in 2015 and 2022 except in the rainy season in 2022 (**Fig. 4a-c**) are in the central and southern parts of Wonogiri Regency. In the rainy season of 2022, LST tends to be hotter in the northern region (**Fig. 4d**), resulting in a transition of LST patterns from south to north.

The El Nino phenomenon, which has an impact on LST in Wonogiri Regency, which caused high surface temperatures in 2015, certainly causes a difference in surface temperature compared to other years. The highest difference from LST in 2015 to 2022 is in the rainy season, where there are locations with an LST difference of 20.68°C, meaning that there has been a decrease of 20.68°C from 2015 to 2022 (**Fig. 5b**). The maximum difference in LST that occurs in the dry season is 18.05°C (**Fig. 5a**). The average difference in LST from 2015 to 2022 in the dry season is 4°C, while the average difference in LST in the rainy season is 2.93°C. In detail, the difference from the LST of Wonogiri Regency is presented in **Table 7**.

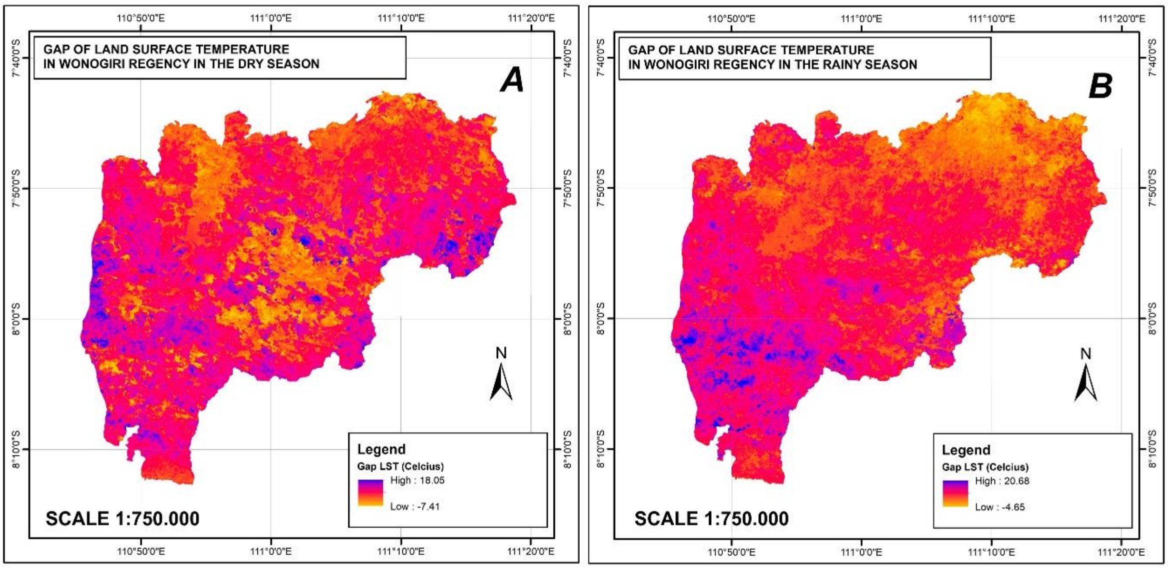

Figure 5. Land Surface Temperature Graphic in Wonogiri Regency 2015 & 2022

Table 7. Gap of Land Surface Temperature in Wonogiri Regency 2015 to 2022

Gap LST	Max (°C)	Min (°C)	Mean (°C)	Sdv
Dry Season in 2015 to 2022	18,05	-7,41	4,00	2,72
Rainy Season in 2015 to 2022	20,68	-4,65	2,93	1,96

LAND USE LAND COVER (LULC) ANALYSIS WITH LAND SURFACE TEMPERATURE (LST)

Land use land cover (LULC) is an important controlling factor as a producer of surface temperature. Built-up land will tend to produce higher heat than other LULC types. Areas with dense built-up land intensity tend to have higher surface temperatures [15]. Wonogiri Regency tends to build up land to produce higher surface temperatures than other LULCs in 2015 and 2022. In detail, the condition of LST in Wonogiri Regency based on LULC is presented in **Table 8.**

Table 8. Land Use Land Cover on Land Surface Temperature in Wonogiri Regency in 2015 & 2023

Land Use Land Cover	LST in 2015 (°C)		Mean 2015	LST in 2022 (°C)		Mean 2022	Mean
	Dry Season	Rainy Season		Dry Season	Rainy Season		
Vegetation	28.83	26.06	27.45	24.78	23.17	23.98	25.71
Water Body	28.63	26.02	27.32	24.94	23.67	24.31	25.81
Agricultural Land	30.72	27.50	29.11	26.12	23.83	24.98	27.04
Built Land	30.08	27.67	28.88	26.33	24.65	25.49	27.18

Table 8 shows that the type of LULC that produces the highest surface temperature is built-up land with an average temperature of 27.18°C. Built-up land averaged the most elevated temperatures in almost all seasons in 2015 and 2022 except in 2015 in the dry season, where agricultural land tended to produce higher surface temperatures of 30.72°C. Agricultural land is a type of LULC with the second highest average surface temperature after land developed in Wonogiri Regency. The average surface temperature in Wonogiri Regency in 2015 and 2022 with the LULC type of agricultural land is 27.04°C. Water bodies have a higher average surface temperature compared to vegetation at 25.81°C. Vegetation is a type of LULC with the lowest average surface temperature in Wonogiri Regency, which is 25.71°C. LST among various types of land use is different, where the highest LST is found on construction land and the lowest on forest land [4,31].

The analysis results show that vegetation can reduce the high surface temperature in an area, while built-up land tends to make LST higher. LST among different types of land use are ranked as follows: built-up land > unused land > cultivated land > water > forests [32]. Wonogiri Regency experienced a similar thing: built land > agricultural land > water body > vegetation. LST and LULC changes have more impact on local climate factors, human life, and ecological balance [24]. Some LULC vegetation types in the Wonogiri Regency have high LST. Dry vegetation types and vegetation unhealth give rise to high LST and air pollution, and water bodies play an essential role in daytime temperature changes [24]. The change of LULC towards built-up land increased LST, but in 2015, Wonogiri Regency received a significant impact from the El Nino phenomenon. Temperature change caused by climate change is still a challenge [30]. The distribution pattern of LST based on LULC is presented in **Figure 6.**

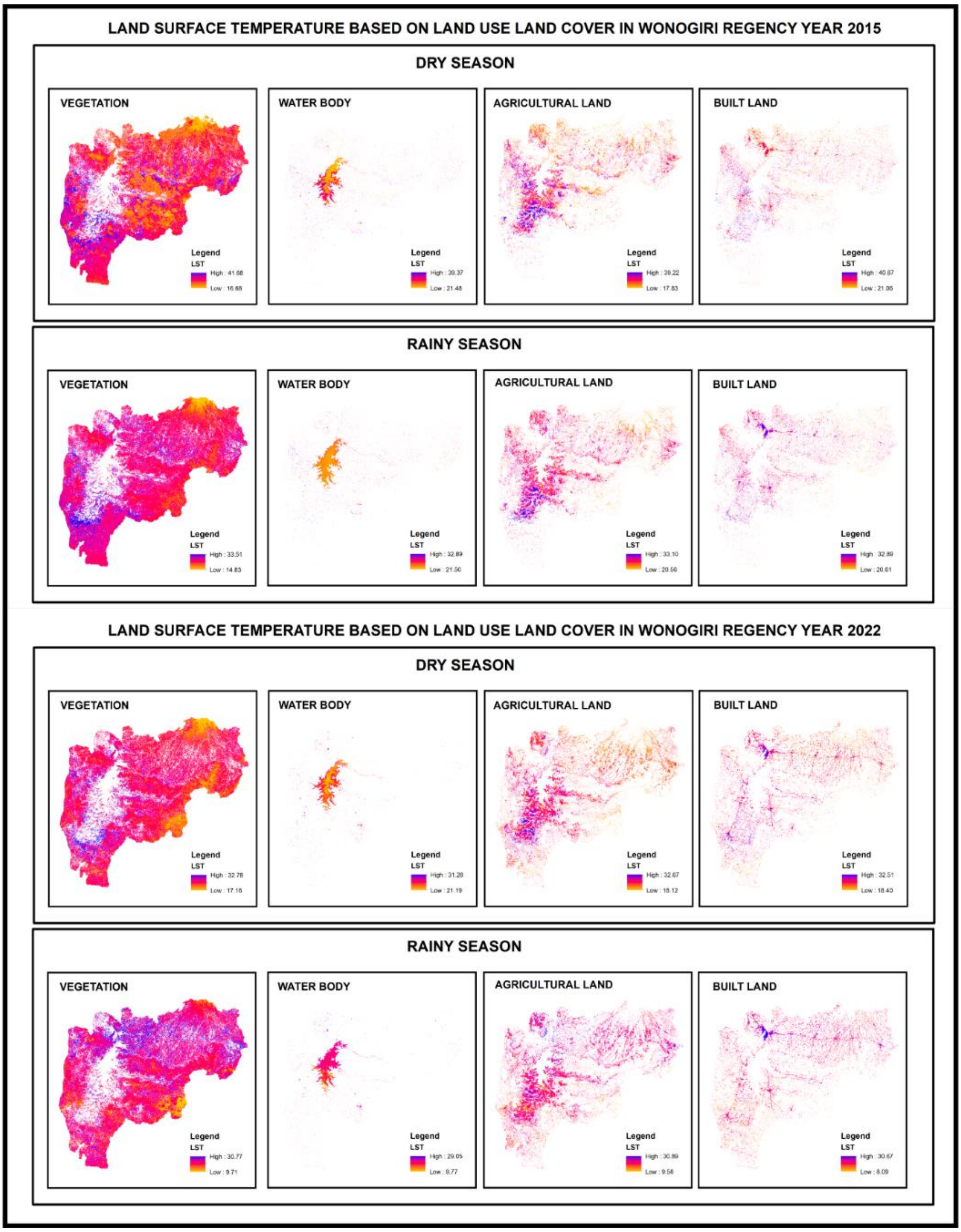

Figure 6. Land Surface Temperature Based on Land Use Land Cover in Wonogiri Regency 2015 & 2022

NDVI ANALYSIS WITH LAND SURFACE TEMPERATURE

The vegetation index is a mathematical combination of the red band and the NIR (Near-Infrared Radiation) band to indicate the presence and condition of vegetation to describe a plant's greenness level. [4]. NDVI can show the vegetation density index; if the NDVI value is close to 1, the vegetation gets denser. Changes in NDVI values serve to monitor the impact of climate change on productivity and vegetation health over time [33]. Overgrown vegetation can reduce surface temperature, while less dense vegetation can increase LST. Wonogiri Regency has NDVI values ranging from 0-1. The NDVI value of each year per season will differ depending on the existing vegetation condition in the Wonogiri Regency. The average NDVI value in Wonogiri Regency ranges from 0.54 – 0.69. In detail, the NDVI values are presented in **Table 9**.

Table 9. LST and NDVI Value in Wonogiri Regency 2015-2022

Land Surface Temperature	Mean of LST (°C)	NDVI
Rainy Season in 2015	26.36	0.61
Dry Season in 2015	29.17	0.54
Rainy Season in 2022	23.43	0.69
Dry Season in 2022	25.16	0.68

Table 9. Indicates that the higher the NDVI value, the lower the surface temperature. Several studies conducted in different countries concluded that land surface temperatures increase with reduced vegetation cover [4,8,21,31–33]. The highest average NDVI value in Wonogiri Regency was in the rainy season in 2022, with a value of 0.69, and at the same time became the season with the lowest average LST of 23.43°C. The lowest NDVI value was in the dry season in 2015, with a value of 0.54 and had a higher average LST than other seasons, namely 29.17°C. In the rainy season 2015, they had an NDVI value of 0.60 (second lowest) and a surface temperature of 26.36°C (second highest). In line with other seasons, the dry season of 2022 has an NDVI value of 0.68 (second highest) with a surface temperature of 25.16 °C (second highest). LST and NDVI have a negative relationship, which means the land surface temperature is lower on surfaces with dense vegetation [8]. The negative relationship between NDVI and LST also occurs in Wonogiri Regency, where seasons with the highest NDVI average tend to have the lowest LST. The results of NDVI analysis in each season can be known as the distribution pattern seen in **Figure 7.**

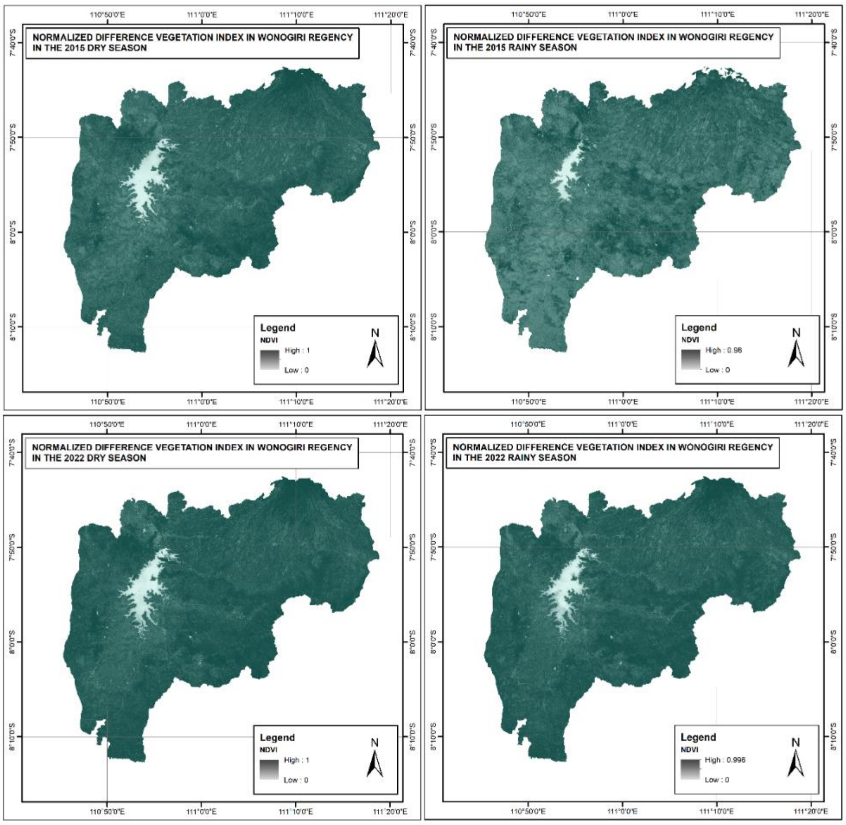

Figure 7. NDVI in Wonogiri Regency in 2015 and 2022

ANALYSIS OF LANDFORMS WITH LAND SURFACE TEMPERATURE

Wonogiri Regency consists of three landform zones. Researchers carry out the basis for dividing landform zones to facilitate analysis. The northern zone is an area with landforms of volcanic and fluvial origin. The transition or middle zone has volcanic, denudational, fluvial, and karst-origin landforms. The southern zone of Wonogiri Regency is an area with karst landforms. Landforms influence surface temperatures, which are based on the materials that make up the landform. The division of zones in Wonogiri Regency based on the original landform is presented in **Figure 1**.

The diversity of landforms in Wonogiri Regency produces different LST. Based on three zones (**Fig. 1**), LST tends to be higher in the southern zone, which is the landform of karst origin. The calculation of the average LST in 2015 and 2022 in the dry and rainy seasons resulted in a surface temperature of 26.75°C. The second high surface temperature emitter is the transition zone consisting of landforms of volcanic, fluvial, karst, and denudational origin of 26.24°C. The zone with the lowest surface temperature is the northern zone, a volcanic and fluvial origin landform of 25.51°C. The difference in results is shown on the graph (**Figure 8**). The mean results of LST based on landform zone division are presented in **Table 10**.

Table 10. Average LST based on Landform Zone in Wonogiri Regency 2015-2022

Landform Zone	Mean of LST in 2015		Mean of LST in 2022		Mean
	Dry Season	Rainy Season	Dry Season	Rainy Season	
North Zone	28.02	25.68	24.40	23.96	25.51
Transition Zone	29.51	26.63	25.56	23.25	26.24
South Zone	31.10	27.34	25.95	22.59	26.75

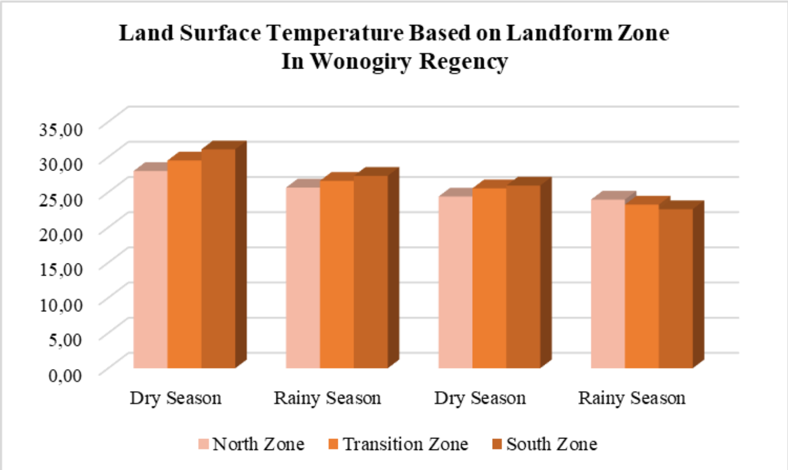

Figure 8. LST Graph by Landform Zone in Wonogiri Regency 2015-2022

The graph in **Figure 8** shows that the southern zone tends to have higher surface temperatures than other zones, and the northern zone has the lowest surface temperatures in almost all seasons in 2015 and 2022. The southern zone is a karst landform. Topography and surface influence The hot temperature in karst-origin landforms [32]. Different results occur in the 2022 rainy season, where the most desirable surface temperature changes occur based on the zone. The northern zone tends to be hotter than other zones, while the southern zone has the lowest temperature compared to other zones. to a different zone.

The results of LST mapping by zone are presented in **Figure 9.** In this study, the LST profile of each zone is depicted using transverse lines. Three LST profiles, namely: (1) Line A-B to describe the surface temperature of the northern zone; (2) Line C-D to describe the surface temperature of the transition zone; and (3) Line E-F to describe the surface temperature of the southern zone. The LST profile shows that the northern zone of Wonogiri Regency has a more stable surface temperature compared to other zones where it has a surface temperature with high fluctuations. The northern zone also tends to have lower average temperatures than the transition and southern zones. The southern zone has the highest surface temperature compared to other zones and has a high-temperature difference between the rainy and dry seasons. High-temperature differences are possible due to the ability of the region to absorb heat and cold. High-temperature fluctuations also occur in the southern zone, where the maximum and minimum temperatures differ. The LST profile also shows that Wonogiri Regency tends to have higher LST in the dry season than in the rainy season. In the summer, LST in the study area had an abnormally high-temperature zone, probably caused by desertification of karst rocks [32]—high rainfall in the rainy season, causing lower surface temperatures than during the dry season. The dry season has higher solar irradiation, so an area's thermal value will also be higher. LST patterns and profiles based on landform zones are presented in **Figure 9.**

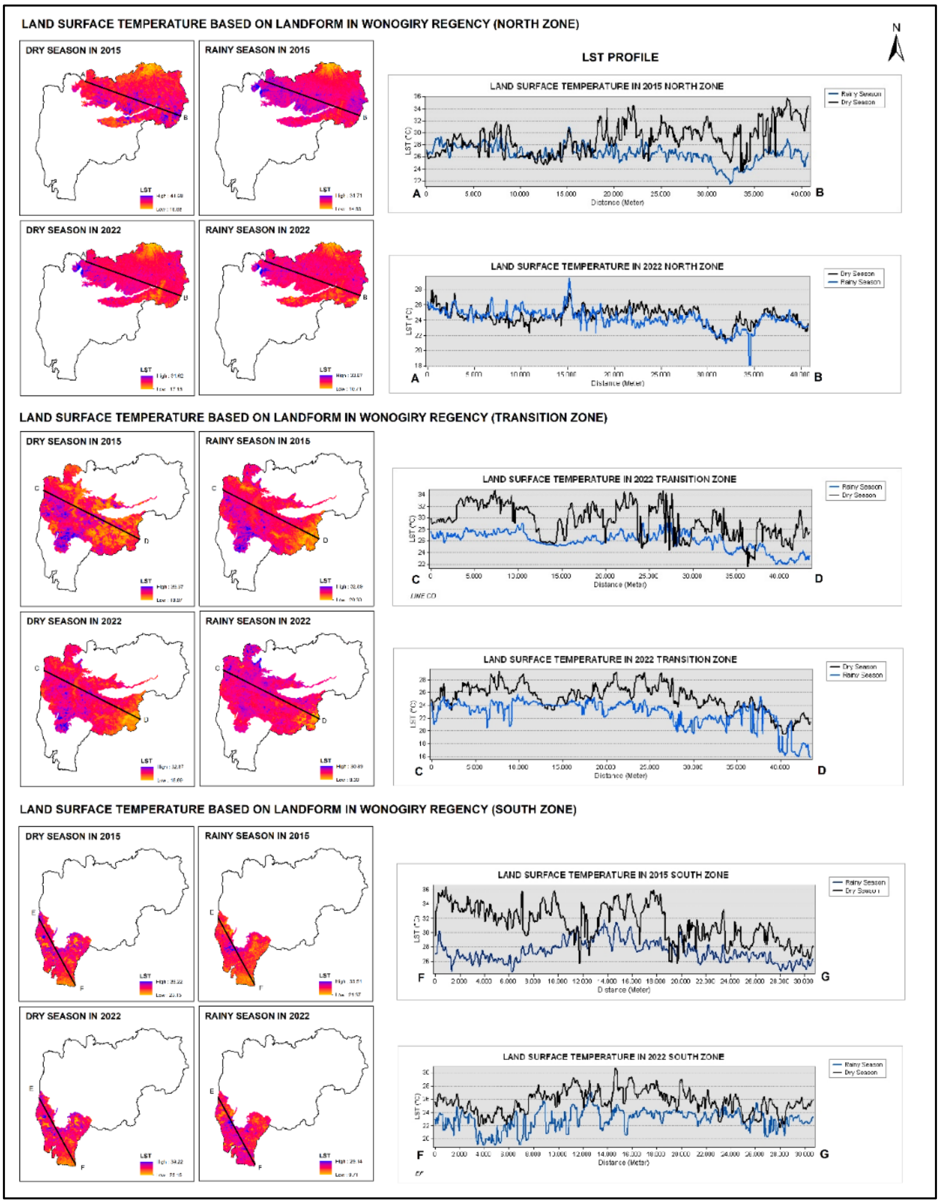

Figure 9. LST Graph by Landform zone in Wonogiri Regency 2015-2022

ANALYSIS OF LAND SURFACE TEMPERATURE DRIVEN FACTORS IN WONOGIRI REGENCY

LST control factors in Wonogiri Regency consist of Season, LULC, NDVI, and landform of origin. The ranking method analyses LST controlling factors in the Wonogiri Regency (Ranking 1-4). Rank 1 indicates that the type of factor produces the highest surface temperature producer compared to the type of factor within. Rank 4 suggests that the kind of factor is the lowest surface temperature producer compared to the class from within the element. Details of the ranking of each facet are presented in **Table 11.**

Table 11. Ranking of LST Control Factors in Wonogiri Regency in 2015-2022

High LST Producer Ranking	Season	LULC	NDVI	Zona
1	Dry season	Built-up Land	0	South
2	Rainy season	Agricultural Land		Transition
3		Water Bodies		North
4		Vegetation	1	

Table 11 shows that each controlling factor has a type that produces a different surface temperature. Seasonal factors indicate that the dry season produces higher LST than the rainy season. The LULC factor shows that the type of built-up land LULC is the highest producer of surface temperature compared to other kinds of LULC. The second type of LULC that is the second highest producer of LST is agricultural land, followed by water bodies and vegetation. One of the controlling factors for LST in the Wonogiri Regency is NDVI. NDVI shows the vegetation density index so that the higher the NDVI value (close to 1), the lower the surface temperature. The NDVI value is more relative to 0, the higher the surface temperature will be. Another controlling factor is zones based on landform, where the Wonogiri Regency consists of three zones. The northern zone is the zone with the lowest LST emitters, composed of landforms of volcanic and fluvial origin. The highest LST-producing zone is the southern zone, consisting of landforms of karst origin. Areas with LULC in the form of developed land in the south zone with NDVI values close to 0 are areas with the highest LST. Periodic macro- and medium-scale monitoring is required to assess the impact of changes from LULC to LST [2].

CONCLUSION

Karst landforms, Normalized Difference Vegetation Index (NDVI), and Land Use/Land Cover (LULC) are interrelated factors and play an important role in influencing Land Surface Temperature (LST). NDVI, which is a measure of vegetation health and density, has an inverse effect on LST; Higher NDVI values tend to be associated with cooler surface temperatures due to the cooling effect of vegetation. In contrast, LULC impacts ESG by determining land surface characteristics. Urban areas, for example, where vegetation cover is low, tend to have higher LST than areas with lots of vegetation. Additionally, landforms, including factors such as slope and aspect, can further modulate LST by influencing solar radiation absorption and heat retention. Wonogiri Regency is one of the regions that has karst areas. Karst areas tend to have higher surface temperatures compared to other landforms. The existence of karst areas is one of the causes of high LST, even though it is supported by the lack of vegetation and vegetation types. Understanding these relationships is critical for effective land management, climate modelling, and urban planning to mitigate the urban heat island effect especially in karst areas.

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