Spatio-temporal Analysis of Land Surface Temperature Changes in Java Island from Aqua and Terra MODIS Satellite Imageries Using Google Earth Engine

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Abstract
Java Island is the island with the most population globally, which is experiencing an increase in population from year to year. This population growth causes an increase in the use of natural resources, which can further increase the potential for climate change. One of the parameters of climate change in an area is Land Surface Temperature (LST). In situ LST observations in the field require a huge number of stations; for that reason, the use of satellites is the right choice. This study analyzes changes in LST spatially and temporally for 16 years, from January 2005 to December 2020, based on Terra and Aqua MODIS satellite imagery using Google Earth Engine as a data processing tool. LST processing was performed gradually to generate the average daily maximum LST of Terra and Aqua, monthly average LST, and annual average LST. This study found the correlation coefficient between the Terra and Aqua LST data and the BMKG weather station temperature data of 0.2599 to 0.8361. It indicated a moderate to very strong correlation. The most significant annual LST change occurred from 2015 to 2016 experiencing a temperature decrease of 1.6 °C and 2.0 °C, respectively, for Terra and Aqua. There was an area of 35105 km^2 (2010-2011) and 65420 km^2 (2015-2016) experiencing LST increases and decreases of at least 1.5°C, respectively. Areas experiencing a temperature increase were mainly in the northern part of East Java Province and the eastern part of Central Java Province. Meanwhile, the areas that experienced a temperature drop were mainly northern East Java, eastern Central Java, and West Java Province. Annual LST fluctuations indicate the changes in land used and land cover, both spatial and temporal.

Keywords: Aqua, Drought, Google Earth Engine, Land Surface Temperature, MODIS, Sustainability, Terra

1. Introduction

Global warming is an aspect of climate change, referring to the long-term rise of the planet's temperatures. It is a global issue that people in the world often discuss. Furthermore, climate change will cause natural phenomena such as sea-level rise, increasing extreme weather phenomena, and changes in rainfall patterns in several parts of the world (Febrianti, 2018).

An indicator that can determine climate change in an area is Land Surface Temperature (LST) (Susanti et al., 2019). LST can be defined as the average surface temperature described in a pixel with many different surface types (Faridah et al., 2014). LST data is often needed as input data in calculating models of evapotranspiration, humidity, soil moisture, energy balance, etc. The data can be obtained from weather stations in several places, but not all weather stations have a surface temperature measuring tool; it generally measures the air temperature only (Prasasti and Sambodo, 1994). Thus, other observational methods are needed that can provide surface temperature data for a wide range of areas.

Remote sensing is one method that can be used to obtain surface temperature data over a wide area. This method obtains information about an object, area, or phenomenon by analyzing data using tools that are not in direct contact with the investigated object, area, or phenomenon (Congalton, 2015). One of the remote sensing sensors is MODIS (Moderate Resolution Imaging Spectroradiometer), which is equipped onboard Terra and Aqua.

The sensor has 2330 km swath dimensions and 36 bands with a spatial resolution of 250 m (bands 1-2), 500 m (bands 3-7), and 1000 m (bands 8-36). Each band of the satellite has a different function. Bands with the main role for land surface temperature extraction are bands 31 and 32 (Maccherone, 2005). With a population of more than 149 million people from six provinces in it, including DKI Jakarta (DKI is Daerah Khusus Ibukota, Special Capital Region), West Java, Central Java, East Java, DI Yogyakarta Jakarta (DI is Daerah Khusus, Special Region), and Banten, Java Island is the most populous island in Indonesia and in the world, (Badan Pusat Statistik, 2018). In 2020, the condition changed. Based on the population census of 2020, the population of Java Island has increased and reached 151.59 million people, or around 56.10% of the total population of Indonesia (Badan Pusat Statistik, 2021). The increased population and urban activities on Java Island will change the balance of heat energy that distinguishes urban areas from other areas that are still dominated by vegetation and other natural elements (Susanti et al., 2019).

There have been several previous research regarding LST. Those research used various satellite imagery data, including Landsat 7, Landsat 8, Terra, and Aqua MODIS. The study areas used in those researches also vary but tend to show the same pattern. The study areas were big cities in Indonesia, one of them was Surabaya, and the observation time was only short. There were still not many researches regarding LST that carried out observations within an extended period. Thus, with Java Island as the study area and 16 years of observation time from January 2005 until December 2020, this research was held. This research aims to obtain information about LST changes, spatially and temporally, in Java Island for 16 years, starting from 2005 until 2020.

1.1 Research Objective

This research objective is to observe and analyze the LST changes, spatially and temporally, in Java Island every year in the range of 2005 to 2020.

2. Material and Methods

2.1 Study Area

This research's study area is Java Island which is located in the coordinate of 5°52′34″ - 8°46′49″ S and 105°05′59″ - 114°36′18″ Java Island is surrounded by the Java Sea to the north, Sunda Strait to the west, the Indian Ocean to the south, and Bali Strait to the east, as presented in Figure 1.

Figure 1: Study area

2.2 Remote Sensing Data

This research uses Terra and Aqua MODIS satellite imageries data (MOD11A1 & MYD11A1) that provide daily LST value with a spatial resolution of 1 km and image recording time from January 2005 until December 2020. Those satellite imageries have level 3 data processing. Cloud masking was applied to the level 2 product.

2.3 Ground-based Observation Data

This research also uses Java Island administrative boundary vector data obtained from the Ina-Geoportal page owned by Geospatial Information Agency (BIG) for defining the study area and daily maximum temperature data obtained from several weather stations owned by Meteorology, Climatology, and Geophysical Agency (BMKG) for calculating the data's correlation coefficient. The weather stations used in this research were Tangerang Geophysics Station (TNG) with the data in 2015 and 2019, Kemayoran Meteorological Station (KMN) with the data in 2006 and 2015, Kertajati Meteorological Station (KTI) with the data in 2006 and 2015, Semarang Climatology Station (SMN) with the data in 2015, Sleman Geophysics Station (SLN) with the data in 2015, and Perak I Meteorological Station (PRK) with the data in 2019.

2.4 Data Processing

LST Retrieval: Land Surface Temperature and Emissivity Daily Global 1 km product of MODIS from Terra (MOD11A1.006) and Aqua (MYD11A1.006) platform were retrieved from Google Earth Engine from January 2005 to December 2020.

Daily Maximum LST: The daily data was calculated in this research by selecting the maximum LST recorded by Terra and Aqua. This step will provide results in the form of daily maximum LST values for the observed period from January 2005 to December 2020.

LST and Air Temperature Correlation: A correlation test was carried out between the LST data obtained from Terra and Aqua MODIS image processing with the daily maximum air temperature data obtained from BMKG weather stations. As two of the data are different, the air temperature from ground station and LST from satellite data can be compared to examine the influence of surface temperature on the surrounding air temperature. This idea follow the study by Hachem in continuous permafrost terrain that found LST and air temperature yields a very high correlation (R=0.97; mean difference (MD) = 1.8◦C; and standard deviation of MD (SD) = 4.0◦C). Surface heterogeneity between the MODIS 1 km^2 grid cells, the presence of undetected clouds, and the inherent disparity between LST and air temperature contribute to the significant of SD (Hachem et al., 2012). The test was carried out to see how strong the correlation between the data is, as indicated by the correlation coefficient value (R).

Calculation of Average LST Per Month: Calculation of average LST per month was performed by scripting on the data processing platform of Google Earth Engine. The calculation was carried out using the input data of Terra and Aqua MODIS images that provide daily maximum LST data from January 2005 until December 2020. This step provided results in the form of average LST values per month for the observed period from January 2005 to December 2020.

Calculation of Average LST Per Year: Calculation of average LST per year was calculated by using Terra and Aqua MODIS images that provide average LST values per month from January 2005 until December 2020. This step provided results in the form of average LST values per year for the observed period from January 2005 to December 2020.

Image Sub-setting: Image sub-setting was performed the final results, which only shows Java Island as the study area. This step is carried out using vector data for the administrative boundaries of Java Island obtained from the Ina-Geoportal page belonging to the Geospatial Information Agency (BIG).

LST Mapping: LST mapping was performed by using ArcMap 10.3 as the software. The LST map describes the area based on the minimum annual average LST value change of 1.5°C (the minimum threshold of extreme weather events (Shiogama et al., 2019)), including temperature increases, constants, and temperature decreases. The map was presented at a scale of 1:3,500,000.

Data Analysis: This step was performed to analyze the LST changes for each year, spatially and temporally, for the observed period from January 2005 to December 2020 based on the annual average LST values obtained from Terra and Aqua image processing.

3. Results and Discussion

3.1 Correlation Test between LST Data from Satellite Imageries and Air Temperature from Weather Stations

A correlation test was performed by using the daily maximum LST data from January 2005 until December 2020 obtained from Terra and Aqua MODIS image processing and the daily maximum air temperature data obtained from 6 BMKG weather stations. Those weather stations are located in each province in Java Island, including Banten, DKI Jakarta, West Java, Central Java, DI Yogyakarta, and East Java. The daily maximum LST data used in this step is the daily maximum LST data for one year in a given year with the most data availability at the relevant weather stations. Based on the correlation test, the following results are obtained. Based on the Table 1, Terra observation data was closer to the field weather station than Aqua with a correlation coefficient of more than 0.5, except in Kemayoran Meteorological Station (KMN).

3.2 Annual Average LST

Based on the annual average LST calculation, the LST distribution in Java Island was presented in a blue to a red color range. The blue color shows the lower LST value with the lowest value of 20°C, and the red color indicates the higher LST value with the highest value of 40°C as presented in Figure 2. The annual average LST values based on Terra and Aqua MODIS image processing were shown as in Figure 3, Table 2 and Table 3.

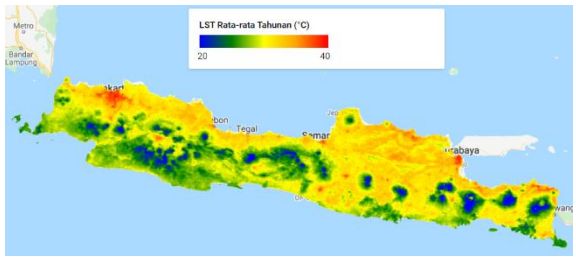
Based on the annual average LST changes, it was known that the most significant average LST change occurred from 2015 to 2016 that decreased in temperature of 1.6°C and 2.0°C for Terra and Aqua, respectively. This phenomenon occurred because of a strong El Nino in 2015 followed by a weak La Nina in 2016 (Athoillah et al., 2017). The further calculation was carried out based on the annual average obtained LST to determine the yearly average LST difference between the processing results with Terra and Aqua MODIS images.

Table 1: Correlation Coefficient (R) of Terra and Aqua MODIS Image Processing and BMKG Weather Station

BMKG Weather Station	**Terra**	**Aqua**
TNG	*0.6718*	0.4405
KMN	*0.2719*	0.2599
KTI	*0.8361*	0.7462
SMN	*0.5183*	0.4661
SLM	0.5157	*0.6440*
PRK	*0.6178*	0.5863

Table 2: Terra MODIS Annual Average LST

Year	**LST Value (°C)**	**LST Change (°C)**	**Year**	**LST Value (°C)**	**LST Change (°C)**
2005	29.4		2013	29.6	
		+ 1.0			+ 0.6
2006	30.3		2014	30.142	
		- 0.5			+ 0.5
2007	29.8		2015	30.6	
		- 0.2			- 1.6
2008	29.6		2016	29.0	
		+ 0.7			+ 0.3
2009	30.3		2017	29.3	
		- 1.4			+ 0.8
2010	28.9		2018	30.1	
		+ 1.0			+ 0.3
2011	29.9		2019	30.4	
		+ 0.3			- 1.2
2012	30.2		2020	29.2	
		- 0.7			



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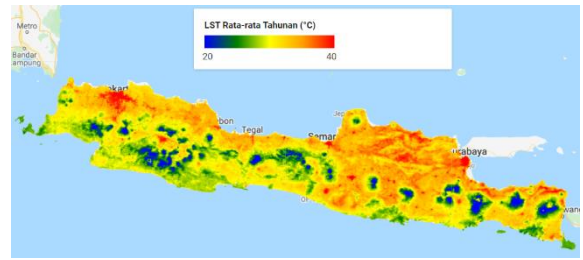

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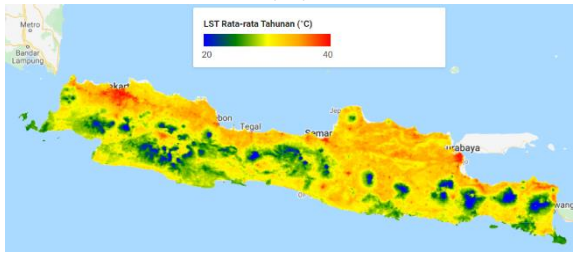

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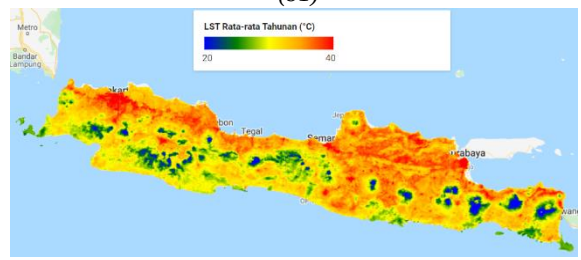

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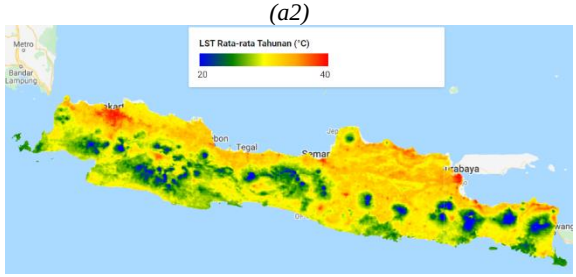

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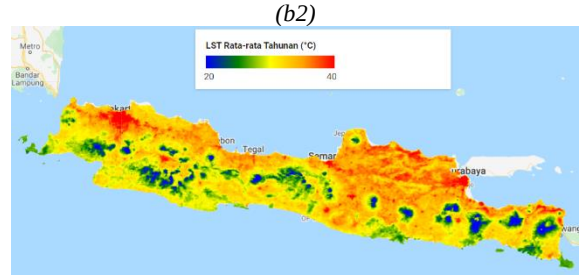

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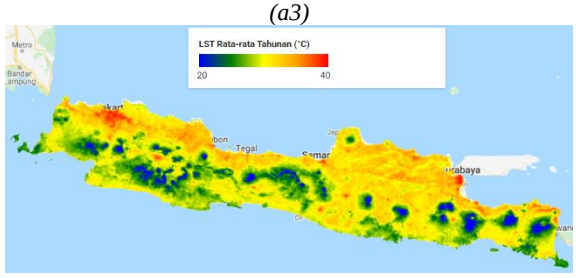

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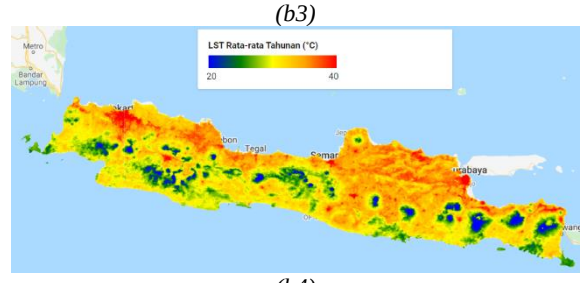

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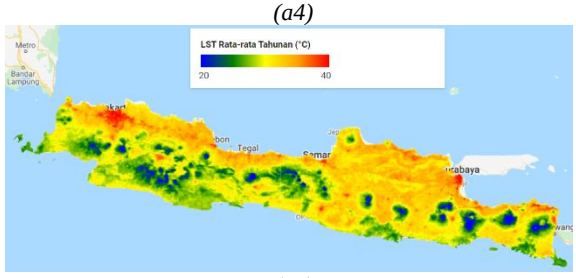

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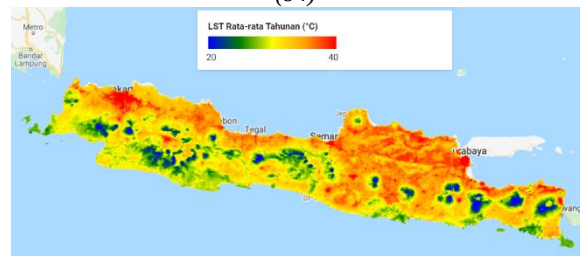

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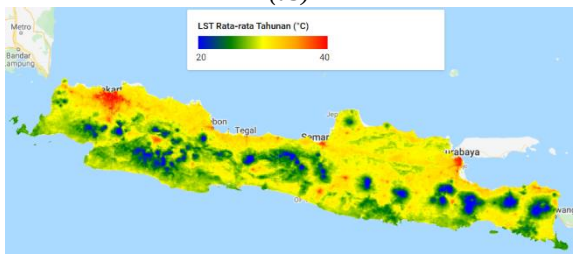

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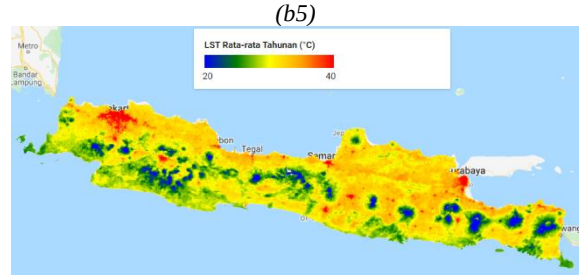

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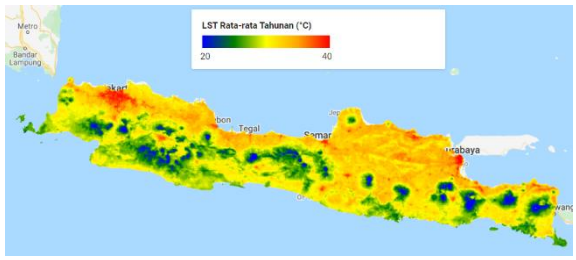
Figure 2: Java Island LST Map Scale 1:3,500,000: Terra MODIS (a1-a16) 2005 - 2020; Aqua MODIS (b1-b16) 2005- 2020 (Continue next page)



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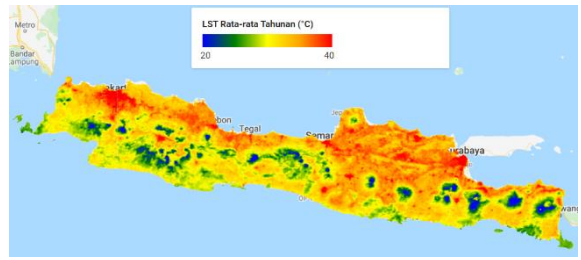

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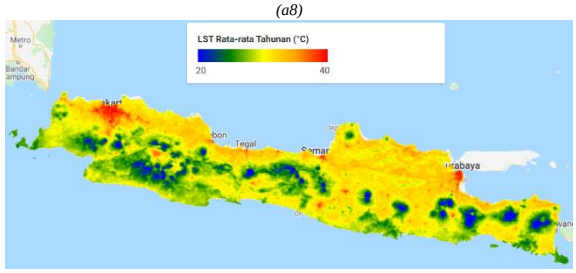

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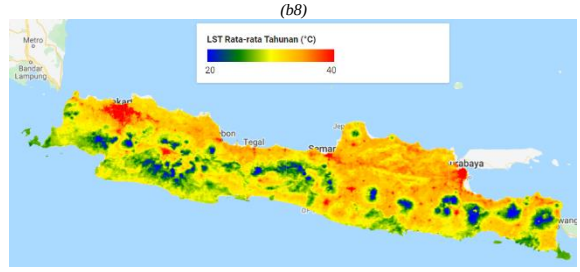

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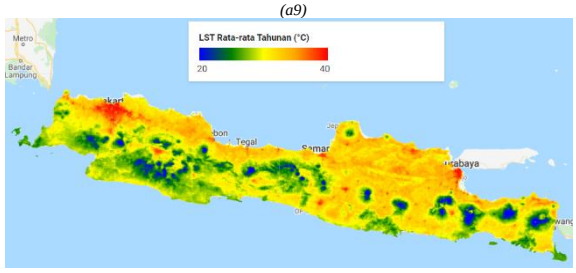

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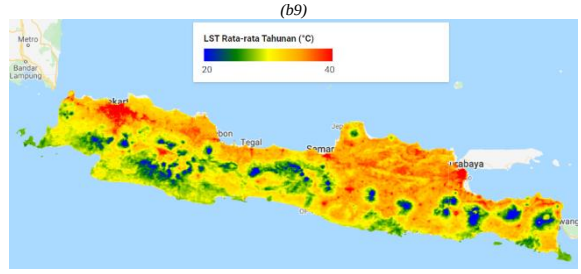

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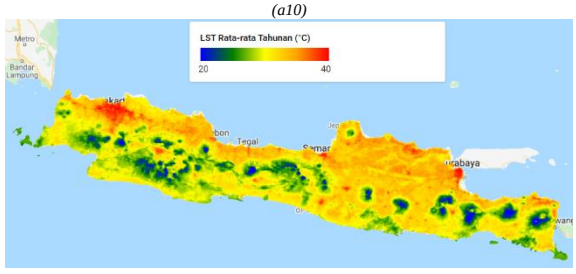

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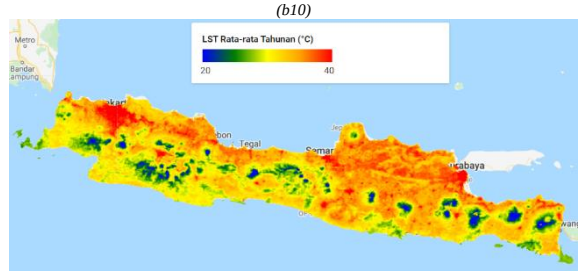

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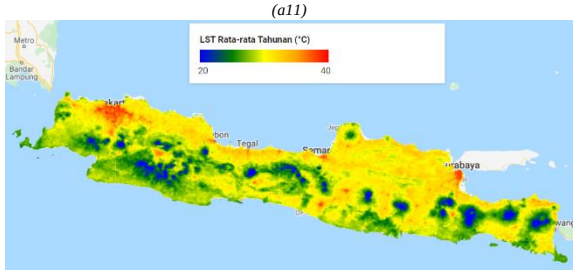

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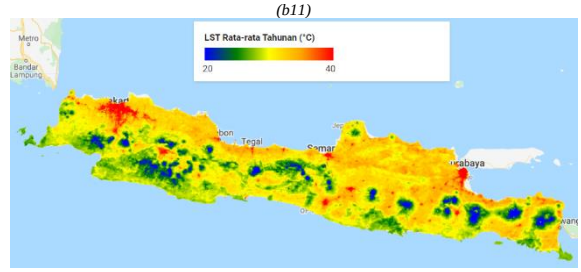

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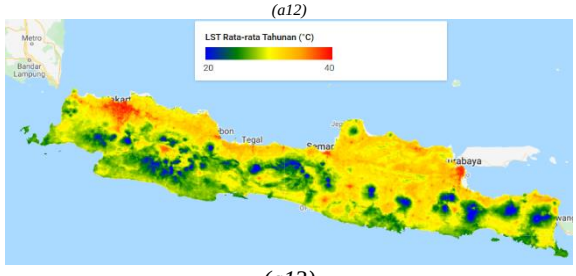

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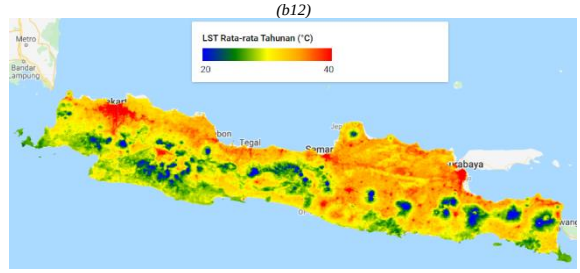

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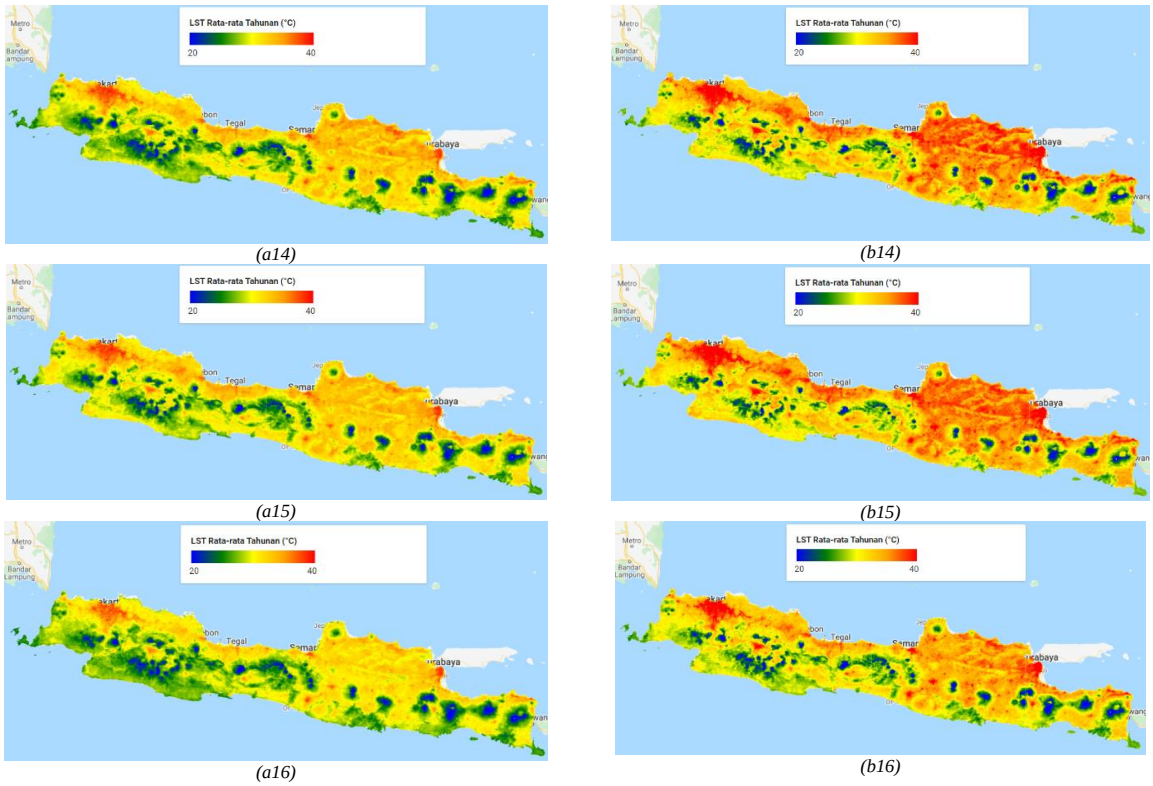
Figure 2: Java Island LST Map Scale 1:3,500,000: Terra MODIS (a1-a16) 2005 - 2020; Aqua MODIS (b1-b16) 2005- 2020 (Continue next page)



(a14) *(b14)*

(a15) *(b15)*

(a16) *(b16)*

Figure 2: Java Island LST Map Scale 1:3,500,000: Terra MODIS (a1-a16) 2005 - 2020; Aqua MODIS (b1-b16) 2005- 2020

Table 3: Aqua MODIS Annual Average LST

Year	LST Value (°C)	LST Change (°C)
2005	31.1	
		+ 1.1
2006	32.3	
		- 0.6
2007	31.6	
		- 0.1
2008	31.5	
		+ 0.4
2009	31.9	
		- 1.775
2010	30.178	
		+ 1.496
2011	31.674	
		+ 0.325
2012	31.999	
		- 1.135
2013	30.864	
		+ 0.467
2014	31.331	
		+ 1.019
2015	32.350	
		- 1.987
2016	30.363	
		+ 0.782
2017	31.145	
		+ 1.276
2018	32.421	
		+ 0.332
2019	32.753	
		- 1.541
2020	31.212	

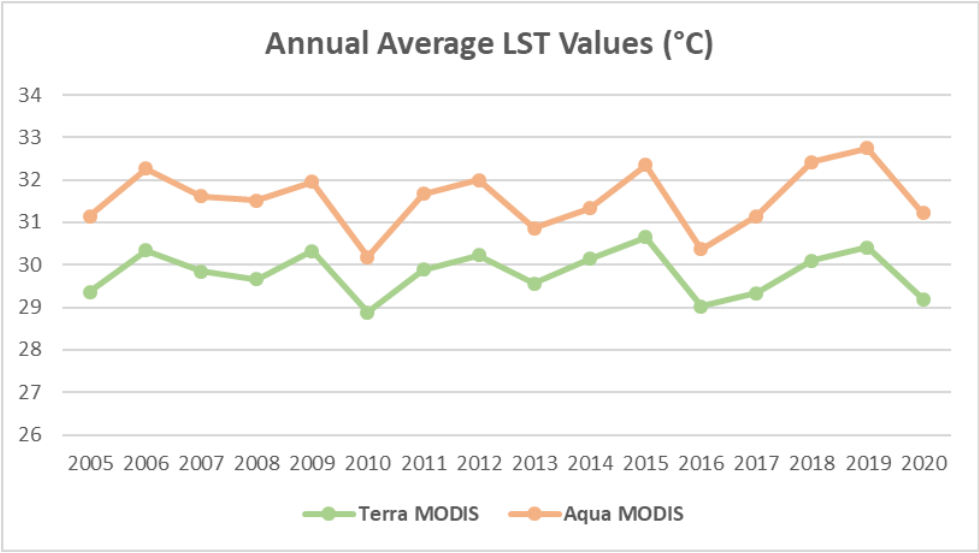


Figure 3: Annual Average LST Change in Java Island from Terra and Aqua MODIS

Table 4: Annual Average LST Difference

Year	Terra (°C)	Aqua (°C)	Difference (°C)
2005	29.4	31.1	1.8
2006	30.3	32.2	1.9
2007	29.8	31.6	1.8
2008	29.6	31.5	1.9
2009	30.4	31.9	1.6
2010	28.9	30.2	1.3
2011	29.9	31.7	1.8
2012	30.2	31.0	1.8
2013	29.5	30.9	1.3
2014	30.1	31.3	1.2
2015	30.6	32.3	1.7
2016	29.0	30.4	1.3
2017	29.3	31.1	1.8
2018	30.1	32.4	2.3
2019	**30.4**	32.7	**2.3**
2020	29.2	31.2	2.0

Based on the Figure 3 and Table 4, it was known that the largest LST occurred in 2019, with a value of 30.4°C and 32.7°C. In 2019, the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) reported global climate anomalies in the Pacific Ocean that triggered drought conditions in southern Indonesia until December 2019. In November 2019, the island of Java was reported to have experienced an extreme drought (Dedy Banurea, 2019 and Wijayanti et al., 2021). Furthermore, drought conditions allow cloud cover data to be less (i. e. clear atmosphere), therefore LST is higher since it is not subjected to be filtered by cloud mask. The clear atmosphere also made a bigger difference of LST between Terra (morning overpass) and Aqua (afternoon overpass). Based on the annual average obtained LST, a spatial analysis was carried out to determine certain areas in Java Island that experienced an annual average LST change of at least 1.5°C, including temperature increases, constants, and decreases. The results of processing with Terra MODIS images were chosen because, based on the correlation test, the LST data obtained from Terra MODIS image processing had a better correlation coefficient than Aqua MODIS. Based on Tables 5 and 6, the highest increase in the area occurred from 2010 to 2011 with 351045 km^2. In contrast, the highest decrease occurred from 2015 to 2016 with 65420 km^2.

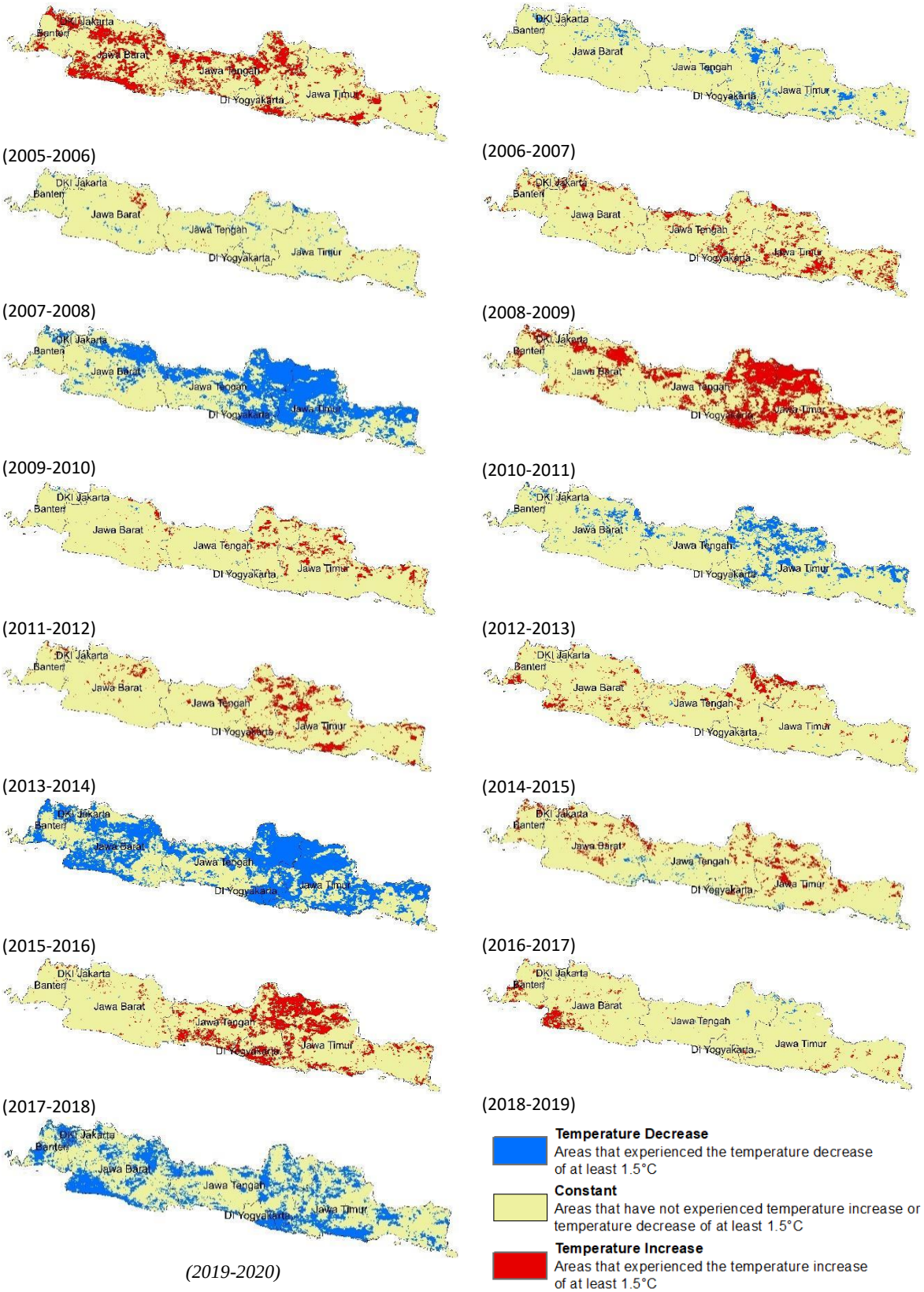


Figure 4: Annual Average LST Changes

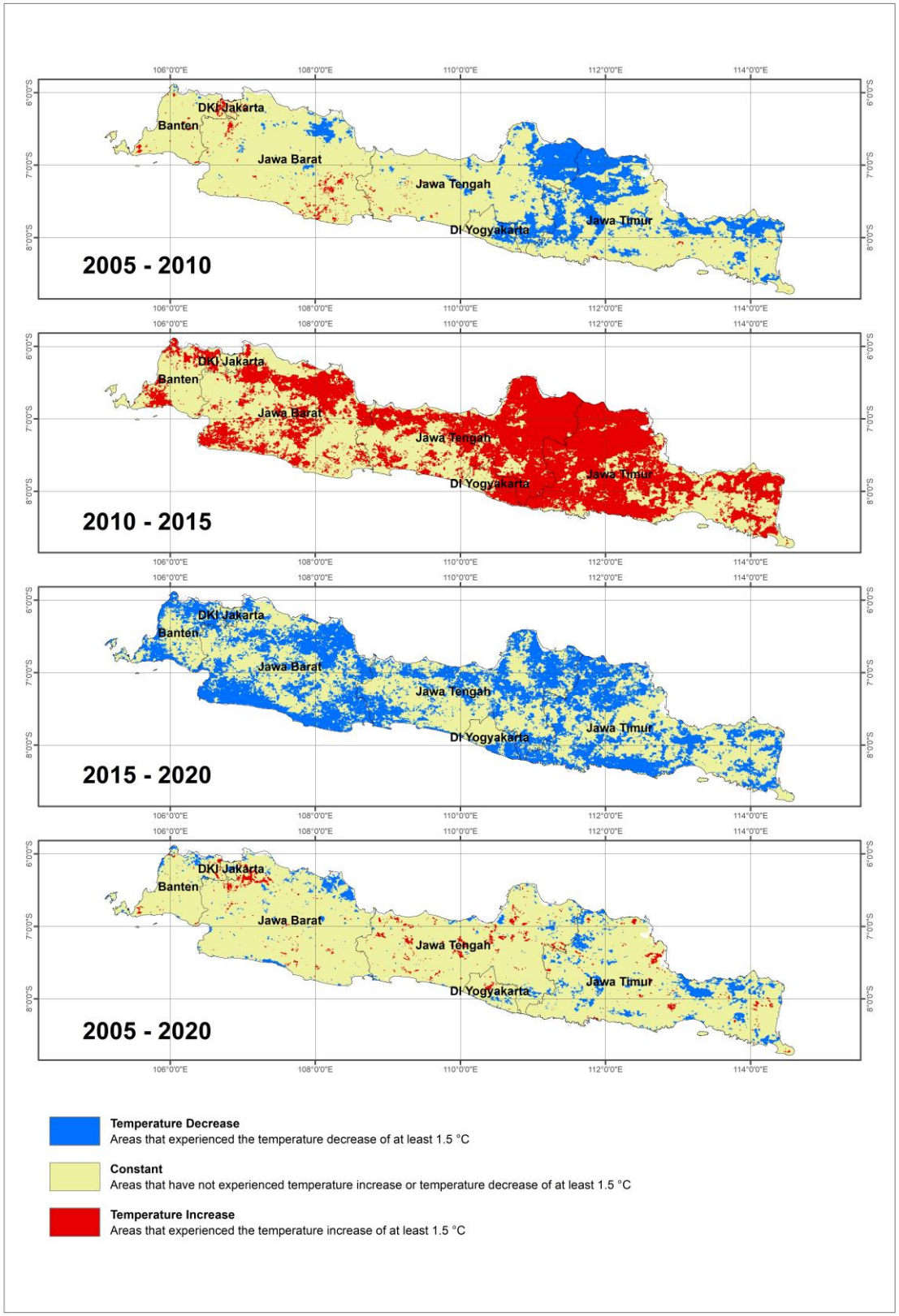


Figure 5: Annual Average LST changes every five years and the whole study period

Table 5: Areas in km^2 Based on The Annual Average LST Changes in Java Island of At Least 1.5°C

Year	Temperature Increase	Constant	Temperature Decrease
2005-2006	29000	97892	57
2006-2007	248	119438	7262
2007-2008	1061	122894	2994
2008-2009	13322	113417	210
2009-2010	85	72126	54737
2010-2011	***35105***	91603	241
2011-2012	6630	119969	350
2012-2013	65	110077	16806
2013-2014	11152	115727	69
2014-2015	7582	119251	115
2015-2016	6	61523	***65420***
2016-2017	9195	116111	1641
2017-2018	22521	104330	97
2018-2019	4511	121855	582
2019-2020	13	85688	41247

Table 6: Areas in km^2 Based on The Five and Whole Period Average LST Changes in Java Island of At Least

Year	Temperature Increase	Constant	Temperature Decrease
2005-2010	1800	102052	23097
2010-2015	68799	58108	42
2015-2020	10	69102	57836
2005-2020	3308	114962	8677

Based on the LST changes map as shown in Figures 4 and 5, these areas that experienced a temperature increase of at least 1.5°C were mainly in the eastern part of Central Java Province and the northern part of East Java Province. Meanwhile, the areas that experienced a temperature decrease of at least 1.5°C were mainly in West Java Province, the eastern part of Central Java Province, and the northern part of East Java Province.

4. Conclusion

This research examines variations in temperature on the earth's surface as an indicator of climate change using LST data from satellites (Terra and Aqua Modis). The use of LST data (rather than air temperature, as is typical) offers various advantages, including the ability to conduct analysis speedily with a significant quantity of data in terms of area and time. These two benefits are extremely difficult to achieve when utilizing ground weather stations. We concluded that the largest average LST change decreasing 1.6°C and 2.0°C occurred in 2015 to 2016 for Terra and Aqua, respectively. The highest increase in the area experienced an average LST change of at least 1.5°C occurred from 2010 to 2011 with 35105 km^2. In contrast, the highest decrease in the area experienced an average LST change of at least 1.5°C occurred from 2015 to 2016 with 65420 km^2. Areas that experienced a temperature increase of at least 1.5°C were mainly in the northern part of East Java Province and the eastern part of Central Java Province. Meanwhile, the areas that experienced a temperature decrease of at least 1.5°C were mostly in the northern part of East Java, the eastern part of Central Java, and in the West Java Province. This research has some limitations such as the temperature validation does not utilize surface temperature, and the area of pixel from weather station should not be equivalent to the 1 km spatial resolution of MODIS. These difficulties must be addressed in future studies.

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