Impact of Temperature on Tuberculosis estimated from Satellite Remote Sensing before and during COVID-19 Pandemic

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ABSTRACT

Several epidemiological studies have examined the effect of temperature on health, such as tuberculosis (TB). Previous researches have used temperature data from local station sites but the temperature in an area is spatially variable. For example temperature in the urban area is normally higher than in the rural area because of the urban heat island. Satellite remote sensing data can provide area information and is, therefore useful to quantify the effect of environmental hazards on health in a wider region. To study the impact of temperature on TB, this study estimates Land Surface Temperature (LST) using Landsat 8 data in Yogyakarta City, Indonesia from 2016 to 2020 and analyzes the relationship between temperature and TB cases. The LST estimates were first verified by the temperature data obtained from the Meteorological, Climatological, and Geophysical Agency. Tuberculosis cases from 2016 until 2020 were collected from Public Health Office. The correlation patterns have also been examined before and after the COVID-19 pandemic. The result shows that the satellite-derived LST reasonably matches the ground measurement, and a negative correlation between TB cases and LST can be recognized: the cases number is higher in low LST while the cases number is lower when LST is higher. This can be explained that the increase of TB case number in the lower temperature is because ultraviolet radiation kills bacterium, which impedes the spread of TB in dwellings. However, this correlation cannot be observed after COVID-19 outbreak. The number of TB cases in 2020 (during COVID-19 pandemic) is generally lower than the previous year (2016-2019, before COVID-19 pandemic) in the study area. This study suggests that social restriction policy may potentially affect the spread of TB and thus shows the irrelevant relationship between LST and TB cases during COVID-19 pandemic.

Keyword : Tuberculosis, Land Surface Temperature, Landsat 8, COVID-19

1. Introduction

Several epidemiological studies have examined the effect of climatic factors on health, such as temperature. Temperature can influence health through direct and indirect effects. Previous studies such as spatiotemporal in Mainland China showed that climatic factors give an impact on tuberculosis cases [4]. Previous researches have used temperature data from local station or ground monitoring sites, the result may be biased for the area which doesn't have extensive monitoring sites. The temperature in an area is spatially variable like in urban areas normally higher than in rural areas because of the urban heat island.

Remote sensing data and technologies Satellite remote sensing data can provide area information and is, therefore useful to quantify the effect of environmental hazards on health in a wider region. Several remote sensing data provide the thermal band to derive Land Surface Temperature such as Landsat, MODIS, and Sentinel 2. Landsat 8 has a thermal infrared sensor that can derive Land Surface temperature. The spatial resolution of Landsat is 30 m for visible bands, 15 m for panchromatic, and 100 m for thermal infrared bands. The satellite has a 16 day repeat cycle or temporal resolution.

Tuberculosis is caused by bacteria (Mycobacterium tuberculosis) and it most often affects the lungs. TB is spread through the air when people with lung TB cough, sneeze or spit. A person needs to inhale only a few germs to become infected [9].

Since 2019 , a series of pneumonia cases have been confirmed in Wuhan City, Hubei Province, China. On February 11th, 2020, the World Health Organization (WHO) by Director-General, Dr. Tedros Adhanom Ghebreyesus declared if the virus which caused the disease is SARS-CoV-2 or known as "COVID-19". On March 11th, 2020 when more than 118,000 cases and over 4000 deaths have found in over 114, then WHO declared the pandemic status [10].

The purpose of this study is to study the impact of temperature on TB, this study estimates Land Surface Temperature (LST) using Landsat 8 data in Yogyakarta City, Indonesia from 2016 to 2020 and analyzes the relationship between temperature and TB cases. The LST estimates were first verified by the temperature data obtained from the Meteorological, Climatological, and Geophysical Agency.

2. Materials and Methods

2.1. Study Area

The study area of Yogyakarta City (between 07°15’24” - 07°49’26” S and 110°24’19” - 110°28’53” E), with a population of 373.589 (in 2020) and area 32.50 m^2. Yogyakarta is an ancient city in Indonesia. The average temperature is 28.34°C and the average of monthly precipitations in Yogyakarta in 2020 is 197.68 mm^3.

Table 1

Area in by Subdistrict in Yogyakarta City

No	District	Subdistrict	Area (km^2)
1	Mantrijeron	Gedongkiwo	0.90
	(2.61 km^2)	Suryodiningratan	0.85
		Mantrijeron	0.86
2	Kraton	Patehan	0.40
	(1.40 km^2)	Panembahan	0.66
		Kadipaten	0.34
3	Mergangsan	Brontokusuman	0.93
	(2.31 km^2)	Keparakan	0.53
		Wirogunan	0.85
4	Umbulharjo	Giwangan	1.26
	(8.12 km2)	Sorosutan	1.68
		Pandean	1.38
		Warungboto	0.83
		Tahunan	0.78
		Muja-muju	1.53
		Semaki	0.66
5	Kotagede	Prenggan	0.99
	(3.07 km2)	Purbayan	0.83
		Rejowinangun	1.25
6	Gondokusuman	Baciro	1.06
	(3.99 km2)	Demangan	0.74
		Klitren	0.68
		Kotabaru	0.71
		Terban	0.80
7	Danurejan	Suryatmajan	0.28
	(1.10 km2)	Tegalpanggung	0.35
		Bausasran	0.47
8	Pakualaman	Purwokinanti	0.33
	(0.63 km2)	Gunungketur	0.30
9	Gondomanan	Prawirodirjan	0.45
	(1.12 km2)	Ngupasan	0.67
10	Ngampilan	Notoprajan	0.37
	(0.82 km2)	Ngampilan	0.45
11	Wirobrajan	Patangpuluhan	0.44
	(1.76 km2)	Wirobrajan	0.67
		Pakuncen	0.65
12	Gedongtengen	Pringgokusuman	0.46
	(0.96 km2)	Sosromenduran	0.50
	Jetis	Bumijo	0.58
13	(1.70 km2)	Gowongan	0.46
		Cokrodiningratan	0.66
	Tegalrejo	Tegalrejo	0.82
14	(2.91 km2)	Bener	0.57
		Kricak	0.82
		Karangwaru	0.70
		Total	32.50

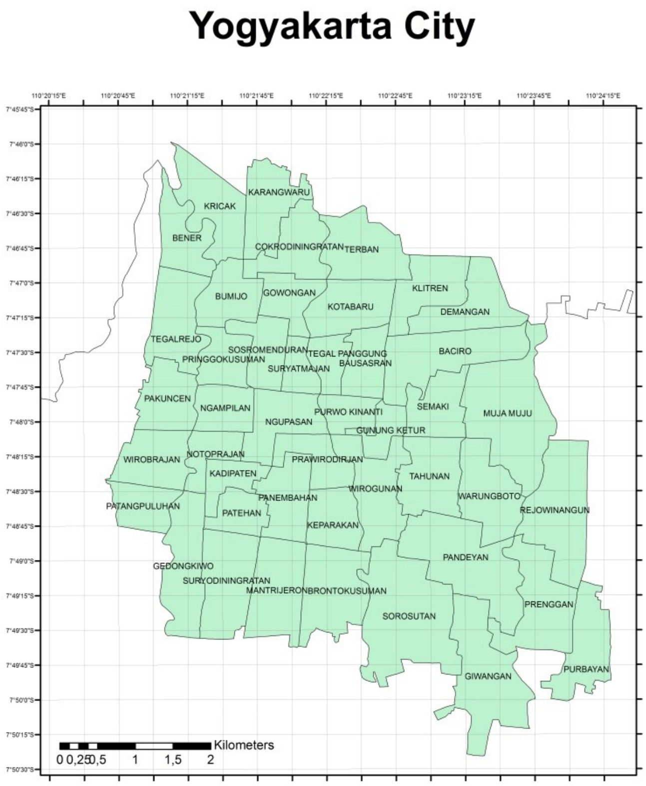


Figure 1

Map of Yogyakarta City

2.2. Data Collection

1. Health data

The map unit of Tuberculosis Cases is sub-district level. The tuberculosis cases are collected from 2016 to 2020. This data is from the public health office. This data is tuberculosis patients or cases in every sub-district.

2. Ground Monitoring Data

Monthly weather data is from the meteorological, climatological, and geophysical agencies. This data includes minimum, average, and average monthly temperature in Yogyakarta City.

3. Satellite Remote Sensing Temperature Data

The Satellite data is Landsat 8 which has 11 bands, for spatial resolution is 30 m is for multispectral images, 15 m is for panchromatic images, and 100 m is for thermal.

2.3. Methodology

2.3.1. Pre processing

2.3.1.1. Top of Atmospheric Spectral Radiance

Top of Atmospheric is a ratio of radiation reflected the incident solar radiation on a given surface. It can be computed from measured spectral radiance using the mean solar spectral irradiance and the solar zenith angle. Landsat Level-1 data can be converted from digital number into TOA (Top of Atmospheric)

$$L\lambda = M_L * Q_{cal} + A_L - O_i$$

Top of Atmospheric

where:

L_λ = TOA spectral radiance (Watts/(m^2 * srad * µm))

M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

2.3.1.2. Calculate Brightness Temperature (Conversion of Radiance to At-Sensor Temperature)

Brightness Temperature is a measure of the radiance of microwave radiation traveling upward from the top of Earth's atmosphere.

$$\text{BT} = \frac{K_2}{\ln\left[\left(\frac{K_1}{L\lambda}\right) + 1\right]} - 273.15$$

where:

T = Top of atmosphere brightness temperature (K)where:

L_λ =TOA spectral radiance (Watts/(m2 * srad * µm))

K1 =Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

K2 =Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

2.3.1.3. Calculate NDVI for Emissivity Correction

NDVI is for quantifies vegetation by measuring the difference between Near Infrared band (NIR) and Red band (R):

$$NDVI = \frac{NIR\ (band\ 5) - R\ (band\ 4)}{NIR\ (band\ 5) + R\ (band\ 4)}$$

The range of NDVI is from -1 to +1. The value closes to +1 means has a high possibility that it's green leave (high vegetation density), otherwise if the value close to -1 means has a high possibility that it's water.

2.3.1.4. Calculate Proportion of Vegetation

Calculate the proportion of vegetation (P_v) is a method for calculating the ratio of the vertical projection area of vegetation which containing leaves, stalks, and branches on the ground to the whole vegetation area [4]. P_v is an important vegetation biophysical variable related to the earth's surface processes, in addition to biodiversity monitoring, climate modeling, and weather prediction model [5].

$$P_v = \left(\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}\right)^2$$

Where:

NDVI = Normal Difference Vegetation Index
$NDVI_s$ = minimum NDVI value
$NDVI_v$ = maximum NDVI value

2.3.1.5. Calculate Land Surface Emissivity

The land surface emissivity (LSE (ε)) must be acknowledged which will estimate LST, for the reason that LSE is a proportionality issue that scales blackbody radiance (Planck's law) to expect emitted radiance, and it's for the performance of transmitting thermal electricity across the floor into the ecosystem [7]. The formula for Land Surface Temperature is:

$$\varepsilon_\lambda = \varepsilon_{v\lambda} P_v + \varepsilon_{s\lambda}(1 - P_v) + C_\lambda$$

Where:
ε_λ = Land Surface Emissivity
ε_v = Vegetation emissivities
ε_s = Soil emissivities
C_λ = Represent surface roughness (C = 0 for homogenous and flat surfaces) taken as a constant value of 0.005

The circumstance can be represented with the following method and the emissivity constant values as the following formula:

$$\varepsilon_\lambda = \begin{cases} \varepsilon_{s\lambda}, & NDVI < NDVI_s, \\ \varepsilon_{v\lambda} P_v + \varepsilon_{s\lambda}(1 - P_v) + C, & NDVI_s \le NDVI \le NDVI_v , \\ \varepsilon_{s\lambda} + C, & NDVI > NDVI_v \end{cases}$$

If the NDVI is below zero, the image pixel can be classified as water, and the emissivity value should be 0.991 is established. For NDVI values between 0 and 0.2, it's considered that the earth's surface is covered with the soil, so the emissivity value of 0.996 is established. The values between 0.2 and 0.5 are taken into consideration mixtures of soil and covered with vegetation and are carried out to retrieve the emissivity. In the last case, when the NDVI value is more than 0.5, it's considered to be covered with vegetation and the value of 0.973 is established [7].

2.3.1.6. Calculate Land Surface Temperature

Land Surface Temperature is

$$T_s = \frac{BT}{\left\{1 + \left[\left(\frac{\lambda BT}{\rho}\right) ln\varepsilon_\lambda\right]\right\}}$$

where:
T_s = LST in celcius
BT = Brightness Temperature is at sensor in celcius
λ = Wavelength of emitted radiance (for which the peak response and the average of the limiting wavelength (λ =10.895) will be used)
$\varepsilon\lambda$ = Emissivity

2.3.2. Statistical Analysis

This study analyzed the correlation between Tuberculosis cases and Land Surface Temperature and the linear regression is used to formulate their relationship.

3. Results

3.1. Tuberculosis Cases

Tuberculosis cases from Public Health Officer. Based on Table 2. Umbulharjo is the highest case and Pakualaman is the lowest case. Table 1 showed that Umbulharjo is the widest area and Pakualaman is the smallest area. The area will affect the number of cases because the population in the wider area could be more than the smaller area.

Table 2

Number of Tuberculosis Cases by District in Yogyakarta City

No	Kecamatan	2016	2017	2018	2019	2020
1	Danurejan	50	35	31	45	36
2	Gedongtengen	44	32	34	40	23
3	Gondokusuman	55	55	59	55	50
4	Gondomanan	25	22	30	30	31
5	Jetis	37	47	43	32	38

6	Kotagede	36	27	34	44	32
7	Kraton	24	34	40	25	31
8	Mantrijeron	43	45	31	52	33
9	Mergangsan	46	41	38	52	42
10	Ngampilan	13	34	25	25	19
11	Pakualaman	17	4	11	10	10
12	Tegalrejo	55	45	43	58	31
13	Umbulharjo	113	89	110	96	70
14	Wirobrajan	36	41	35	40	34
	Yogyakarta	594	551	564	604	480

3.2. Land Surface Temperature

Land Surface Temperature is the temperature on the earth's surface, especially on the ground. From a satellite's point of view, the term of the surface means whatever it sees when it looks through the atmosphere to the ground. That could be snow and ice, grass on a lawn, roofs of the building, or leaves in the canopy of the forest. Land surface temperature is not the same as the air temperature that is included in the daily weather report. Table 3 shown the minimum, average, and maximum from 2016 until 2019. Based on the result if in 2020 the temperature is lower than previous year (2016 – 2019). The COVID-19 outbreak may get affected by the land surface temperature.

Table 3

Minimum, Average, and Maximum Land Surface Temperature in Yogyakarta City by district in 2016 - 2020

Kecamatan	Min 2016	Max 2016	Ave 2016	Min 2017	Max 2017	Ave 2017	Min 2018	Max 2018	Ave 2018	Min 2019	Max 2019	Ave 2019	Min 2020	Max 2020	Ave 2020
Danurejan	30,13	32,21	31,33	32,13	34,21	33,33	31,85	33,77	32,85	29,38	31,90	30,94	26,49	29,85	28,83
Gedongtengen	29,08	32,59	31,03	31,08	34,59	33,03	29,79	34,58	32,66	28,55	32,55	30,44	25,80	29,43	28,13
Gondokusuman	29,67	32,80	30,88	30,30	35,22	32,89	30,10	35,52	32,52	27,86	33,50	30,64	25,27	31,38	28,52
Gondomanan	29,89	32,15	31,48	31,89	34,15	33,48	30,76	33,81	32,99	29,10	31,79	31,02	27,19	30,92	28,88
Jetis	28,81	31,51	30,89	30,81	34,03	32,89	30,04	33,65	32,48	28,46	31,72	30,50	26,75	29,85	28,60
Kotagede	25,72	31,99	30,45	27,72	33,99	32,45	26,67	33,78	31,89	25,83	32,01	30,30	24,45	29,92	28,26
Kraton	30,32	32,41	31,38	32,32	34,41	33,38	32,09	34,24	33,13	30,15	32,32	31,25	28,47	30,40	29,29
Mantrijeron	27,81	31,49	30,47	29,81	33,50	32,47	29,34	33,82	32,00	27,93	31,65	30,23	25,32	29,64	28,45
Mergangsan	27,07	32,26	30,91	29,08	34,26	32,91	28,55	33,92	32,36	27,22	32,56	30,73	25,77	29,69	28,59
Ngampilan	28,91	32,73	31,12	30,91	34,73	33,12	30,72	34,70	32,83	28,27	32,63	30,82	27,08	29,84	28,67
Pakualaman	30,48	32,15	31,43	32,48	34,15	33,43	31,94	34,05	33,16	30,15	31,95	31,05	27,34	29,37	28,61
Tegalrejo	25,72	34,27	30,63	27,72	36,27	32,63	26,67	35,52	32,19	25,83	33,50	30,40	24,45	31,38	28,40
Umbulharjo	25,72	34,27	30,63	27,72	36,27	32,63	26,67	35,52	32,19	25,83	33,50	30,40	24,45	31,38	28,40
Wirobrajan	28,29	31,46	30,50	30,29	33,46	32,51	29,73	33,27	32,32	28,04	31,44	30,29	26,05	29,48	28,54

3.3. Ground Truth Measurement

Ground Truth Measurement Temperature Data is the average monthly temperature consist of minimum, average, and maximum. Compare the LST value and ground truth measurement if the LST value is lower than the ground truth measurement. Based on the validation data if R^2 values is 0.751, it means if LST is acceptable. Remote sensing can solve the limitation of the ground station.

Table 4

The Validation of LST Value and Ground Truth Measurement

No	Information	LST Value	Ground Truth
1	Minimum 2016	25.7237	23.2

2	Maximum 2016	34.267	31.4
3	Average 2016	30.6276	26.4
4	Minimum 2017	27.7249	20.6
5	Maximum 2017	36.2685	33.4
6	Average 2017	32.629	26.4
7	Minimum 2018	26.6691	21.2
8	Maximum 2018	35.521	34
9	Average 2018	32.19174	26.2
10	Minimum 2019	25.8254	20.7
11	Maximum 2019	33.4959	30.8
12	Average 2019	30.4027	24.5
13	Minimum 2020	24.4479	21
14	Maximum 2020	31.3764	33.4
15	Average 2020	28.3977	28.25

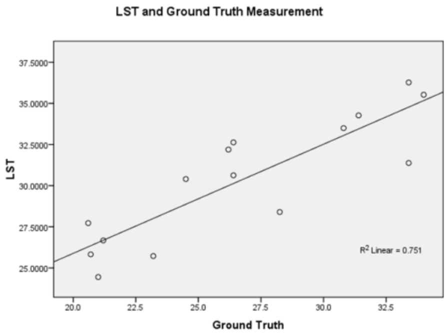
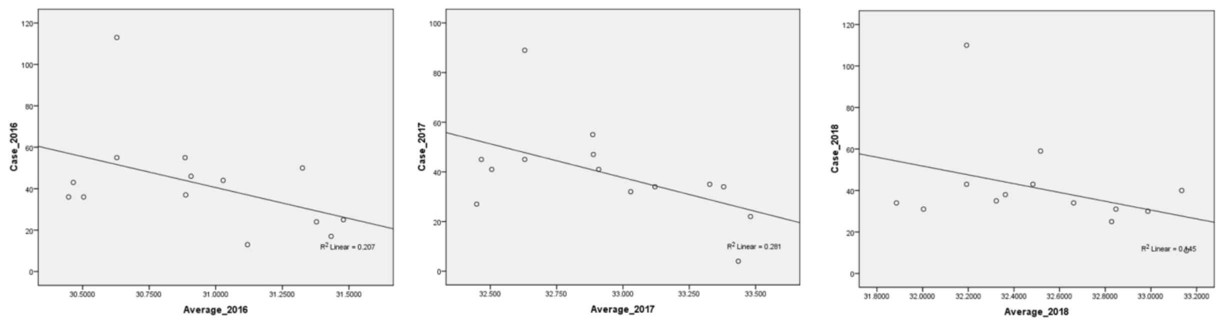


Figure 2
Scatter Plot of LST value and Ground Truth Measurement

3.4. Effect of temperature on Tuberculosis

This research use regression. COVID-19 Pandemic may have some positive influences such as the Land Surface temperature becomes lower than usual and the number of tuberculosis cases also lower than usual. The relationship between temperature and tuberculosis cases is significant radiation from the sun based on the regression. Lower temperature will increase the case because ultraviolet kills bacterium in dwellings. Based on Figure 3 if the result in 2020 looks different compare to previous years.



Year	R^2
2016	0.207
2017	0.281
2018	0.145
2019	0.31
2020	0.012

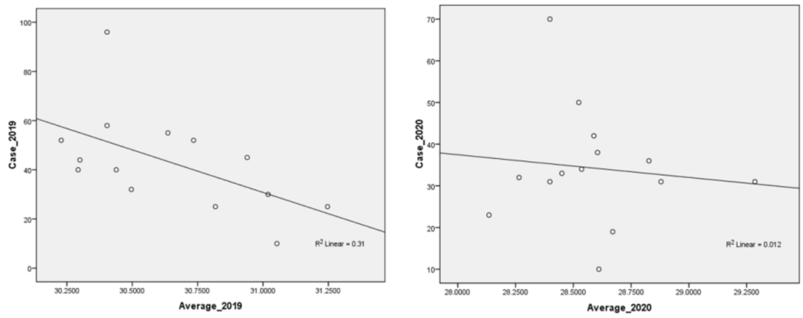


Figure 3
Scatter Plot of Tuberculosis Cases and LST Value 2016 – 2020

4. Discussion

The COVID-19 outbreak has some impacts on people daily lives, and environment by social restriction policy that make people to stay at home and reduce their activities. The change of the environment can be seen from Land Surface Temperature. By obtaining multitemporal information of Land Surface Temperature can give the evidence if there is differences between before and during COVID-19 pandemic. Based on Table 3 if the Land Surface Temperature in the unit analysis on 2020 lower than previous year. It means the COVID-19 pandemic has positive impacts to the environment. Good environment also can influenced the health population.

Land Surface Temperature also has the impacts on tuberculosis cases. High temperature will decrease the case because ultraviolet radiation kills bacterium in dwellings. Based on the Figure 3 if the cases will be higher in low temperature and lower cases in high temperature. Another parameters can be added such as population density or social economic and another environmental factors to the future studies. Analysis of medical data and risk factors involved would be worthwhile, which will give the decision makers (government) more comprehensive support on make a new regulation about tuberculosis during pandemic. This paper tends to offer quantitative analytics the impact of the temperature on tuberculosis before and during pandemic.

Ground measurement data is underestimated compared to Land Surface Temperature from Landsat 8. Land Surface Temperature research is very challenging because the temperature is fluctuating data. Land Surface Temperature research conducted in developing nations (i.e Indonesia) with insufficient surface temperature stations is challenging to conduct. Air temperature is more feasible to be used, but the absence of getting the hourly observation to compare with the satellite acquisition date is also another challenge. This study showed to overcome the limitation of ground stations is use satellite remote sensing to derive Land Surface Temperature. Derive temperature data from Land Surface Temperature is convenience, efficient, and not too expensive. It's a good alternative to analyze the environment and health impact, especially for tuberculosis case. One of the tuberculosis risk factor is temperature so temperature will give the significancy of the cases.

5. Conclusions

The R^2 for LST and Ground Truth measurement is 0.751, which means if Land Surface Temperature can be used to derive the environmental temperature. The result shows that the satellite-derived LST reasonably matches the ground measurement, and a negative correlation between TB cases and LST can be recognized: the cases number is higher in low LST while the cases number is lower when LST is higher. This can be explained that the increase of TB case number in the lower temperature is because ultraviolet radiation kills bacterium, which impedes the spread of TB in dwellings.

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