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Environmental Critical Analysis of Urban Heat Island Phenomenon Using ECI (Environmental Critically Index) Algorithm in Surakarta City and Its Surroundings

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Abstract

One of the impacts of unplanned urban growth is the decrease of urban vegetation which is replaced by land **development** such as buildings, roads and open land with paving block materials. This causes the environmental quality to decline. Surakarta City is one of the cities with rapid growth in Central Java. This is indicated by the increase in population over the years. This research examines the phenomenon of changes in environmental quality using ECI with variables NDVI and LST using Landsat 8 in 2013 and 2019. In particular, this study analyzes the relationship between ECI and UHI and the relationship between LST and NDVI to ECI. The results show that in 2013 ECI area was dominated by the City Center, then in 2019 it expanded to the outer areas surrounding Surakarta City. The Urban - Rural gradient also illustrates that the highest average of ECI in urban areas will decrease when heading to Rural areas. The decrease happened due to the pressure from the growing population. Each variable has a strong correlation with one another and influences each other. Efforts to overcome environmental criticality are sustainable greening, because green spaces can help reduce the warming effects of UHI.

Keywords: LST, NDVI, ECI, UHI

1. Introduction

Surakarta City is one of the fastest growing cities in Central Java Province. Surakarta City development occurs in the economic, industrial, education and tourism sectors. The development of the city will spur the flow of economic growth. This makes the city a magnet that attracts people to come for finding work and a place to live or so-called urbanization. The urbanization causes an increase in population, which causes an increasing need for land as residential areas.

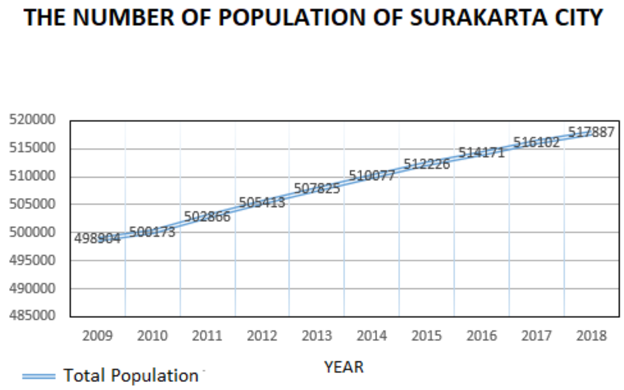

Figure 1

Figure 1 is a graph of the total population of Surakarta City in 2009 - 2018 obtained through Population Statistics Data through the Surakarta City Central Bureau of Statistics. This graph shows the increase in the population from 2009 to 2018. The phenomenon of increasing population causes changes in land use, such as green land (RTH) into residential and industrial land. Less greenland causes an increase in temperature in urban areas. Building materials such as cement, asphalt and concrete are absorbent and store solar heat. Tursilowati (2006) found that the use of heating, air conditioning and power plants which produce heat waste, industrial activities, transportation and household activities that use fossil fuels also contribute to the increase in urban temperatures.

The temperature in the office area, industry and asphalt roads experienced a dramatic change in surface temperature. In contrast, green areas in urban areas have low surface temperatures. This has resulted in changes in climate elements, especially in urban centers and industrial areas. These climatic elements include wind speed, clouds, temperature and radiation. Temperature is an element that can be observed directly by the community. Puji Waluyo (2009) argues that the existence of a different city temperature distribution is called the Urban Heat Island (UHI). UHI is a natural phenomenon where the temperature in a densely built area is higher than the temperature in the open area around it. Development of the area should not only focus on the economic and infrastructure aspects, but also environmental aspects. Therefore, it is important to consider the environmental aspects of Surakarta City in order to achieve sustainable development. If the issue is not taken seriously, it will have long-term effects, one of which is environmental problems.

Based on the above reasons, this study has three objectives: (1) to analyze changes in surface temperature and vegetation density in the city of Surakarta, (2) to analyze the environmental criticality due to the Urban Heat Island phenomenon that often occurs in urban areas, and (3) to analyze the relationship between surface temperature and vegetation density on environmental criticality. The analysis process is carried out spatially to help understand the distribution and value of environmental criticality in Surakarta City.

2. Research Method

The object of research is the city of Surakarta and its surroundings, including surface temperature, vegetation density, heat islands (UHI) and environmental criticality. The method for data analysis is using secondary data. The data used include Landsat 8 imagery for 2013 and 2019. Data processing is carried out using the NDVI, LST, UHI and ECI algorithms.

2.1 Vegetation Density Processing (NDVI)

a. Radiometric Calibration

The algorithm that works in the Radiometric Calibration tool is as follows:

$$L_{\lambda} = Gain * Pixel\,Value + Offset \text{ ....(1)}$$

Information:

Gain *Pixel Value* *Off set*

b. Atmospheric Correction (*FLAASH*)

FLAASH works using the MODTRAN4 code.

$$L_{\lambda\,atmcorr} = \left(\frac{A\rho}{1-\rho_e S} + \frac{B\rho_e}{1-\rho_e S}\right) + L_a \text{ ....(2)}$$

Information:

ρ : reflectance value ρ_e : mean of the reflectance value

S : albedo value L_a : L_{λ} value

A and B: band coefficient value x

c. Normalized Difference Vegetation Index (NDVI)

The algorithms that can be used are sourced from USGS. as follows:

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \text{ ....(3)}$$

Information:

NIR : Band *Near Infrared* (reflectance value) Red : Band *Red* (reflectance value)

2.1 Surface Temperature (LST) Treatment

a. Radiometric Calibration (ToA Radiance)

ToA radiance radiometric correction can be performed using the *USGS* formula.

$$L_{\lambda} = M_L \times Q_{cal} + A_L \text{ ....(4)}$$

Information:

L_{λ} : ToA Radian Spectral (Watt/m2*srad*µm)

M_L : Value of *radiance_multi_band_x* (from metadata)

Q_{cal} : *Digital Number*

A_L : Value of *radiance_add_band_x* (from metadata)

a. Emissivity

The algorithm used refers to Valor and Caselles (1996).

$$Pv = ((NDVI - NDVI_{min}) / (NDVI_{Max} - NDVI_{Min}))^2 \text{ ....(5)}$$

$$\varepsilon = 0.004Pv + 0.0986 \text{ ....(6)}$$

Information:

Pv: *Proportion of Vegetation* *NDVI Max*: Maximum Vegetation Index Value

NDVI Min: Minimum Vegetation Index Value Ɛ : Emissivity Value

a. *Brightness Temperature Satellite (Kelvin)*

Calculated using the USGS algorithm*:*

$$Tb = \frac{K_2}{Ln\frac{K_1}{L_{\lambda\, atmcorr}}+1}\text{.................................(7)}$$

Information:

Tb : Brightness Temperature Satellite (Kelvin)

K1: Band_X Spectral radiance Calibration Constants

K2: Band_X Spectral radiance Calibration Constants

$L_{\lambda\, atmcorr}$: Spectral Radiance *(Watt/m2*srad*µm)*

b. Land Surface Temperature

The surface temperature is calculated by using the USGS:

$$Ts = \frac{Tb}{1+\left(\lambda \times \frac{Tb}{c2}\right) ln\, \varepsilon}\text{ ....(8)}$$

Information:

Ts : Surface Temperature (*Kelvin)*

Tb : *Brightness Temperature Satellite (Kelvin)*

λ : Radiance Emission Wavelength

$c2$: Derived from hc / σ with a value of 1.438 × 10-2 mK = 14388 µmK (h = Planck constant 6.26 x 10-34 Jsec, c = speed of light 2.998 x 108 m / s and σ = Boltzam constant 1.38 × 10-23 J / K)

ε: emissivity

c. Convert Kelvin Temperature to Celsius

d. Tcelsius = Tkelvin – 273.15 ....(9)

2.2 Environmental Critical Treatment (ECI)

Environmental Criticality Index (ECI) is an index that describes the critical condition of the environment due to an increase in surface temperature and a reduction in green land (Senanayake et. Al., 2013). The algorithm that can be used is as follows:

$$ECI = \frac{LST}{NDVI}\text{.................................(10)}$$

Information:

LST: Value of LST NDVI : Value of NDVI

2.3 UHI processing

UHI can be generated by modifying the equation from Rajasekar & Weng (2009) and entering the equation presented by Ma et al (2010). If applied, the UHI is obtained by subtracting the LST value from the mean value that has been added by half the standard deviation (Fawzi & Jatmiko, 2018).

$$\mathbf{UHI = T - (\mu + 0.5\alpha)} \quad \text{.................................(11)}$$

Information:

UHI : Urban Heat Island (°C) T : LST (°C)

μ : Average LST Value (° C) α: Standard Deviation Value LST (° C)

3. Results and Discussion

3.1 Land Surface Temperature (LST) of Surakarta City and Its Surroundings in 2013 and 2019

LST is the condition of the earth's surface land temperature. LST can be obtained by extracting remote sensing information through thermal data.

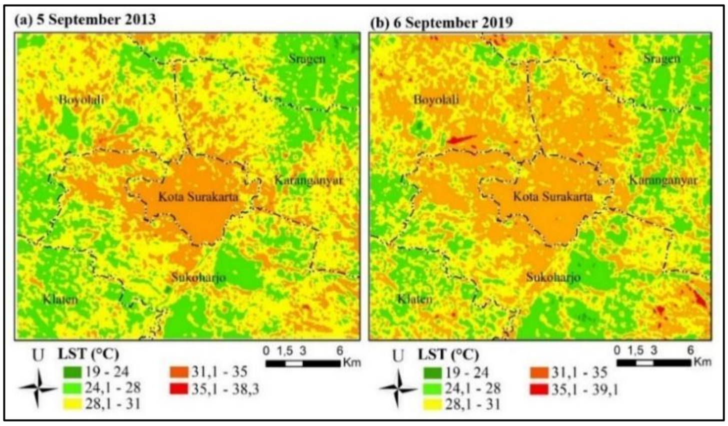

Figure 2 LST of Surakarta City and Its Surrounding Area (a) 2013 and (b) 2019

LST on September 5, 2013 (at 10:43:58 WIB) ranged from 19.01 ° C - 38.34 ° C with an average of 29.31 ° C. LST on September 6, 2019 (at 10:42:09 WIB) ranges from 20.34 ° C - 39.15 ° C with an average of 29.97 ° C. In this study, the LST classification was divided into very low - very high classes. The very high class are scattered in Klaten Regency, Karanganyar Regency, Sukoharjo Regency, Boyolali Regency and Sragen Regency. The high class resides in all districts /cities but is dominated by Surakarta City. Medium to very low class are located in all districts / cities, especially in the area around Surakarta City. Based on the above distribution pattern, it can be concluded that high LST is centered in the city, then the LST will vary more when moves away from Surakarta City

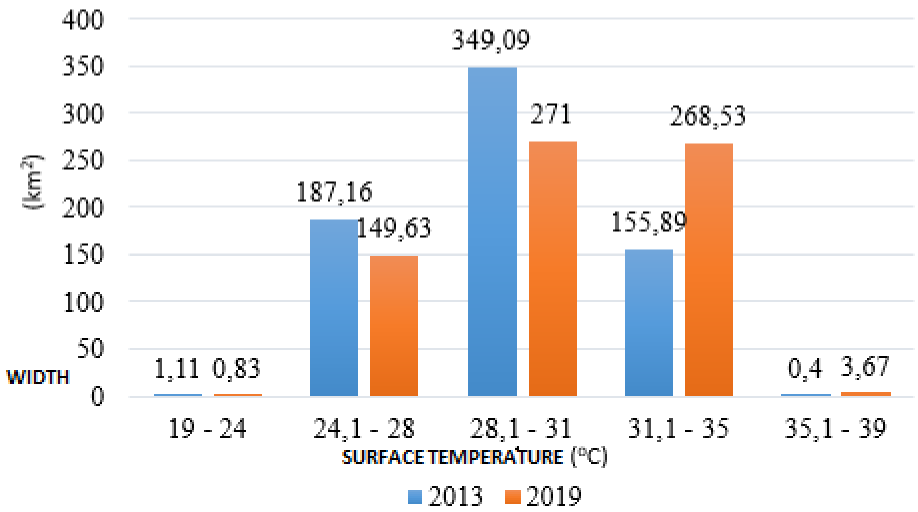

Figure 3 Comparison of Change in LST Area in 2013 and 2019

In general, there is an increase in LST to a higher temperature level. This can be seen in the changes that occurred in the Surakarta City area and its surroundings between 2013 and 2019, which was indicated by a decrease in the area with a very low - medium temperature classification (19 ° C - 31 ° C), and an increase in the area of a high - very high classification~~. high~~ (31.1 ° C - 39 ° C).

3.2 NDVI of Surakarta City and Its Surroundings in 2013 and 2019

NDVI is an index that describes the condition of vegetation density in an area. This index can be obtained by processing the spectral values of Band Red and Band Near Infrared.

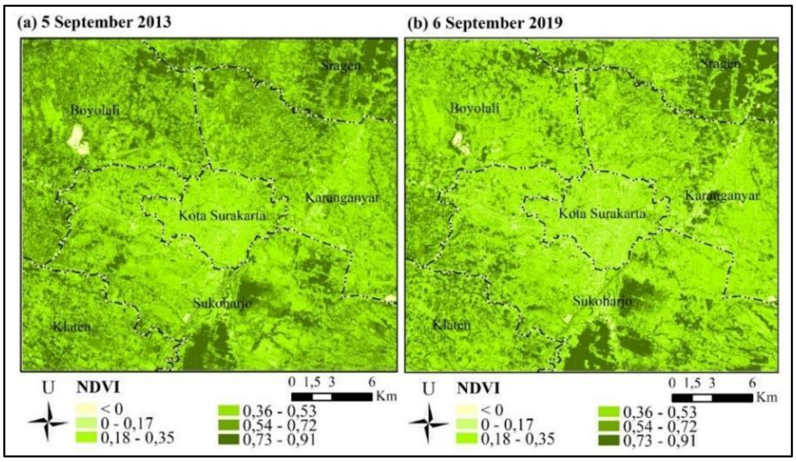

Figure 4 NDVI of Surakarta City and Its Surrounding Area (a) 2013 and (b) 2019

The distribution of the NDVI of Surakarta City and its surroundings in 2013 and 2019 has quite varied values. In this study, NDVI is classified into six groups, namely non-vegetation class - very high class. The classification is visualized in the NDVI Map in Figure 3.3. Symbology uses cream colors to represent non-vegetation areas, while green shades represent vegetation areas. The green gradient starts from light green to dark green. The brighter the green color shown, the less vegetation in the area, and the darker the green color shown, the denser the vegetation. Non-vegetation to low classes dominated in the city center. The middle to high class is dominated in the area around Surakarta City, namely Sukoharjo Regency, Boyolali Regency, Karanganyar Regency and Sragen Regency. The further away from Surakarta, the vegetation classes vary.

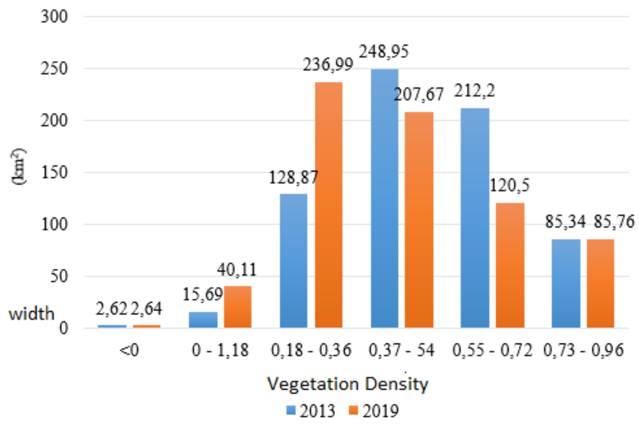

Figure 5 Comparison of NDVI Area Change in 2013 and 2019

Based on this data, it can be seen that in general there was a decrease in NDVI in 2013 and 2019. This is known from the changes that have occurred in each classification class. In the classification of non-vegetation classes (<0), very low (0 - 1.8), and low (0.19 - 0.36), the area increased. Medium (0.37 - 0.54) and high (0.55 - 0.72) classification classes experienced area decreases. The factor that largely affects changes in vegetation density is changes in land use. As the second largest city is well known in Central Java Province, Surakarta attracts people to come looking for work and a place to live. However, the city of Surakarta is already dense and does not have sufficient vacant land for immigrants which made land conversion occur more in the areas surrounding Surakarta City.

3.3 ECI Surakarta City and Its Surrounding Area in 2013 and 2019

Environmental Criticality Index (ECI) is an index that describes the criticality of the environment. The parameters used are LST and NDVI.

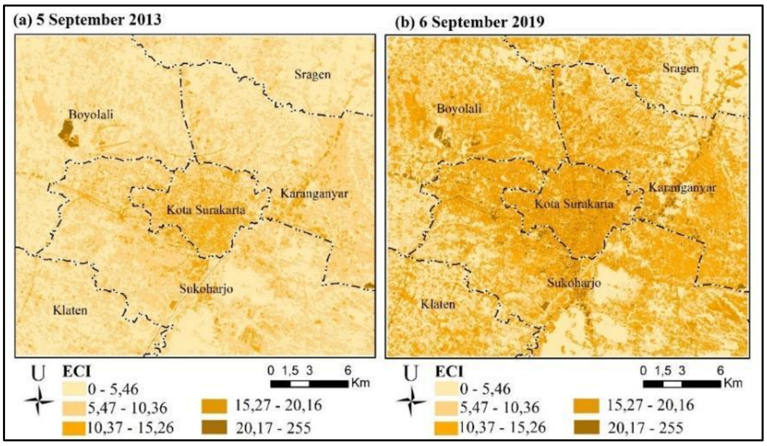

Figure 6 ECI Surakarta City and Its Surrounding Area in 2013 and 2019

In this study, ECI was classified into five classes, very low (0 - 5.46), low (5.47 - 10.36), moderate (10.37 - 15.26), high (15.27 - 20.16) and very high (20.17 - 255). The symbology used is orange, which represents a very low to very high classification class. The darker the orange color shown, the higher the ECI in that area. Very high and high classes ECI are centered in Surakarta City, medium to very low classes ECI dominate the areas surrounding Surakarta City, namely Boyolali Regency, Klaten Regency, Sukoharjo Regency, Karanganyar Regency and Sragen Regency. The further away from Surakarta City, the more varied the ECI classes.

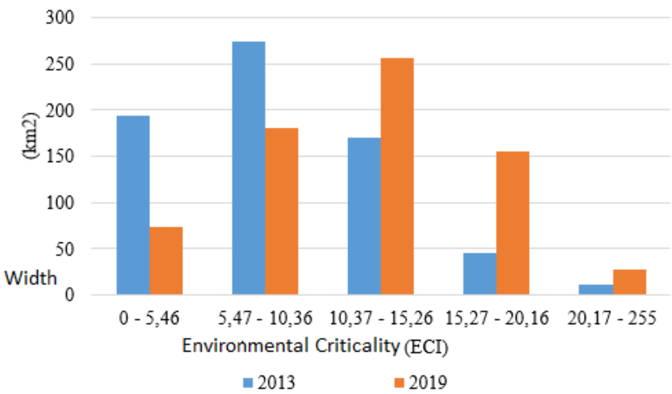

Figure 7 Comparison of Changes in ECI Extent in 2013 and 2019

Based on the data, there is a change in the area of each classification class. The increase in ECI occurred in the medium class classification (10.37 - 15.26), high class (15.27 - 20.16) and very high (20.17 - 255). The decline occurred in the very low class classification (0 - 5.46) and the low class (5.47 - 10.36). The ECI exists due to changes in environmental conditions. These changes can be observed from the condition of the vegetation density in the surrounding environment. While the surface temperature cannot be seen visually, the effect can be felt. Surface temperature affects the sensible heat flux, especially during the day because the surface temperature of the object is higher than the air temperature. The higher the surface temperature in an area, the hotter the sensible heat felt.

3.4 Relationship between ECI and UHI in Surakarta and its Surroundings

Urban Heat Island (UHI) is a phenomenon of increasing temperature that occurs in an area. This generally occurs in metropolitan cities which have significantly warmer temperatures than the surrounding areas due to greater activity. The method used to identify UHI in this study refers to the algorithm from Fawzi & Jatmiko (2018) which was developed from the methods of Rajasekar & Weng (2009) and Ma et al. (2010).

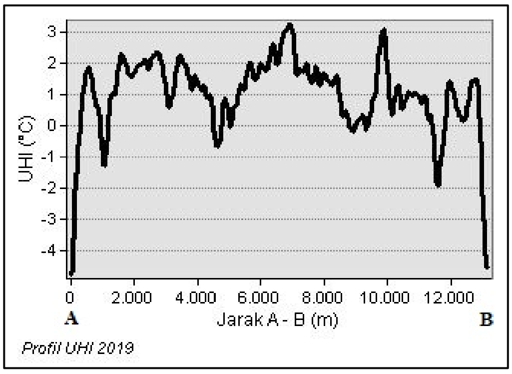

Figure 8 Profile of UHI in Surakarta City and its Surrounding Area in 2019

The transverse profile of UHI Surakarta City and its surroundings taken horizontally. Through this graph, it is explained that the highest UHI is in the city center and then the UHI will decrease further when it comes to suburban areas. Fuladlu et al. (2018) in their research explained that the UHI describes the temperature differences between urban and rural. The research found that the condition of rural areas has a lower UHI value because it is still dominated by vegetation. If there is an increase in the uses of land such as buildings, then UHI will expand to increasingly developing areas. Urban development will affect UHI.

Table 1 Descriptive Statistics of the Relationship between ECI and UHI

A) Summary

Statistics Regression	
Multiple R	0,854
R Square	0,729
Adjusted R Square	0,726
Standard Error	1,225
Observations	100

B) Regression Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-4,4885	0,31	-14,47	$4{,}6e^{-26}$	-5,10	-3,87
ECI	0,409	0,03	16,24	$1{,}5e^{-29}$	0,36	0,46

Source: Author’s calculation (2020)

The correlation coefficient is 0.854 or very strong, which means that there is a close relationship between the ECI and UHI. The coefficient of determination is 0.729 or 72.9, this indicates that the ECI can explain UHI by 72.9%, the rest is influenced by other variables not mentioned in the model. The p-value in the table of the results of the regression coefficient (Table 5.7) of 1.5 x 10^{-29} has a value less than 0.05, so there is sufficient evidence to reject H_o and take H_a at the 5% significance level. Furthermore, the ECI coefficient value is positive (0.409). In other words, it can be concluded that the ECI has a significant effect on UHI.

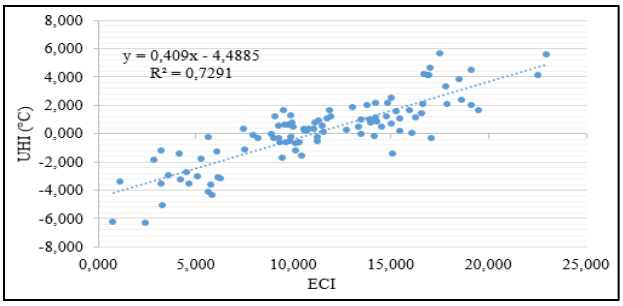

Figure 9 Relationship between ECI and UHI in 2019

The ECI regression equation to UHI is Y = 0.409X - 4.48. The value of the constant a is -4.48 indicating that the value of the UHI when the ECI is zero (0) is -4.48. The regression coefficient value b of 0.409 means that the ECI value has a positive relationship, meaning that when the ECI increases, the UHI increases too.

3.5 Relationship between LST and ECI in Surakarta and its Surrounds

Assessment of the LST and ECI relationship is explained using simple linear regression. The relationship between the two is in the descriptive statistics in table 2.

Table 2 Descriptive Statistics of LST? Relation to ECI

A) Summary

Regression Statistics	
Multiple R	0,854
R Square	0,729
Adjusted R Square	0,726
Standard Error	2,557
Observations	100

B)Regression Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-44,462	3,44	-12,91	$7{,}2e^{-23}$	-51,30	-37,63
LST	1,783	0,11	16,24	$1{,}5e^{-29}$	1,57	2,00

Source: Author’s calculation, 2020

The correlation coefficient of LST is 0.854, this indicates a strong relationship between LST and ECI. The coefficient value of ESG determination on ECI is 0.729 or 72.9%. It implies that the LST value can be explained by the ECI condition in Surakarta City and its surroundings by 72.9%, while the remaining 27.1% is influenced by other variables not mentioned in this model. The p-value in the table of the results of the regression coefficient Table 2 is 1.5 x 10^{-29} which has a value less than 0.05 so that there is sufficient evidence to reject H_o and take H_a at the 5% significance level. Furthermore, the value of the LST coefficient is positive (1.783). In other words, it can be concluded that LST has a significantly proportional effect on ECI.

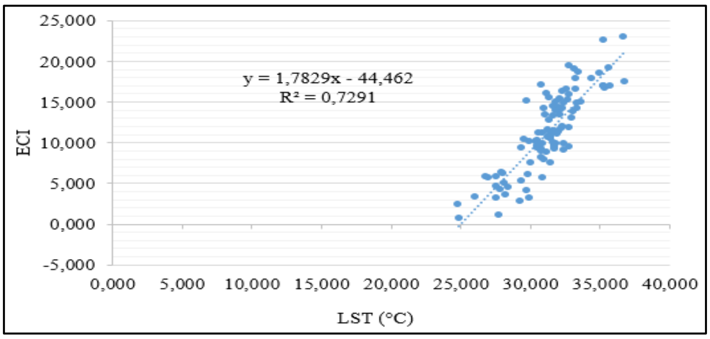

Figure 10 Graph of ESG Relationship to ECI in 2019

The LST regression equation to ECI is Y = 1,783X - 44,462. The value of the constant value is -44,462 indicating that when LST is zero (0), then the ECI value is equal to that constant. The value of the coefficient, LST 1.7829, which means that there is a positive influence between LST and ECI, if LST increases then ECI will also increase.

3.6 NDVI and ECI Relationship in the City of Surakarta and Its Surroundings

The assessment of the NDVI and ECI relationships is explained using simple linear regression. The value of the relationship between the two is in the descriptive statistics in table 3.

Table 3 Descriptive Statistics of NDVI Relationship to ECI

A) Summary

Regression Statistics	
Multiple R	0,929
R Square	0,864
Adjusted R Square	0,862
Standard Error	1,8110
Observations	100

B) Regression Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	21,352	0,44	48,45	$2{,}9e^{-70}$	20,48	22,23
NDVI	-25,598	1,03	-24,97	$2{,}9e^{-44}$	-27,63	-23,56

Source: Author, 2020

The value of the correlation coefficient of both is 0.929, this indicates a strong relationship between NDVI and ECI. The coefficient of determination was 0.864 which illustrates that NDVI can explain ECI by 86.4%, while the remaining 13.4% is influenced by other variables not included in this modeling. The p-value, namely 2.9 x 10^{-44}, or less than 0.05, so that there is sufficient evidence to reject H_o and take H_a at the 5% significance level. Furthermore, the NDVI coefficient value is negative -25.598 . In other words, it can be concluded that NDVI has a significant inverse effect on ECI.

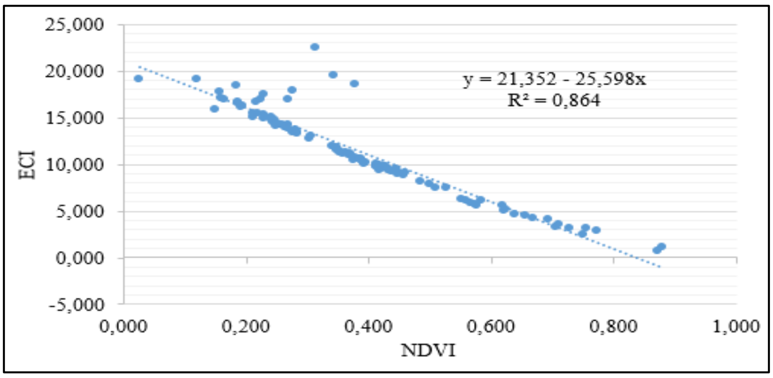

Figure 11 NDVI Relationship to ECI in 2019

The NDVI and ECI model equations are Y = 21,352 - 25,598X. The value of the constant a is 21,352, indicating that when NDVI is zero (0), ECI has a value of 21,352. The value of the coefficient NDVI is -25.598, which means that there is a negative effect (inverse relationship). When NDVI decreases, the ECI will increase.

3.7 Urban - Rural Gradient Analysis

The gradient analysis in this study was used to observe the NDVI, LST and ECI patterns along the Urban - Rural line. This pattern is described in Figure 3.11. Along the Urban - Rural gradient of Surakarta City and its surroundings, it can be observed that NDVI has a higher value as it moves to rural areas. This indicates that there are differences in vegetation conditions shown by NDVI in urban and rural areas. It is different from LST and ECI, the highest values are in urban areas (city centers) and decreases further as it moves to rural areas.

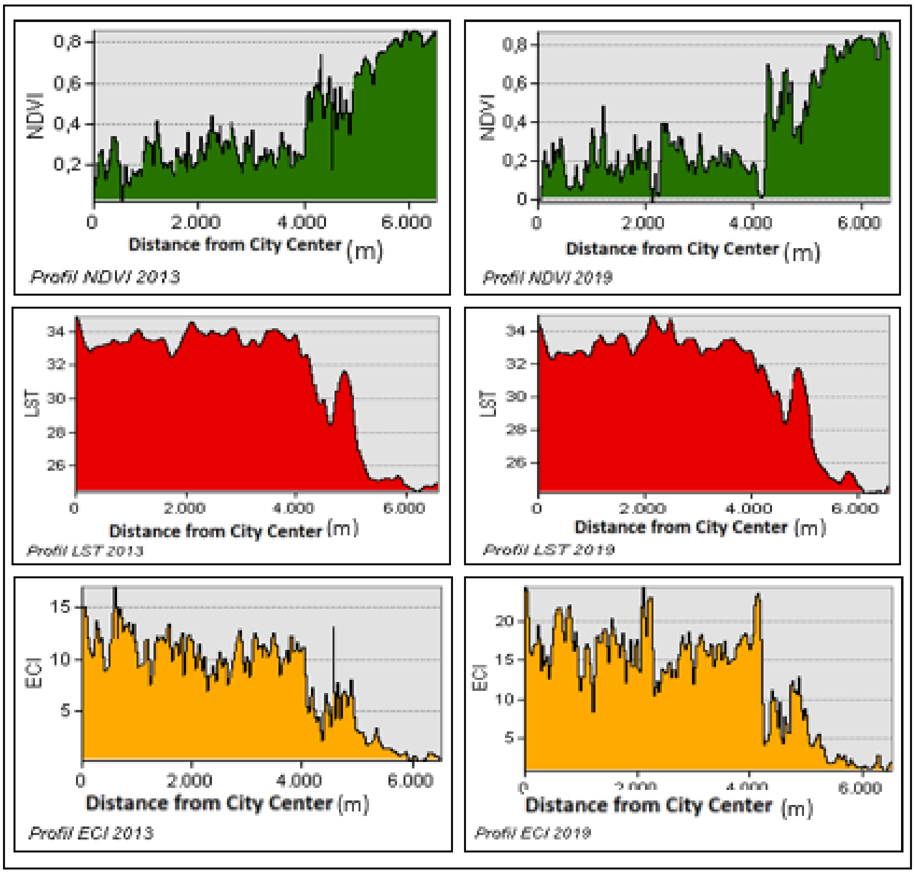

Figure 12 NDVI, LST and ECI Patterns Along Urban-Urban City Lines

All of the# indices are related to land functions. Urban areas are dominated by buildings, so NDVI tends to be lower and affects the increasing LST and ECI conditions. Ranagalage et al. (2017) in the study also explained that there is a relationship between the NDVI, LST and ECI patterns and urban development. When there is a physical expansion of the city area, the NDVI, LST and ECI patterns will also change.

4. Conclusion and recommendations

4.1 Conclusion

1. The City of Surakarta and its surroundings experienced changes in LST and NDVI values between 2013 and 2019. These changes occurred in many areas surrounding the city of Surakarta. These changes occurred due to the conversions of green land into building areas along with regional developments.

2. ECI in Surakarta City underwent changes over years of 2013 to 2019. The changes occurred in the Surakarta City Center and expanded to the surrounding areas. Changes in the ECI are influenced by the land uses. Urban - Rural gradient shows that the highest average value of ECI is in urban areas and will decrease as it is heading to rural areas. The existence of ECI has a positive correlation to UHI with a significant effect. When the ECI increases, the UHI will also increase.

3. LST and NDVI on ECI have a significant effect but with different signs. LST and ECI have positive relationships, an increase in LST will result in increasing ECI. NDVI and ECI have an inverse relationship, an increase in NDVI will result in a decrease in ECI.

4.2 Recommendations

Environmental criticality in the city of Surakarta and its surroundings occurs because of a change in land use from open land to building land. Therefore, to overcome this problem can be done by:

a. Make sustainable reforestation efforts, because green spaces can help reduce the warming effects of UHI.

b. Conducting socialization and guidance to the community to carry out tree planting movements in their respective homes.

c. Develop a Green Roof system to minimize the effects of indoor heat or prevent an increase in outdoor temperatures.

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